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Examining the Effects of a Curriculum-Based Professional Learning Community on Teacher Efficacy Toward Inquiry-Based Science Instruction

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EXAMINING THE EFFECTS OF A CURRICULUM-BASED PROFESSIONAL LEARNING COMMUNITY ON TEACHER EFFICACY TOWARD INQUIRY-BASED SCIENCE INSTRUCTION

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This dissertation is dedicated to my wife, Kara, for her constant encouragement and unfailing love. No matter how challenging things seemed, Kara never stopped believing in me. Whenever the journey took an unexpected turn, she pointed me in the direction of what truly matters: God, family, friends, and my students. Kara has made countless sacrifices, mostly in secret, in supporting me to pursue my dreams. Thank you, Kara, for helping my dreams come to fruition. There is no one else I would rather dream with than you.

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Improving STEM education is pivotal to our country's economic future and security. Unfortunately, most young students have limited access to standards-based science education. Science instruction is notoriously difficult to implement in the early grades. This dissertation explored the root causes for the lack of effective science instruction in elementary schools, including accountability testing, instructional time, historically weak standards, family factors, teacher efficacy, and professional development.

This study aimed to understand how elementary school teachers' attitudes promote or hinder the implementation of science instruction. This study's primary driver to improve science education in the early grades was a curriculum-based professional learning community (PLC). The PLC sought to promote collective teacher efficacy in teaching science by engaging participants in scientific inquiry (i.e., 5E Inquiry-Based Instructional Model) using STEM resources, analyzing student data, making instructional decisions, and developing common science assessments. Implementation of the study's intervention relied on adaptive leadership, transformational coaching, constructivism, and other pertinent educational learning theories.

The first round of intervention was a virtual PLC with a vertical team of six classroom teachers and a curriculum specialist. Data revealed an increase in participants' self-efficacy levels toward science curricula and the 5E Inquiry-Based Instructional Model, but there was a minimal improvement in classroom implementation. Iterations to the intervention included opportunities for instructional coaching in a hybrid environment. I personalized coaching strategies according to participants' personalities and preferences. Revisions to the intervention aimed to enrich collaboration between teachers and coaches and transform science education at the elementary school level.

This study used improvement science as a methodology and mixed methods to examine a curriculum-based PLC's effects on teachers' self-efficacy toward inquiry-based science instruction. I collected data through surveys, interviews, observations, and document analysis (e.g., curriculum maps, lesson screeners). The quantitative and qualitative data collection indicated that the study's drivers directly or vicariously empowered teachers and increased their self and collective efficacy levels.

Findings from this study suggest that vertical teaming is a viable approach to elementary school teachers' professional development. Results indicate that subject-based PLCs built on collaborative lesson planning, reflective curricular guides, and ongoing coaching can improve teacher efficacy in designing and implementing standards-based instruction.

CHAPTER I: INTRODUCTION

Problem of Practice

The Kentucky Department of Education adopted the Next Generation Science Standards (NGSS) in 2013. The NGSS include engineering practices and scientific inquiry, which involves the formulation of a question that is addressed through investigation or design (National Science Teaching Association [NSTA], n.d.-b). NSTA posits that the Next Generation Science Standards is an effective, research-based approach to providing students high-quality science education that prepares them for college, careers, and citizenship (NSTA, n.d.-b). Science standards help lay the groundwork for students to be critical, educated consumers of scientific information in their everyday lives.

The general population of students at this study site has limited access to the NGSS-supported inquiry-based science, technology, engineering, and mathematics (STEM) learning. XYZ Elementary School's daily schedule allocates 50 minutes for teaching the following three subjects: science, social studies, and writing. The pseudonym XYZ Elementary School is used throughout this dissertation to maintain the research site's anonymity. In 2017, I administered an online survey to 10 third grade classroom teachers at XYZ Elementary School that contained questions regarding science instruction (Northern, 2017). Survey questions are presented in Appendix A. The survey results found that 70% of teachers spent less than 20 minutes per day on science instruction. Ninety percent of teachers considered the resources students use to master science standards as "somewhat" to "not very effective." In addition to a lack of time and resources for teaching science, some teachers were inexperienced at designing and implementing an inquiry-based STEM curriculum.

Students attend XYZ Elementary School for first, second, and third grades. The school district has an intermediate school containing fourth and fifth grades. A lack of effective STEM education at XYZ Elementary may have contributed to low test scores by fourth grade students on the science section of the state-mandated criterion-referenced test. In 2018, 69.4% of fourth grade students at XYZ County Schools scored Novice or Apprentice in science on the Kentucky Performance Rating for Educational Progress (KPREP) test (Kentucky Department of Education, 2018).

According to DeCoito and Myszkal (2018), most teachers rarely use interactive STEM instructional practices. Many teachers feel ill-equipped or have a limited understanding of what inquiry-based STEM education entails. DeCoito and Myszkal investigated the factors that promote and hinder science instruction in the early grades. The chief driver for change was the implementation of a science curriculum-based professional learning community with teachers representing all grade levels.

Purpose of the Study

To gain a better understanding of how to increase elementary science teacher efficacy toward the implementation of inquiry-based science instruction.

Research Questions

1. What are the perceptions of elementary school teachers toward the integration of inquiry-based learning in STEM education?
2. How does immersion in a hands-on STEM curriculum impact teachers' self-efficacy beliefs with regard to conducting scientific inquiries?

3. How does immersion in a hands-on STEM curriculum impact teachers' beliefs related to the constructivist theory of learning/5E Inquiry-Based Instructional Model?

General Methodology

This research study used an improvement science framework to address challenges that affect school equity and innovation. Improvement science can lead to an organizational culture of continuous learning and improvement (Schneider, 2017). There are many definitions for improvement science. Hinnant-Crawford (2020) presents a well-crafted summary:

> Improvement science is a methodological framework that is undergirded by foundational principles that guide scholar-practitioners to define problems, understand how the system produces the problems, identify changes to rectify the problems, test the efficacy of those changes, and spread the changes (if the change is indeed an improvement). (Introduction section, para. 1)

School reform is about system change (Mehta et al., 2012) and must involve the whole school (Owens & Valesky, 2014). "The science of improvement is not being applied until systems thinking is incorporated into improvement methods and activities" (Perla et al., 2013, p. 182). This kind of "systems thinking" shows how aspects relate to one another as a whole. Performance comes from not one change but a structure of systems that includes policies, processes, organization structures, operating rules, and culture.

Improvement involves creativity, innovation, and problem-solving. These activities must be balanced by a form of justification, such as data and testing (Perla et al., 2013). Improvement research and the context of justification "entails getting down into the micro details as to how any proposed set of changes is actually supposed to improve outcomes" (Bryk et al., 2015, p. 8). According to Perla et al. (2013):

> The fundamental contribution of the science of improvement is that it provides a scientific lens to bridge the context of discovery and human experience in the real world and the context of justification (using systematic methods and theories). (p. 179)

Discovery, justification, and, alas improvement, is an iterative and ongoing process.

This dissertation's research project aimed to use the inquiry-based learning process and the constructivist theory of learning to improve STEM education in the early grades. The improvement cycle included a review of selected literature, a theory of action, and the Plan-Do-Study-Act (PDSA) model. Revisions to this study's theory of action and its intervention design resulted from professional literature, participant outcomes, and reflective practice.

Defining STEM Education

There is no single, standard definition of STEM education. J. Williams (2011) defines STEM as an approach that supports student participation in learning by using engineering and technology, improving students' learning in science and mathematics (p. 29). Technology and engineering are proving to be "critical components in solving today's societal problems and are equally important related to an individual's ability to create, design, and utilize problem-solving skills" (Spellman et al., 2014, p. 30). Israel et al. (2013) take a different perspective and define STEM education as an approach that supports student-centered learning beyond the context of the four fields that comprise the STEM acronym (science, technology, engineering, and mathematics).

According to Roger Bybee (2010), retired executive director of the Biological Sciences Curriculum Study, “A true STEM education should increase students’ understanding of how things work and improve their use of technologies” (p. 996). In learning “how things work,” students will develop basic literacy in science, mathematics, and technology (Kesidou & Koppal, 2004). According to Bybee, “STEM literacy includes the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues” (p. 31). In addition to the advancement of students’ science literacy skills, there are several key assumptions about STEM education’s nature. According to P. Williams (2019), STEM education:

- involves the integration of science, technology, and mathematics,
- is student-centered,
- engages students in collaborative activity,
- focuses on processes,
- occurs within the curriculum (is not extra-curricular), and
- is project and/or problem-based (p. 1).

STEM education should be accessible to all learners of all ages beginning in early childhood. Eshach and Fried (2005) make six assertions supporting the idea that young children should be exposed to science. The reasons are as follows:

- Children naturally enjoy observing and thinking about nature.
- Exposing students to science in the early grades develops positive attitudes toward the subject in later years.

- Early exposure to scientific phenomena leads to a better understanding of the scientific concepts studied later in a formal way.
- The use of scientifically informed language at an early age influences the eventual development of scientific concepts.
- Children can understand scientific concepts and reason scientifically.
- Science is an efficient means for developing scientific thinking. (Eshach & Fried, 2005, p. 319)

Science and STEM education should begin in the early grades of formal schooling. At the elementary school level, STEM education is often integrated into the math and science curriculum that is required for all students (Xie et al., 2015). More specifically, STEM concepts are defined as the curriculum becomes progressively specialized at each student's education level (Xie et al., 2015). When students from XYZ Elementary School reach middle school, they must take a computer science course. The high school offers students several math, science, and technology courses, including Biology, Calculus, and Game Design. At all grade levels, STEM education should develop students' content knowledge, critical thinking, creativity, peer collaboration, empathy, and problem-solving skills (Cotabish et al., 2013; Elliot et al., 2001).

A meta-summary of qualitative research about STEM education in Turkey found that this field contributes to developing students' positive attitudes toward STEM domains: the learning of physical phenomena and the development of life skills, psychomotor skills, inquiry skills, and critical thinking skills (Kanadli, 2019). A study group composed of 28 teachers working in Istanbul completed a semi-structured interview form consisting of 10 questions to determine secondary school science teachers' and mathematics teachers' opinions toward STEM education (Yildirim & Türk, 2018). Analysis of teachers' opinions by Yildirim and Türk (2018) revealed:

> STEM education is important because it contributes to creative thinking and creativity, and also, it contributes to critical thinking and problem-solving skills, enables to learn by practicing, doing and living, and most importantly contributes to the development of innovation and economic development. p. 58

STEM education is ideally an integrated curricular approach to studying the grand social, economic, and environmental challenges of our time, such as climate change, energy efficiency, and resource allocation (Bybee, 2010). This is why the National Science Board proclaims a need for "STEM innovators"—those individuals who have the capacity to become leaders in STEM-related fields and possibly the architects of advances in science and technology (National Science Board, 2010). The growing demand for qualified candidates for STEM-related occupations underscores the need for standards-based STEM education in grades P–12.

Inquiry-Based STEM Instruction

The inquiry process is a major component of STEM education, especially as the Next Generation Science Standards (NGSS) and the National Science Education Standards indicate (Mahzoon-Hagheghi et al., 2018). Research suggests that inquiry-based science instruction enhances students' understanding of science concepts and increases students' interest in the field (Hoftsein & Mamlok-Naaman, 2007). Inquiry-based learning (IBL) experiences help students develop skills, make them feel like scientists, and give them a sense of accomplishment (Deters, 2005).

With IBL, students learn information and develop skills by completing sequenced exercises. Students ask questions, experiment, propose solutions, and use feedback from their peers and instructors to modify solutions (MacKenzie & Bathurst-Hunt, 2018; Steurer, 2018). Instead of casually listening to teacher lectures, students work to develop a deeper understanding during IBL. Inquiry teaching anchors academic concepts in practical situations, making content come to life. The goals of IBL are for students to learn content while also developing students' problem-solving, communication, and collaborative skills and cultivating their autonomy (Steurer, 2018). The significance of IBL in the NGSS is enunciated in the organization's executive summary:

> Implementing the NGSS will better prepare high school graduates for the rigors of college and careers. In turn, employers will be able to hire workers with strong science-based skills—not only in specific content areas, but also with skills such as critical thinking and inquiry-based problem-solving. (National Science Teaching Association, n.d.-c, para. 4)

Numerous studies have been conducted to measure student outcomes as a result of STEM education and IBL. For example, results from a qualitative data analysis of learning feedback from 73 undergraduates majoring in Information Technology and 21 instructors showed that an inquiry-based curriculum program provided benefits for students and improved their STEM knowledge and skills (Lai, 2018). In addition to improving students' understanding of STEM concepts, inquiry-based instruction is central to the achievement of scientific literacy (Hofstein & Mamlok-Naaman, 2007). STEM literacy is critical to a person's sound personal consumer choices, ranging from various everyday life scenarios to workplace events (Committee on STEM Education National Science & Technology Council, 2013).

Inquiry-based teaching practices have implications for students' behavior and affective regulation. Caswell and LaBrie (2017) documented the benefits of active IBL over traditional teaching methods. Inquiry-based teaching improves student engagement, motivation, and self-confidence (Blaire, 2014; Caswell & LaBrie, 2017). The researchers analyzed qualitative data on a graduate secondary mathematics student's personal experience engaging in IBL. The subject reported increased critical thinking skills, higher motivation levels, greater feelings of efficacy, and a better understanding of the content than in other mathematics courses taken (Caswell & LaBrie, 2017). With inquiry-based learning, students develop a sense of agency to maximize their educational experiences.

Wilson et al. (2010) conducted a laboratory-based randomized control study to examine inquiry-based instruction effectiveness. The same teacher taught 58 students aged 14–16 the same science learning goals. One group from the study was taught from inquiry-based materials and the other group from materials organized around conventional teaching practices. Students in the inquiry-based group outperformed students in the comparison group regardless of ethnicity, socioeconomic status, gender, and English Language Learner status. Wilson et al. (2010) found that commonplace science instruction resulted in an identifiable achievement gap by race, whereas the inquiry-based approach did not. Inquiry-based teaching has the potential to reduce achievement gaps and increase equitable outcomes for students.

A study by Deters (2005) analyzed the methods of 571 chemistry classrooms across the United States. The study found that some students report a negative view of inquiry because this method requires more effort, and students are afraid of being in control. Despite some students' negative perceptions of IBL, there were many positive aspects of this methodology. Deters found that with scientific inquiry, students develop skills, feel like scientists, and have a sense of success. Educators at this study site can use IBL to foster students' interest in scientific content and STEM careers.

Zafra-Gómez et al. (2015) developed a research methodology based on longitudinal data from a single year to measure and compare performance outcomes and student satisfaction when engaging in IBL. Considering the mean grades obtained before and after the change in teaching method, the researchers observed an improvement in student grades, which rose from an average of 3.56 to 5.18. However, there is more to IBL than higher scores on an achievement test. Zafra-Gómez et al. reported that students' satisfaction with developing an inquiry-based course was higher than the grade they actually obtained.

IBL allows teachers to employ various instructional strategies and modifications so that all students can reach learning goals. Inquiry-based teaching reduces the gap between subgroups of students (e.g., gender, race, socioeconomic status) and improves student motivation (Caswell & LaBrie, 2017). More and more schools are beginning to adopt the IBL process over traditional teaching methods, resulting in rigorous and enriching learning experiences.

Leadership Context of STEM Education

Workers in the STEM fields are in high demand. The U.S. Bureau of Labor Statistics projected that, during the period 2010–2020, employment in science and engineering occupations would grow by 18.7%, compared to 14.3% for all occupations

(National Science Foundation, 2019). “Approximately 20 percent of careers require STEM skills, with STEM-intensive careers (5% that are science, engineering, mathematics) and STEM-infused (another 15% that rely heavily on content from one or more of the STEM disciplines)” (B. Peterson, 2017, p. 23). Due to the need for STEM-skilled workers, the U.S. government is pushing initiatives to increase the number of students studying in STEM fields during secondary and postsecondary education (Scott, 2012). In 2018, the U.S. Department of Education obligated $279 million in discretionary grant funds for high-quality STEM, including computer science, education (U.S. Department of Education, n.d.).

In addition to the need for all students to have access to rigorous STEM instruction, students need opportunities to learn about STEM careers. Students’ immersion in the scientific inquiry process will impact their inclinations of entering the STEM workforce. According to Holmes et al. (2018), the likelihood of student interest in STEM increases for those students who have a parent working in a STEM occupation, emphasizing that insider knowledge of STEM careers can increase awareness and interest. Providing more students with this kind of knowledge is a potentially fruitful approach for career education in schools.

The National Science Board (2010) believes that to ensure our nation’s lasting prosperity, we must renew our collective commitment to excellence in education and scientific talent development. “Improving STEM education, especially for traditionally disadvantaged groups, is widely recognized as pivotal to the U.S.’s long-term economic growth and security” (Xie et al., 2015, p. 331). Identifying and developing STEM innovators will help drive future economic success and improve the quality of life for all (National Science Board, 2010).

During the era of No Child Left Behind (2002–2015), most school districts diminished science education to focus on reading and mathematics. It has been said that the reauthorization of the Elementary and Secondary Education Act (ESEA) in 2015 by President Barack Obama could emphasize the importance of STEM in school programs (Bybee, 2010). The Committee of STEM Education of the National Science and Technology Council (NSTC, 2018) set a:

> federal strategy for the next five years based on a vision for a future where all Americans will have lifelong access to high-quality STEM education, and the United States will be the global leader in STEM literacy, innovation, and employment. (p. v)

NSTC is a Cabinet-level Council that understands STEM education's value and urgency for learners of all ages.

In a report titled, *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*, the National Research Council (2011) offers several recommendations to schools seeking to improve STEM outcomes:

- Devote adequate instructional time and resources to science in grades K-5.
- Ensure that STEM curricula are focused on the most important topics in each discipline.
- Enhance the capacity of K-12 teachers.
- Elevate science to the same level of importance as reading and mathematics.

- Develop effective systems of assessment that are aligned with the Next Generation Science Standards. (p. 27)

In 2013, the Next Generation Science Standards (NGSS) were approved by the Kentucky Board of Education and incorporated into the Kentucky Academic Standards for implementation in the classroom (Kentucky Department of Education, 2019b). The NGSS aimed to create a set of research-based, up-to-date K–12 science standards. The Kentucky Department of Education hired a "thought partner" to ensure that state assessments thoroughly assess the NGSS (Pruitt, 2015). These standards give local educators the flexibility to design classroom learning experiences that stimulate students' interests in science and prepares them for college, careers, and citizenship (Next Generation Science, n.d.-f). According to Pruitt (2015), "The NGSS provides an opportunity to look at science instruction coherently by connecting the different disciplines to better understand a phenomenon" (p. 18). STEM education brings the wonder back to classrooms and makes science relevant to students.

STEM Achievement in the United States

In 2017, American College Testing (ACT) reported that 48% of ACT-tested high school graduates expressed interest in STEM. Yet, the percentage of ACT-tested high school graduates meeting the ACT STEM Benchmark was only 21. (ACT, 2017). According to ACT's fifth and latest edition of its annual STEM report, not enough U.S. students are equipped for STEM opportunities.

Kentucky Teacher (2019) reported that "the percentage of Kentucky 2019 public high school graduates meeting college readiness benchmarks on the ACT college-entrance exam in English, mathematics, science, and reading saw a two-point percentage decrease since last year [2018], according to data released October 30 by ACT" (para. 1). Table 1 exhibits average ACT scores in science for students in Kentucky and the nation over five years. Between 2015 and 2019, Kentucky students' average composite in science has failed to increase. The results are alarming in today's economy, of which many occupations require postsecondary education or training.

Table 1

Five-year Average ACT Scores in Science

Year	ACT Scores in Science	
	Science Kentucky	Science Nationwide
2015	19.8	20.9
2016	19.6	20.8
2017	19.8	21
2018	19.6	20.7
2019	19.3	20.6

Note. Data in the table was displayed in *Kentucky Teacher* (2019), a Kentucky Department of Education publication.

Data from international mathematics and science assessments indicate that U.S. students are behind most other advanced industrial countries (DeSilver, 2017). Every three years, the Programme for International Student Assessment (PISA) tests 15-year-old students worldwide in reading, mathematics, and science (Organization for Economic Co-operation & Development, n.d.). The United States ranked 25th and 40th in science and mathematics, respectively, on the 2015 PISA (National Center for Education Statistics [NCES], n.d.-b). The Trends in International Mathematics and Science Study

(TIMSS) is another assessment that provides data on the mathematics and science achievement of U.S. students compared to that of students in other countries. The most recent TIMSS assessment was administered in 2015, of which U.S. fourth graders ranked 14th in mathematics and 10th in science (NCES, n.d.-c).

The National Assessment of Educational Progress (NAEP) is a congressionally mandated project administered by the NCES within the U.S. Department of Education and the Institute of Education Sciences (NCES, n.d.-a). According to The Nation's Report Card (n.d.-b), the average fourth grade NAEP mathematics score in 2017 was 240 (on a scale of 0 to 500), and the average eighth grade score in mathematics was 283. Compared to 2015, there was no significant change in the average score for mathematics at either grade (Nation's Report Card, n.d.-a). NAEP rated 40% of fourth graders as "proficient" or "advanced" in mathematics in 2017.

The National Assessment of Educational Progress (NAEP) also tests U.S. students on science, though not as regularly (DeSilver, 2017). The 2015 NAEP results indicated some improvement for fourth and eighth grades in science. The average NAEP science scores increased four points between 2009 and 2015 in fourth and eighth grades but did not change significantly at grade 12 (Nation's Report Card, n.d.-a). Students need access to rigorous science courses if they are expected to excel at high levels. ACT research has indicated that almost a quarter of students taking at least three years of high school math or science met the STEM Benchmark (American College Testing [ACT], 2017). Only 2% to 6% of students who took no more than two years of math or science met the STEM Benchmark (ACT, 2017). Fortunately, students at the high school level are beginning to take more science courses. According to The Nation's Report Card (n.d.-a):

> In 2015, the percentage of 12th-graders taking a science course has increased from 53% in 2009 to 57%. The percentage of 12th-graders taking courses in Biology, Chemistry, and Physics since eighth grade has also increased, from 34% in 2009 to 41%. (p. 2)

STEM careers are growing in demand. Schools must prepare students for STEM occupations by offering more science courses and beginning STEM instruction in the early grades.

Implementing an inquiry-based science curriculum can positively influence student achievement (Cotabish et al., 2013). Cotabish et al. (2013) conducted a randomized field study to assess elementary school students' science process skills, content knowledge, and concept knowledge after one year of participation in an elementary grades STEM program. The study revealed a significant gain in science skills and content-knowledge by students in an experimental group using the STEM program compared with students in the control group. Findings from the study suggest that students who engage in an inquiry-based STEM curriculum yield higher results on science assessments than students who experience conventional science instruction, such as completing assignments in a textbook.

Zollman (2012) states that "there is a general consensus that everyone needs to be STEM literate" (p. 12). It is widely accepted that reading and writing skills are essential for personal and professional success. The National Research Council defines STEM literacy as "the knowledge and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (2011, p. 5). According to B. Peterson (2017), a STEM-literate student:

- Demonstrates problem-framing and problem-solving skills, applying them across disciplines.
- Articulates that technology is used to expand knowledge and ability.
- Draws connections to the opportunities specific technologies create for individuals.
- Persists through productive struggle to attain success, especially as it relates to technology and engineering design.
- Makes informed decisions using sound reasoning that can be appropriately expressed.
- Articulates reasoning based in mathematical and scientific concepts and processes.
- Evaluates information for relevancy and accuracy. (p. 23)

STEM literacy is composed of skills, abilities, procedures, concepts, and metacognitive capacities to gain further knowledge in many content areas (Zollman, 2012). Shanahan and Shanahan (2012) write that STEM education and reading instruction should be considered closely related in supporting content-related literacy, emphasizing the techniques that a novice reader might use to understand a disciplinary text. Because teachers present STEM content through complex expository texts such as primary sources, textbooks, and news articles, students need to apply reading and writing strategies to fully comprehend the material (Israel et al., 2013). Israel et al. (2013) stress the value of integrating authentic STEM learning and literacy in the curriculum:

> By integrating explicit instruction into authentic STEM activities, students can have opportunities to authentically engage in STEM learning, access content in a meaningful way, and have opportunities to improve their content-literacy skills. (p. 24)

In addition to STEM education's role in improving students' reading skills, STEM can also reduce the mathematical achievement gap. STEM instruction supports the development of students' spatial skills. It is generally accepted that there is a strong association between spatial reasoning and mathematics performance, especially with children in the elementary grades (Zimmermann et al., 2019). Research suggests that early spatial skill intervention may increase students' spatial competencies for future success in mathematics and all STEM subjects (Lowrie & Jorgensen, 2018).

Spatial skills are the tools we use to visualize our surroundings and manipulate objects in our environment (Zimmermann et al., 2019). "Fortunately, spatial skills are malleable, meaning they can be improved through practice" (Zimmermann et al., 2019, p. 25). Hands-on, inquiry-based STEM instruction encourages spatial and mathematics learning. For instance, virtual models that foster learning about spatial phenomena are becoming integral to STEM education (Barrett & Hegarty, 2016). Zimmermann et al. (2019) write that spatial education promotes school readiness and performance in STEM-related fields. STEM instruction in the early grades helps reduce the achievement gap in reading and mathematics while also developing students' critical thinking and problem-solving skills.

Success Predictors for Students Who Experience STEM Education

Despite the challenges of integrating a STEM curriculum in the early grades, there are numerous benefits for students who engage in scientific inquiry. According to the National Science Board (2010), “There are students in every demographic and in every school district in the United States with enormous potential to become our future STEM leaders and to define the leading edge of scientific discovery and technological innovation” (p. 5).

STEM instruction increases the emphasis on technology in school programs (Bybee, 2010). Research has shown that technology use in the classroom positively affects students’ success and attitudes toward instructional activities (Eyyam & Yaratan, 2014). A study by Eyyam and Yaratan revealed that the mathematics post-test results of the students who were instructed using technology were significantly higher than the post-test results of the groups who were instructed without technology. Students of all ages appreciate the usefulness and possibilities that come with digital learning materials.

By engaging in STEM instruction, students will develop 21st-century skills (Bybee, 2010), including communication, collaboration, critical thinking, and creativity. Cohen et al. (2017) administered the Information Communication Technology (ICT)/Twenty-First Century Skills Questionnaire to STEM professionals. The study found that problem-solving, critical thinking, and communication were the most valued and frequently used skills in their environments. STEM education allows students to develop 21st-century skills such as adaptability, social skills, self-management, and systems thinking needed in STEM-ICT workplaces (National Research Council, 2010). STEM also means increasing the recognition of engineering in K–12 education (Bybee, 2010). Engineering is heavily involved in problem-solving and innovation (Lichtenberg et al., 2008), which helps students generate creative solutions and new ideas.

Reading and writing strategies are vital components of science learning. Soules et al. (2014) believe that engaged reading and oral or written explanations will enable students to interact fully with content to develop sound understandings. For example, to understand a scientific text, students must construct meaning before, during, and after reading (Soules et al., 2014). As students learn how to activate schema and connect new information to existing knowledge in STEM class, they will grow as readers. Embedding reading, research, and writing in STEM classes foster students' ability to apply multiple literacies when solving problems and learning underlying concepts in any subject area (Soules et al., 2014).

The impact of STEM education can also be seen by the performance of students who attend STEM-focused high schools. STEM schools engage their students in real-world problem-solving, internships, and capstone projects that increase students' exposure to STEM content learning (Scott, 2012). STEM schools embed problem-solving and inquiry throughout their curriculum, from course syllabi and lesson plans to student projects (Morrison et al., 2015). Scott indicates that STEM school students outperform their peers at similar establishments on end-of-course mathematics and English language arts assessments.

Integrating STEM education in the early grades is an excellent opportunity for students to learn about the physical world while mastering instructional objectives. With an inquiry-based STEM curriculum, students develop sound understandings of scientific processes and concepts. Additionally, STEM instruction nurtures students' literacy skills and mathematical reasoning. STEM education invites students to apply core competencies for success in today’s world, such as critical thinking, collaboration, digital literacy, and problem-solving.

Significance of the Study

This research study is significant because it supports the implementation of inquiry-based STEM instruction in the early grades. STEM education contributes to 21st-century learning skills and innovation development (Yildirim & Türk, 2018). Elementary education plays an important role in preparing students for career fields in science, technology, engineering, and mathematics (Blank, 2013). This research project helped XYZ Elementary School focus more time and attention on science instruction.

A hallmark of STEM education is the inquiry process. Results from this study support the professional development and instructional coaching on implementing inquiry-based learning (IBL). Kingston (2018) analyzed 20 studies that used project-based learning (PBL), an inquiry-based instructional approach, as an intervention or principal teaching method. The report showed that “PBL can promote student learning in social studies and science; and, to a more limited degree, in mathematics and literacy” (Kingston, 2018, p. 2). This study’s intervention gave participants knowledge of the inquiry process. Teacher efficacy toward IBL improved because of participants’ first-hand experience with the inquiry process. Inquiry-based instruction also has the potential to increase student engagement and outcomes in core content areas (i.e., reading and math) (Kingston, 2018).

This study is important because it transformed the way teachers experienced professional growth opportunities. Professional development is often a one-day training event, isolated from teachers' day-to-day duties and objectives. All the same, professional learning should be continuous and evidence-based. Teachers should discuss what they have learned and figure out classroom activities they could use in their weekly meetings. This study exemplifies the positive outcomes associated with subject-based professional learning communities. The results of this study support learning communities where teachers test ideas, share what works, and use feedback to plan accordingly.

The ultimate benefit of this study was its influence on creating equitable learning environments at XYZ Elementary School. According to Barth (2016), "Equity is achieved when all students receive the resources they need, so they graduate prepared for success after high school" (Equality v Equity section, para. 2). The present study's curriculum-based PLC and its key drivers to improve inquiry-based science instruction expanded students' opportunities for learning about the world. The science-focused PLC inspired personalized learning activities that addressed students' needs while providing appropriate levels of support so all students can master learning goals. Regardless of a student's background, race, language, or socioeconomic status, each individual deserves a first-class, equitable education. This research study gave school leaders the evidence needed to make smart decisions for our students and their future.

Delimitations

Every student should engage in inquiry-based learning (IBL) activities, not just students identified as gifted and talented or selected for after-school programs. This research project was motivated by a desire to find solutions to the lack of inquiry-based science instruction in the early grades. I was curious about how STEM education supports Kentucky Academic Standards for literacy and math so that science can be regularly integrated into other curriculums. My ambition to become an expert in STEM education influenced the selection of this study's research topic.

I am a proponent and practitioner of inquiry-based instructional practices. From January to April 2018, I resided in Helsinki, Finland as a participant in the Fulbright Distinguished Awards in Teaching Program. During the Fulbright program, I studied and observed best practices for an inquiry-based approach to teaching that the Finnish National Agency for Education calls "phenomenon-based learning." For my culminating Fulbright project, I designed a website at www.pbltoolkit.weebly.com to share research resources on IBL. My passion for constructivism as a paradigm for teaching and learning led me to pursue a doctorate in educational leadership. This research project gave me the opportunity and capacity to investigate teachers' attitudes toward constructivism and IBL at the elementary school level.

The dissertation's theory of action also delimits the study. My professional ambitions lie in teacher support and curriculum development. I selected educational theories for my theoretical framework that supported teacher collaboration. I plan to use my expertise in the constructivist learning theory to fulfill my professional ambition of being a school or district-level instructional coach. My study integrated transformational coaching in its theory of action, hence strengthening my capacity to support educators as a curriculum coach.

I am a practicing educator in a public school district. My dual agenda of influencing instructional practice and developing new knowledge makes me a scholar-practitioner. Delimitations to this study are to be expected when using the scholar-practitioner model and improvement science framework. As a scholar-practitioner, I am informed by experiential knowledge and motivated by personal values (Distefano et al., 2003). Decisions made during the design and implementation of this study arose from my passion for improving students' educational experiences.

Other problems of practice could have been investigated at the study site. I decided to target students' limited access to inquiry-based science instruction as a catalyst for organizational change. The design of this study can be scaled to other contexts by conducting new cycles of improvement in what Bryk et al. (2015) call "adaptive integration" (p. 16). This study and its interventions accelerated school improvement at XYZ Elementary through dimensions of change from both a user and a system perspective.

Limitations

This research study was conducted through the lens of teacher professional development on science education in the early grades. Due to scheduling and time constraints, participants were limited to certified staff at XYZ Elementary, a rural school in Kentucky. Therefore, the implications of this study's constructivist approach to professional learning are specific to XYZ Elementary School. Findings may not be generalizable to other educators and school systems. Furthermore, this research study is limited to the science curriculum and the topics covered. Future research could apply this study's design principles with educators at different grade levels who teach content other than science.

The results of this study show that the intervention positively impacted teachers' self-efficacy in teaching STEM. However, the study does not indicate each intervention's design principles' exact contribution to this effect (Voet & De Wever, 2018). Additional research could compare varied configurations of the study's methodology through quasi-experimental design.

Additionally, the duration of the study's interventions was relatively short. It is unknown how additional training and instructional coaching on inquiry-based science teaching would have further influenced participants' beliefs and attitudes.

I was responsible for this study's data collection and the facilitation of improvement cycles. Therefore, analyses and findings were limited to the data collected. Pre- and post-intervention surveys did not include open-ended responses. These instruments included closed-ended Likert scale responses for the primary purpose of collecting quantitative data. Selected-response surveys usually warrant a higher completion rate. To minimize the possibility of errors from self-reported data, I used triangulation for making decisions (Gonyea, 2005). Multiple data sources included pre- and post-surveys, progress monitoring surveys, interviews, field notes, and artifacts.

Definitions

The following terms were used during the course of this research and are defined for this study.

- 5E inquiry-based instructional model: a pedagogical framework that "provides teachers with the strategies to initiate any level of inquiry and to guide their students successfully through an investigation" (Lederman, 2009, p. 1).
- Collaboration: Educators work together to make important decisions, support one another, learn from one another, and assume collective responsibility for the learning for all students (DuFour & Fullan, 2013, p. 13).

- Constructivism: The constructivist theory of learning assumes that students build knowledge as part of a process of making sense of their experiences (Rolloff, 2010; Seimears et al., 2012).
- Curriculum: the structure and content of a unit of study or program and "a dynamic, emergent and collaborative process of learning for both student and teacher" (Fraser & Bosanquet, 2006, p. 272)
- Efficacy: refers to people's beliefs that they can do something successfully (Short, 2014).
- Improvement science: "a methodological framework that is undergirded by foundational principles that guide scholar-practitioners to define problems, understand how the system produced the problems, identify changes to rectify the problems, test the efficacy of those changes, and spread the change" (Hinnant-Crawford, 2020, Introduction section, para. 1)
- Inquiry-based instruction: "students learn concepts by completing carefully sequenced exercises in which they work examples, experiment, ask questions, develop solutions, get feedback from their peers and instructor, and modify solutions based on feedback" (Steurer, 2018, p. 40).
- Instructional coaching: "Coaching programs can and should be designed to support teachers' professional development and growth" (Roy & Heflebower, 2012, p. 142). Instructional coaches provide guidance for teachers to improve their content knowledge and pedagogy (Eisenberg et al., 2017).
- Next Generation Science Standards (NGSS): The NGSS are K–12 science content standards. "The NGSS lay out the disciplinary core ideas, science and engineering

practices, and crosscutting concepts that students should master in preparation for college and careers" (Next Generation Science, n.d.-a, FAQ section, para. 10).

- Professional development (PD): "a wide variety of specialized training, formal education, or advanced professional learning intended to help administrators, teachers, and other educators improve their professional knowledge, competence, skill, and effectiveness" (Edglossary, 2013, para. 1).
- Professional learning community (PLC): "an ongoing process in which educators work collaboratively in recurring cycles of collective inquiry and action research to achieve better results for the students they serve" (Dufour et al., 2013, p. 20).
- Scientific literacy: "to be literate in science, students need to know facts, but they must also be able to experiment, observe, problem-solve, work collaboratively, and think critically" (Chitman-Booker & Kopp, 2013, p. 8).
- STEM education: an approach that supports student participation in learning by using engineering and technology, improving students' learning in science and mathematics (J. Williams, 2011).
- *STEMscopes*: an online, comprehensive, and hands-on preK-12 STEM curriculum for schools.
- Vertical alignment: when standards and assessments are aligned with one another so that they "reflect the logical, consistent order for teaching the content in a subject area from one grade level to the next" (Case & Zucker, 2005, p. 4).

Summary

"Our future depends on a public that can use science for personal decision-making and to participate in civic, political, and cultural discussions related to science" (Cafarella et al., 2017, para. 1). Student achievement in science and their preparedness for STEM-related occupations are national concerns. Despite the emphasis on STEM education through updated standards, federal grants, and scholarly research, science is often disregarded—especially at the elementary school level. The next chapter examines the factors that contribute to the lack of effective science teaching at XYZ Elementary School. Naming the problems of practice helps answer the first of the essential improvement science questions, “What is the exact problem I am trying to solve” (Hinnant-Crawford, 2020, Chapter 3, Naming Problems section, para. 2). For this study, the overarching question was: *What promotes or hinders implementing science instruction in the early grades?*

CHAPTER II: ROOTS OF THE PROBLEM

Introduction

Chapter 1 illustrated the significance of this study's research topic. STEM education nurtures 21st-century learning skills and increases students' understanding of how things work. Frequent and rigorous STEM education should be accessible by all learners of all ages beginning in elementary school. This dissertation's problem of practice was a lack of inquiry-based Science, Technology, Engineering, and Mathematics (STEM) education at XYZ Elementary, a school serving students in grades 1–3.

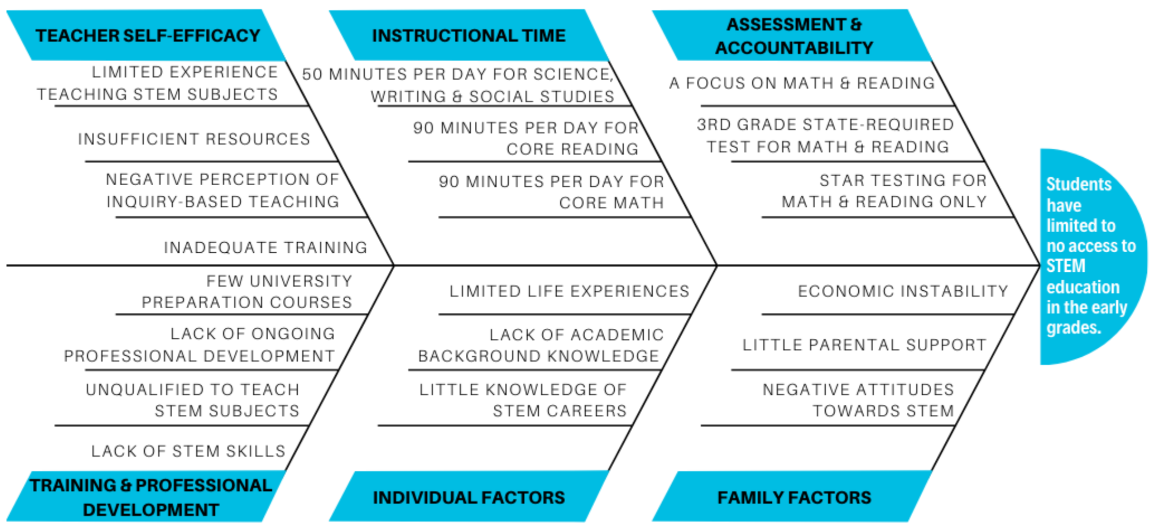
This chapter explores the problem's context and complexity. Prevailing principles of improvement science are user-centered and problem-specific (Bryk et al., 2015). Improvement scientists are interested in defining problems with an understanding of who is involved and most impacted (Hinnant-Crawford, 2020). Numerous factors affect science teaching in the early grades, such as lack of training, limited resources, and teacher efficacy. Improvement science is rarely a linear process. Drivers of organizational change (e.g., change to strategy, products, or operations) may face resistance from employees and other stakeholders. That being said, the first phase of the improvement should be a root cause analysis to uncover the sources of the problem (Bryk et al., 2015; Hinnant-Crawford, 2020; Mintrop, 2019).

Root Causes and Situational Context of Problem

This dissertation focused on the lack of inquiry-based science instruction in the early grades at XYZ Elementary, a public school in Kentucky. The review of the professional literature in this chapter explores the root causes of the study's problem of practice. A fishbone diagram was created to represent the factors that cause students to have limited access to inquiry-based science instruction (see Figure 1). According to Bryk et al. (2015), a fishbone diagram assists in working through the problem analysis. The fishbone diagram was created using tools from *Canva*, a graphic design platform. Root causes and the problem's situational context were explored through the following topics: assessment and accountability, instructional time, historically weak STEM standards, family factors, individual factors, teacher-self efficacy, teacher training, and professional development.

Figure 1

Factors Contributing to the Lack of Science Instruction



Note. Root cause analysis. This figure depicts the reasons why students at XYZ Elementary School have limited access to STEM instruction.

Assessment and Accountability Testing

No Child Left Behind (NCLB) legislation emphasized reading and math, which may have unintentionally contributed to the lack of inquiry-based science education in the early grades. The 2002–2015 federal NCLB law heavily emphasized measurable improvements in reading and math but included little discussion of improving student engagement or interest in school (Maltese & Tai, 2011). As a result, inquiry-based learning (IBL) and STEM education may have been low priority items for most elementary schools during NCLB.

The elementary years are vital to incite students' interest in science (National Research Council, 2011). Yet, school districts face pressure to perform well on state assessments of student learning. Most Kentucky elementary schools prioritize reading and math due to the state's accountability system, which aligns with federal mandates for testing reading and math every year in first through eighth grades. For example, at XYZ Elementary School, third grade students participate in the end-of-the-year Kentucky Performance Rating for Educational Progress (K-PREP) tests in reading and math. The state does not assess Kentucky students' mastery of science standards until fourth grade.

The Kentucky Department of Education enacted a new school rating system in 2018 per The Every Student Succeeds Act (ESSA) (Kentucky Department of Education, 2019a). Elementary schools that score in the bottom five percent of the K-PREP assessment receive the federally-required accountability designation of Comprehensive Support and Improvement (CSI). Schools where certain student groups consistently underperform are labeled Targeted Support and Improvement (TSI) (Lee, n.d.). CSI and TSI schools face state intervention consisting of a comprehensive support and improvement plan. "For CSI schools, the law only states that there must be statewide exit criteria, which, if not satisfied within a state-determined number of years—not to exceed four—results in more rigorous action determined by the state" (Lyons et al., 2017, p. 10).

The comprehensive support and improvement labeling system causes many schools to focus resources on the areas that are measured by the state's accountability system.

Because of demands from the Kentucky Department of Education's accountability system, XYZ Elementary School closely monitors mathematics and reading data and instruction. The school administers the STAR standardized assessments for reading and math four times a year to monitor achievement and growth and track understanding of focus skills aligned to state-specific learning standards (Renaissance, n.d.). In addition to quarterly STAR Reading and STAR Math tests, students at XYZ Elementary School are given common assessments in the subjects mentioned above. Prior to this study, there were no standardized assessments at the study site that measured students' mastery of the state's science standards. A lack of state and district-mandated assessments for science has caused teachers to spend less instructional time on the subject, even though professional literature suggests that STEM education can support the fundamental academic skills students need to excel in literacy, math, and science assessments.

Instructional Time

Reading and math are covered on a more regular basis at XYZ Elementary School compared to other subjects. Informal interviews revealed that some teachers preferred teaching core subjects such as reading, writing, and math. Teachers had more experience teaching these content areas. Other subject areas, such as science and social studies, were not as integral to the curriculum. XYZ Elementary prioritized reading and math because of annual standardized tests administered by the state department of education. During the 2019–2020 school year at XYZ Elementary School, a lack of instructional time continued to pose a challenge for STEM education in the early grades (see Appendix B for a sample student schedule). Students in today's classrooms do not receive the science content knowledge and skills they need to succeed in our global society (Slaughter, 2008). Trundle (2008) affirms that students who develop scientific thinking during early childhood can more easily transfer their thinking skills to other disciplines.

Jez and Wassmer (2015) found that more instructional time has a statistically significant and positive impact on students' academic performance. A regression analysis of data from elementary schools in California revealed that increasing the school day by 15 more minutes was related to an increase in academic achievement of 1% overall and 1.5% for at-risk students (Jez & Wassmer, 2015). Lavy (2010) examined the simple correlations and the simple regression relationship between instructional time per week and test scores of 15-year-olds from over 50 countries that took the 2006 Program for International Student Assessment (PISA) exams in math, science, and reading. Evidence from the sample shows that instructional time has a positive and significant effect on test scores. Rivkin and Schiman (2015) also investigated instructional time's effects on student performance on the PISA. The authors' analyses of 2009 student test data showed that achievement increased with instructional time. Cattaneo et al. (2017) confirmed the positive relationship between time and achievement. Their study revealed that one additional hour of instruction per week might increase the PISA score by between 0.05 and 0.06 standard deviations.

During the NCLB era, elementary school teachers were preoccupied with English Language Arts and mathematics test preparation, causing students to miss experiences with science instruction (Duckworth et al., 2006). The National Institute of Child Health and Human Development (2005) reported that third grade classrooms during NCLB spent a significant amount of time teaching literacy (56%) and mathematics (29%) and little time teaching science (6%). An analysis of data sources by Blank (2013) revealed a relationship between instructional time per week and student achievement on national science assessments. During NCLB, 71% of school districts cut time in at least one subject other than mathematics and reading (Center on Education Policy, 2006). A study by the Center on Education Policy reported that 29% of school districts reduced time for science during NCLB. Elementary schools continue to contend with limited instructional time, especially in subjects other than reading and math. According to Abadzi (2007), "Worldwide, yearly instructional hours are, on average, lower in grades 1–3 and higher in grades 4–6" (p. 6).

Blank (2013) organized the 2009 fourth grade National Assessment of Educational Progress (NAEP) assessment results in science by instructional time. Blank's analysis of the data found that "students in the classes with the highest amount of class time per week (four hours) had average NAEP achievement scores 12 points higher than students in the classes with the lowest amount of class time (one hour)" (Blank, 2013, p. 842). Seventy-three percent of the teachers interviewed in a study by Milner et al. (2012) reported that lack of time for quality science was the biggest challenge NCLB imposed on elementary classroom teachers.

Maltese and Tai (2011) found that eighth grade students who believed science would be useful in their future were more likely to earn degrees in STEM. Therefore, students need opportunities to make connections between STEM and the real world to develop an interest in the sciences. Students may develop an interest in STEM if given class time to explore STEM occupations and investigate contemporary issues and innovations. Students' understanding of science's relevance in their everyday lives may increase students' appreciation for science and math education.

Historically Weak STEM Standards

The Kentucky Board approved the Next Generation Science Standards (NGSS) of Education in 2013. According to Next Generation Science (n.d.-a), the NGSS are "rich in content and practice, arranged coherently across disciplines and grades to provide all students an internationally benchmarked science education" (para. 6). Arguably, the NGSS provide a more robust framework for learning content and skills than prior science standards. The Thomas B. Fordham Institute, a nonprofit education policy think tank, gave the NGSS a C grade, a higher score than the existing standards in 26 states (Gross et al., 2013). "The NGSS include many standards that clearly delineate what students need to know and be able to do, including the integration in some cases of altogether worthwhile 'practices'" (Gross et al., 2013, p. 27).

The NGSS Framework identifies three dimensions of scientific literacy: disciplinary core ideas (content), crosscutting concepts (themes), and scientific and engineering practices (processes) (Houseal et al., 2016). Incorporating three-dimensional learning into the curriculum gives students a more realistic view of how the world works. With the NGSS, students realize that our world is not compartmentalized but interconnected (Mesmer, 2015).

Compared to older science standards, the NGSS make higher-order thinking strategies the norm (Marshall, 2014). The NGSS encourage students to appreciate STEM skills' practical value by learning content through hands-on practice (Mervis, 2013). The

Next Generation Science Standards bid students to inquire and investigate before they construct explanations and provide evidence-based claims (Mashall, 2014; Mesmer, 2015).

New science standards provide countless opportunities to make learning relevant, challenging, and meaningful for students. According to Marshall (2014), “This shift from lesser to greater meaning is inherent in the basic architecture of the standards, which are referred to as performance expectations” (p. 17). An analysis of the NGSS by Hoeg and Bencze (2017) found that the new standards prioritize measurable and reproducible performances.

Before the NGSS, state and national science standards were directly aligned with objectives as if students were to demonstrate mastery of each standard in isolation (Marshall, 2014). With NGSS, students are now challenged to demonstrate learning through performance outcomes that require various skills and connections to multiple content areas. “Science and engineering practices in the NGSS discursively constitute innovation and creativity as a commodity to be acquired by students conducive to performance in jobs predicted to drive the future economy” (Hoeg & Bencze, 2017, p. 294).

Teacher Factors

Teacher Self-Efficacy

Self-efficacy refers to people’s beliefs that they can do something successfully (Short, 2014). These beliefs originate primarily in part from first-hand experience and reflection. Teachers need experience engaging in scientific inquiry before they feel confident enough to implement the process in the classroom. Results of a study by Voet and De Wever (2018) indicated that immersion in inquiry-based learning (IBL) is an effective approach for positively influencing teachers' beliefs regarding the inquiry process and contributed to their understanding of how disciplinary knowledge is constructed.

An inquiry-based approach to STEM education has the potential to generate excitement and a commitment to learning. However, teachers can be reluctant to open up classroom activities to student control (Blair, 2014). Typical classroom instruction often results in the teacher controlling the lesson, leaving little room for children's exploration and autonomy. In most teacher-centered classrooms, the teacher exerts control by having all students complete the same task and designing the physical space that limits student activity, which might disrupt the teacher's focus (T. Garrett, 2008). Ideally, a STEM classroom is on the opposite side of the spectrum from a teacher-centered classroom. STEM education focuses not only on content knowledge but also on problem-solving skills and inquiry-based instruction (H. Wang et al., 2011).

Voet and De Wever (2018) investigated how teachers' self-efficacy influences their decision to use IBL. Without proper training and support from peers on using the science classroom's inquiry process, teachers will choose to use a teacher-centered approach (Lebak & Tinsley, 2010). To successfully implement inquiry-based, student-centered learning, teachers need to develop as practitioners by collaborating and reflecting with peers and other education experts.

STEM education is cross-curricular by design. Although most teachers want to apply an interdisciplinary approach in their courses, they struggle to do so if they do not have sufficient knowledge and skills in other fields. As a result, many teachers tend to implement segmented curriculums (Türk et al., 2018). According to Owens (2017):

> Siloing subjects is easier for schools because it's easier to map out curriculum. But as students focus on each topic individually, they may be less proficient with the material, since they do not study complex, real-world applications or understand how interrelated subjects affect each other. (para. 2)

Through the implementation of STEM education, teachers can bring multiple subjects to life. Formal training is needed to strengthen teachers' knowledge of the instructional strategies and innovative resources that support interdisciplinary STEM instruction. As stated by Türk et al. (2018), "It is really important that the teachers, who have the responsibility to design the entire learning process, should have a pedagogical content knowledge of STEM and professional teaching knowledge" (p. 1288). Professional development on STEM education and IBL should begin at the undergraduate level and continue throughout teachers' careers.

Teacher Training

Türk et al. (2018) used a semi-structured interview form to conduct a needs analysis of STEM education's curricular design to be proposed for undergraduate science education programs. The researchers coded qualitative data obtained from university lecturers, practicing teachers, and preservice teachers. More than half of the teachers who participated in the study did not have experience teaching STEM. The teachers in the study who had some knowledge about the field learned it through workshops, social media, and academic studies. Teachers' lack of knowledge about STEM education can negatively affect their efficacy and beliefs in integrating scientific inquiry in the classroom.

Efforts have been made over the past decade and a half to improve STEM teachers' qualifications (Nguyen & Redding, 2018). One method for strengthening the STEM teacher workforce has been to recruit teachers from more selective universities who have state certification in a STEM subject (Nguyen & Redding, 2018). Nguyen and Redding's regression analysis suggests that certified STEM teachers are difficult to retain, especially in high-poverty schools. Teachers need more than undergraduate and graduate-level training in STEM education—they need ongoing professional support.

Professional Development

Professional development on inquiry-based STEM instruction may increase teachers' confidence and ability to teach using STEM integration approaches in their classrooms. Findings from a case study by H. Wang et al. (2011) suggest that year-long STEM professional development programs enhance teachers' perceptions about STEM integration. Professional development increases teacher efficacy with STEM integration by familiarizing teachers with STEM standards, providing teachers with instructional strategies in implementing STEM contexts into their classrooms, and exploring mechanisms for integration across the STEM disciplines (H. Wang et al., 2011).

Few guidelines or models exist for teachers to follow concerning the design and implementation of STEM instruction (H. Wang et al., 2011). Bybee (2010) suggests using exemplar instructional units as the basis for introducing an integrated approach to STEM education. These units can serve as a model of STEM education for instructors, administrators, and parents. Models of exemplary STEM education can increase understanding and acceptance of STEM among school personnel, increase support by decision-makers and promote understanding of STEM by the public (Bybee, 2010).

Some of the issues contributing to schools not implementing a coherent STEM curriculum are limited resources, teachers' lack of content knowledge, and ineffective professional development. Results from an exploratory quantitative descriptive study of six high school STEM educators by Porter (2015) found that even STEM educators severely lack skills in certain domains (i.e., Machine Learning/Big Data skills) (Porter, 2015). STEM educators need continuous professional development and training on specific STEM domains, such as Big Data skills, to enhance future data scientists' global competitiveness.

The lack of ongoing support and feedback may be why some teachers struggle to teach NGSS-aligned instruction. DeCoito and Myszkal (2018) used surveys, teacher reflections, and semi-structured interviews to explore the impact of STEM professional workshops on long-term educational outcomes for kindergarten through 12th grade students and teachers. The researchers reported that although middle school teachers felt confident in their ability to teach science and mathematics, teachers implemented interactive, hands-on learning in their classrooms about half of the time. A survey administered by Deters (2005) indicated that of the 571 responses from high school chemistry teachers across the U.S., 45.5% indicated that they did not use inquiry labs. Despite the positive effects that studies have established in support of IBL in a STEM curriculum, there are many reasons why teachers demonstrate caution when they promote and implement STEM education (Olsen, 2016).

Individual Factors

A student's intent to excel in STEM education and pursue a career in those fields is mostly affected by their exposure to math and science courses, math self-efficacy beliefs, and achievement in STEM subjects (Tai, 2006; X. Wang, 2013). Several individual factors impact a person's achievement in STEM courses. Individual cognitive ability, numeracy, spatial ability, or other indicators of basic cognitive functions are all correlated with achievement in math and science (Spelke, 2005).

Individual Cognitive Level

A student's cognitive ability can be a predictor of their academic performance in science. Spelke (2015) reviewed claims that cognitive differences account for the differential representation of men and women in high-level mathematics and science careers. The author's review of the literature on cognitive development in children provides evidence that "mathematical and scientific reasoning develop from a set of biologically based cognitive capacities that males and females share" (Spelke, 2015, p. 950). Spelke reported that males and females showed somewhat different cognitive profiles when presented with complex tasks. However, both groups of students showed equal performance on tasks associated with the core foundations of mathematical thinking. Educators can evaluate students' STEM talents by analyzing students' mathematical thinking on basic math concepts and asking what goes on in STEM classrooms before social forces and other external factors begin to influence their academic pursuits (Spelke, 2015).

Numeracy

The National Council of Teachers of Mathematics (2018) insists that a strong foundation in mathematics is crucial to any STEM education program. For example, engineering design supports students' problem-solving skills, which is a priority for mathematics teachers. STEM instruction is an effective means for nurturing students' numeracy skills. According to National Numeracy (n.d.), numeracy involves the use of numbers to make decisions and solve real-world problems.

Technology integration is a central component of STEM instruction. Miller (2018) conducted a study to measure the impact of interactive technology (e.g., mathematical iPad apps) on kindergarten students' learning of number sense in a play-based learning environment. Pre- and post-test data indicated small gains in mathematics achievement. Miller's observations of students using the iPads apps revealed that technology does not lessen children's opportunity to learn numeracy concepts. With STEM education, students apply mathematical concepts (e.g., basic operations, simple algebra) to scientific and engineering questions and problems (Sneider et al., 2014).

Spatial Ability

Like numeracy, spatial reasoning is necessary to understand and solve real-world problems. According to the John Hopkins Center for Talented Youth, "Spatial ability is the capacity to understand and remember the spatial relations among objects" (p. 1). Spatial awareness is a skill needed for success during STEM-based activities. Spatial reasoning is necessary for engineering design and construction—important aspects of the NGSS (Schroeder et al., 2015).

Findings from a study by Wilhelm et al. (2013) suggest that 2D and 3D experiences in an Earth/Space setting help develop students' spatial reasoning. The experimental group in the study engaged in inquiry-based instruction. An RMANOVA of Lunar Phases Concept Inventory assessment data revealed a significant increase in the mean values from pre (21.2%) to post (33.7%) on overall test scores. The results support the notion that an inquiry-based STEM curriculum nurtures students' spatial reasoning skills.

McConnell (2015) took a mixed-method approach to study seven 7th grade students who underwent an instructional intervention involving design-based instruction, modeling, and argumentation—salient characteristics of STEM instruction. Pre- and post-test data were collected using The Purdue Spatial Visualization Test: Rotation, the Mental Rotation Test, and interviews. An analysis of the data found that spatial reasoning increased for six out of the seven participants. The study indicated that students experienced challenges when using computer-aided design (CAD) software. Despite their struggles with CAD technology, students preferred constructing 3D models to assist them in scientific argumentation over paper drawings. Students not only enjoy using technology in the classroom, but they also excel at learning new digital tools.

Effects of one's spatial ability on STEM achievement have been studied for decades. Wai et al. (2009) analyzed 11-year follow-up data from Project TALENT, a national longitudinal study that surveyed over 440,000 American secondary students in 1960, to determine the extent to which spatial ability is a significant characteristic among those who succeed academically and occupationally in STEM fields. Longitudinal findings by Wai et al. were aligned with pre-1957 findings and recent data from the Graduate Record Examination and the Study of Mathematically Precocious Youth. Results indicate that spatial ability is vital to developing one's expertise in STEM (Wai et al., 2009).

Other Indicators

Students who excel academically in science and mathematics often choose to pursue STEM fields and careers. Maltese and Tai (2011) reported that students also concentrate on STEM because they are genuinely interested in STEM subjects. It is generally accepted that student aspirations are developed from a combination of intrinsic and extrinsic factors. Students have different learning science and math experiences that influence their desire to focus on STEM in secondary and postsecondary education. The students most likely to pursue a STEM major have had classroom experiences where the teachers were enthusiastic, the content was placed in a real-world context, lessons were stimulating, and science careers were regularly discussed (Maltese & Tai, 2011). Students need access to an engaging and rigorous STEM curriculum that not only covers science and math learning objectives but also motivates students to further their understanding of STEM subjects.

Family Factors

Family factors are strongly related to students' achievement in math and science and interest in STEM as a field of study and career (Xie et al., 2015).

Low-Income Families

Sixty-five percent of students at XYZ Elementary School received free or reduced meals in 2017 (Kentucky Department of Education, 2018). In 2016, 50% of children in XYZ County came from low-income families (Kentucky Youth Advocates, 2018). This economic instability limits students' academic background knowledge that children from affluent families might gain from museum tours, cultural events, or after-school programs.

The 2018 Kentucky Performance Rating for Educational Progress (K-PREP) test indicated an achievement gap between economically disadvantaged students and non-economically disadvantaged students. The percentage of low-income students in the third grade at XYZ Elementary School to score Proficient/Distinguished on K-PREP in Math in 2018 was 41.7 compared to 67.6 for non-economically disadvantaged. On the Reading section of the 2018 K-PREP assessment, 60.6% of non-economically disadvantaged students performed Proficient/Distinguished. Forty-seven percent of economically disadvantaged students scored Proficient/Distinguished in Reading. Data for third grade students at XYZ Elementary from the 2018 K-PREP test reveals a correlation between income and student achievement.

Parental Education

Parental educational levels can influence a child's behavior and academic outcomes. Harackiewicz et al. (2012) found that children of more highly educated parents took more mathematics and science courses in high school. In 2016, 13.8% of XYZ County residents aged 25 or older held a Bachelor's Degree (Kentucky By The Numbers, 2016). Students at XYZ Elementary School whose parents do not possess a postsecondary degree may not receive support at home to pursue interests in STEM subjects. Research shows that parent support positively affects students' self-efficacy in STEM processes and concepts (Turner et al., 2004). Parents' encouragement to explore STEM-based activities is especially important in developing students' expectations that math and science are important to their future careers (Turner et al., 2004). Understanding how STEM subjects connect to other topics and careers may develop students' greater sense of motivation to learn science.

Family Attitudes Toward Science

Before eighth grade and in elementary school, life experiences may have a meaningful impact on future career plans (Tai, 2006). Analysis of survey data by Archer et al. (2012) found that family attitudes to science and their fostering of science in their everyday family life are more important than a family's demography. Family interests actively influence students' home life (Dabney et al., 2013). The more a family engages in science-related activities, the more the parents will encourage their children to develop an interest in science. An interest in STEM subjects can inspire students to one day pursue a STEM-related career.

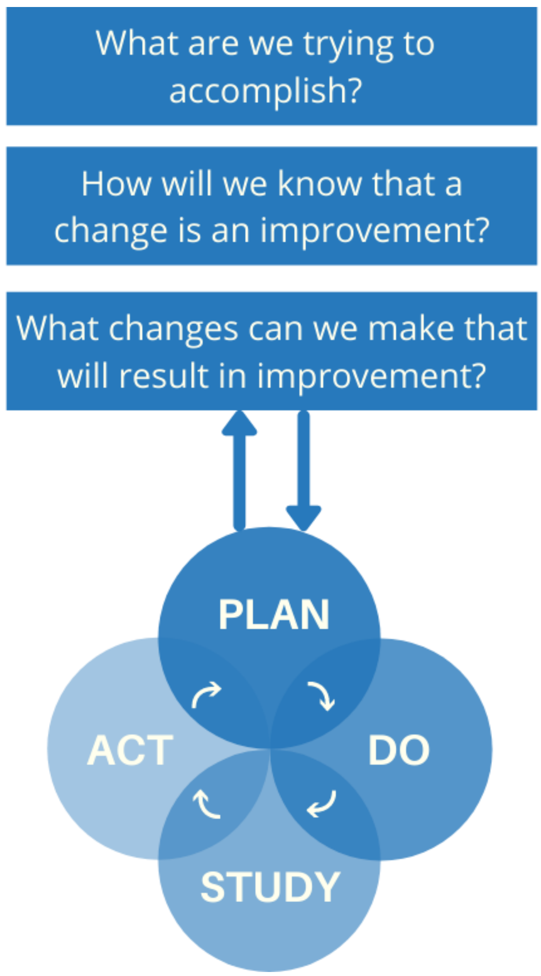
Today's students are future scientists, inventors, engineers, and similar professionals. Students need the content knowledge and skills required for success in STEM fields and occupations, some of which have yet to be created. Students in the early grades need exposure to inquiry-based STEM instruction. An inquiry-based STEM curriculum at the elementary school level cultivates students' understanding of scientific concepts and processes. STEM education supports students' acquisition of core competencies such as critical thinking, communication, collaboration, and creativity. Students can apply these desirable skills across various content areas and real-life situations now *and* in the future.

Plan-Do-Study-Act Cycle

The continuous improvement process relies on three critical tasks. Hinnant-Crawford (2020) identifies the foundation of the improvement process as "developing theory, testing that theory, and then revising that theory based on the results of those tests" (Chapter 8, The PDSA Cycle section, para. 1). The Plan-Do-Study-Act (PDSA) cycle is a framework for testing and implementing changes based on theory (Langley et al., 2009). Three essential questions guide a PDSA cycle approach to improvement. Figure 2 displays the fundamental questions from Langley et al. (2009) that drive improvement work.

Figure 2

The PDSA Cycle



Note. The PDSA cycle and essential questions of the improvement process.

First, a researcher must develop a theory. The theory should target a problem of practice. This dissertation's initial phase in the improvement cycle focused on problem definition. I conducted a needs assessment to investigate the factors that cause limited science instruction at XYZ Elementary School. The planning stage of the PDSA cycle included an examination of literature, an analysis of organizational factors, survey responses, and interview data. The plan was further detailed after collecting and analyzing the quantitative and qualitative data described in the Research Design section.

Research Questions

1. What are the perceptions of elementary school teachers toward the integration of inquiry-based learning in STEM education?
2. How does immersion in a hands-on STEM curriculum impact teachers' self-efficacy beliefs with regard to conducting scientific inquiries?
3. How does immersion in a hands-on STEM curriculum impact teachers' beliefs related to the constructivist theory of learning/5E Inquiry-Based Instructional Model?

Research Design

Aims

This portion of the research study aimed to investigate teacher attitudes toward STEM education and inquiry-based learning. This study examined the root causes of a lack of inquiry-based STEM education at XYZ Elementary School.

Methods

Students at XYZ Elementary School have limited access to an inquiry-based STEM curriculum. This research design aimed to investigate teacher efficacy and attitudes toward STEM education. Participants included one school principal, one district-level gifted and talented (GT) coordinator, one school curriculum specialist, special education teachers, and classroom teachers at XYZ Elementary who taught first, second, and third grades. This study used mixed methods research. In December 2019, I administered a survey to classroom teachers to understand teacher attitudes toward STEM instruction. To better understand the root causes of a lack of effective STEM instruction at XYZ Elementary, I interviewed the school's principal, curriculum specialist, and a district-level GT coordinator.

Participants

This research study was conducted at XYZ Elementary School, located in a rural area of Kentucky. A convenience sample comprised one school principal, one district-level GT coordinator, one curriculum specialist, five special education teachers, and 25 classroom teachers from grades first, second, and third ($N = 33$). Thirty-five percent of participants taught first grade, 32% taught second grade, and 32% taught third grade. Seventy percent of participants had at least ten years of teaching experience, with the mean being 15.6 years. Seventy percent of participants possessed a Master's degree or an advanced professional degree beyond a Master's.

This study needed participants who were available and could be easily recruited. Participants' characteristics affected the research findings' generalizability since most participants were limited to teaching first, second, and third grades at XYZ Elementary School.

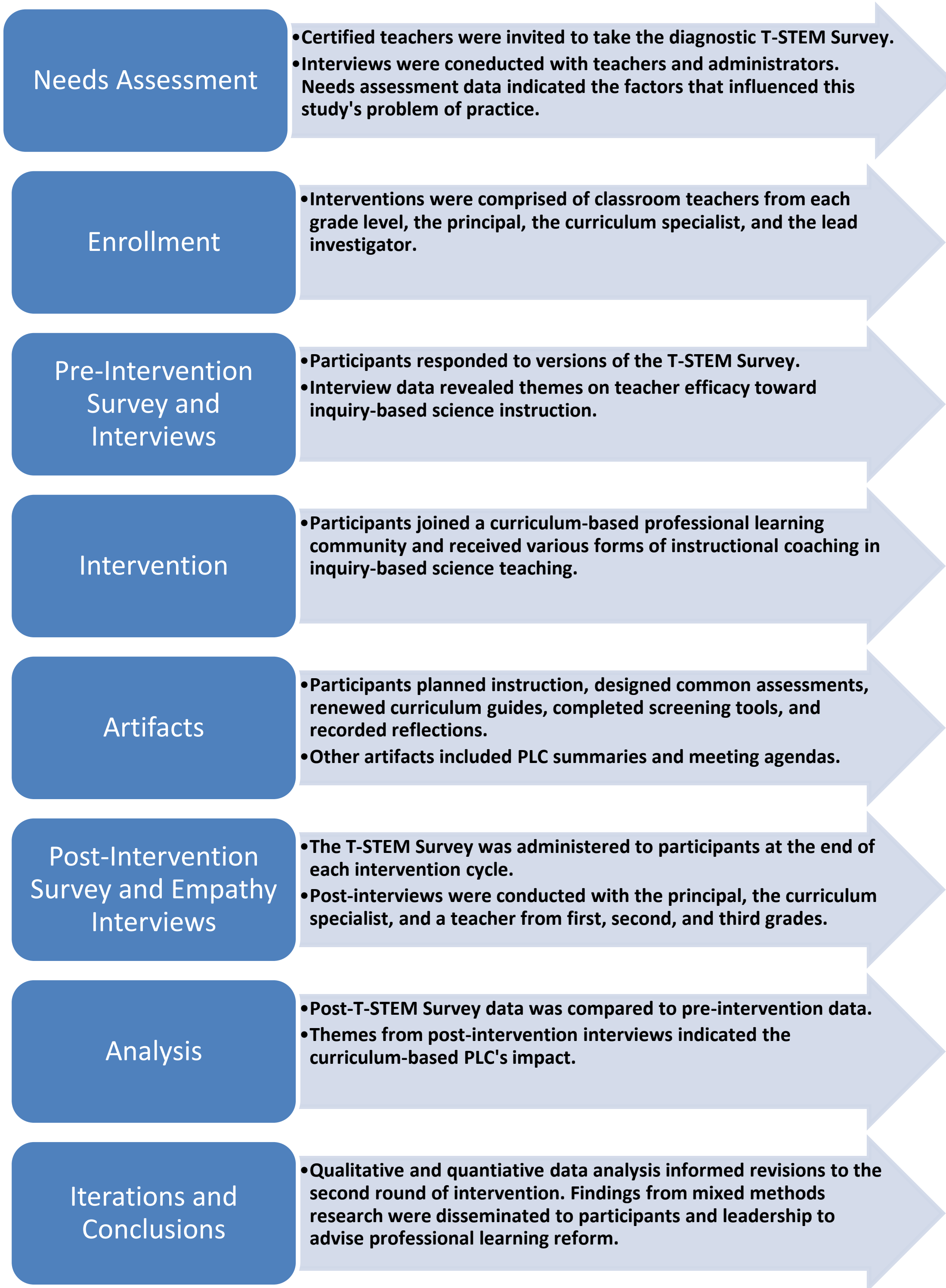
Data Sources and Instruments

The present study used mixed methods. Qualitative measures were used to collect data regarding teachers' beliefs and self-efficacy related to STEM education and inquiry-based learning. Cases that comprised instances of the phenomenon included teachers' use of or lack thereof of scientific inquiry in the classroom. Case features on which data collection analysis was focused included teachers' self-efficacy and beliefs toward STEM education's inquiry process.

This study used concurrent triangulation, where two or more methods are used to confirm, cross-validate, or corroborate findings. Data collection was concurrent. The primary purpose of concurrent triangulation is to overcome a weakness in using one method with another's strengths (Biddix, n.d.). Sets of data were collected using a survey and empathy interviews. See Figure 3 for a flow diagram of this research study's main phases.

Figure 3

Flow Diagram of Research Phases



Note. Flow diagram of the research process.

Surveys

General views and perspectives from teacher participants were obtained using the Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) for elementary grades. The T-STEM survey was developed by The Friday Institute for Educational Innovation at North Carolina State University with partial support from the National Science Foundation and by the Golden LEAF Foundation. The Friday Institute for Educational Innovation granted permission for this study to use and/or modify the evaluation instrument. According to the Friday Institute for Educational Innovation (n.d.):

> The T-STEM surveys are intended to measure changes in STEM educators' confidence and efficacy toward STEM; their attitudes toward 21st-century learning and teacher leadership; the frequency with which they use some instructional practices related to STEM; and the frequency of student technology use. The surveys are available to help program coordinators make decisions about possible improvements to their program. (Appropriate Uses section, para. 1)

The T-STEM survey is divided into the following nine scales:

1. Science Teaching Efficacy and Beliefs
2. Science Teaching Outcome Expectancy
3. Mathematics Teaching Efficacy and Beliefs
4. Mathematics Teaching Outcome Expectancy
5. Student Technology Use
6. Elementary STEM Instruction
7. 21st Century Learning Attitudes
8. Teacher Leadership Attitudes

9. STEM Career Awareness

For this study's purpose, scales one and two were combined to make a single scale called Science Teaching. Scales three and four were combined to create a scale titled Mathematics Teaching. Symeonaki et al. (2015) developed a "methodology for developing a fuzzy set theory solution to combine Likert items into a single overall scale (or subscales)" (p. 739). Symeonaki et al. found that a review of relevant literature, statistical analysis, and the knowledge of an expert (e.g., scholar-practitioner) could support the case for "cross-loading" items into a single scale. My decision to cross-load items into Science Teaching and Mathematics Teaching scales supported data collection and focused data analysis.

For Student Technology Use and Elementary STEM Instruction, respondents were asked to indicate the frequency students engage in specified tasks on a 5-point Likert-scale as follows: *never* (1), *occasionally* (2), *about half the time* (3), *usually* (4), and *every time* (5). For the other scales, respondents were asked to indicate their level of agreement with survey items on a 5-point Likert-scale (*strongly agree* (1), *agree* (2), *neither agree nor disagree* (3), *agree* (4), *strongly agree* (5)).

Participants were asked about their perception of teaching and learning in terms of assessments and accountability, instructional time, self-efficacy, professional development, individual student factors, and student family factors. The survey's ultimate goal was to cultivate some understanding of fostering and implementing best practices in integrated STEM education at XYZ Elementary School.

There were no "right" or "wrong" answers to items presented on the survey. The only correct responses were those that are true for each participant. Survey results presented themes that were explored through interviews with the school principal, the district-level GT coordinator, the school curriculum specialist, and three classroom teachers.

Empathy Interviews

Results from the surveys guided the development of interview questions. I created a semi-structured interview form consisting of questions to determine teachers' and administrators' perceptions at XYZ Elementary School (see Appendix C).

To gain further insights regarding STEM instruction at XYZ Elementary School, I interviewed three classroom teachers, the principal, the curriculum specialist, and the district-level GT coordinator. My empathy interviews explored respondents' understandings and beliefs about STEM education and the use of inquiry-based pedagogy. Interview data provided clarity on teachers' responses to fields on the needs assessment survey.

Data obtained from the interviews were subjected to the content analysis method. Content analysis allows the research to explore concepts and themes not recognized by a predetermined theme (Akran & Asiroglu, 2018).

Methods of Data Collection

The study measured participants' beliefs on self-efficacy, inquiry-based learning, and STEM education using survey data and interviews.

Survey Data Collection

Participants responded to the survey using a digital form generated in Qualtrics, an online survey tool. Survey data was stored in a spreadsheet for sorting and analysis. The T-STEM survey collected perceptive data (what respondents think or feel) from teachers regarding their teaching confidence and efficacy and attitudes, and frequency data regarding the use of specific instructional practices and technology in the classroom" (T-STEM Survey, n.d., para. 4).

Interview Data Collection

I conducted semi-structured interviews with teachers and administrators in the study to better understand the research questions. I deciphered interview data by listening to the voice recordings. An accurate transcript was prepared for each interview. I used Microsoft Word to highlight keywords and phrases from the interview transcripts. Keywords were organized into data tables. Coded qualitative data were grouped into categories from which themes emerged.

Data Analysis

Teachers' self-efficacy related to conducting inquiry-based learning and their attitudes toward STEM education will be measured using survey data and interviews. This step in the research process examined the root causes for the lack of inquiry-based STEM education in the early grades at XYZ Elementary School. Viewpoints from teacher participants were obtained using the Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) for elementary grades. The T-STEM survey measured educators' confidence and efficacy toward STEM; their attitudes toward 21st-century learning and teacher leadership; the frequency with which they use some instructional practices related to STEM; and the frequency of student technology use.

Survey Data Analysis

Descriptive statistics provided necessary information about the data in a study. This study used summary statistics to examine the mean, minimum, maximum, and standard deviation for each survey's designated scale. The survey conveyed classroom teachers' attitudes and the rates with which specified activities occur at XYZ Elementary School.

Interview Data Analysis

Qualitative data obtained through empathy interviews were analyzed using thematic coding to address the study's goals. I coded participant reflections and interview transcripts for recurring themes. Coded qualitative data were then categorized and summarized into broad, overarching thematic areas. Themes and excerpts were organized, summarized, and crafted into a narrative (Schmidt & Fulton, 2017).

This portion of the study examined the root causes of a lack of inquiry-based STEM education in the early grades. The survey and interviews were used to determine elementary school teachers' general efficacy and attitudes toward STEM instruction. This study's research methods can be broadly applied to the investigation of inquiry-based instruction in other grade levels and areas other than STEM, such as English Language Arts, social studies, world languages, and social sciences.

Reliability

This study used the Cronbach alpha reliability coefficient as an index of scale internal consistency indicating the extent to which items on the survey in a given scale measure the same construct (Gupta & Fisher, 2012). Each scale of the T-STEM survey was a set of items that describe a single characteristic when the items' responses are calculated as a single result (STEM Learning and Research Center, n.d.).

This study was limited to the participants at XYZ Elementary School. I minimized external threats by using a scale that can be applied to multiple groups of participants. I kept the treatments' implementation as consistent as possible.

Criteria relevant to judging the credibility and trustworthiness of results yielded by my research design included:

- A well-designed survey that adhered to educational research's essential principles (R. B. Johnson & Christensen, 2017).
- The collection of data from a large sample of participants.
- Methods triangulation by utilizing different data collection instruments in order to check the consistency of the findings.

For purposes of this study, I analyzed data from the T-STEM survey's following scales: Math Teaching, Science Teaching, Student Technology Use, Elementary STEM Instruction, 21st Century Learning, Teacher Leadership Attitudes, and STEM Career Awareness. Cronbach's alpha reliability coefficient was calculated to measure the internal consistency of items in each scale (Cronbach, 1951). "Coefficient alpha has since become a standard component of the toolkits of researchers attempting to measure reliability" (R. A. Peterson & Kim, 2013, p. 194). Table 2 shows the Cronbach's alpha coefficient for each scale of the T-STEM survey.

Table 2

Cronbach's Alpha for T-STEM Survey

Scale	*Number of Items*	*Average Interitem Covariance*	*Scale Reliability Coefficient*
Math Teaching	22	0.2293107	0.9151
Science Teaching	22	0.1213125	0.8132
Student Technology Use	8	0.2897825	0.8298
Elementary STEM Instruction	15	0.1567396	0.8166
21st Century Learning	15	0.2643337	0.9755
Teacher Leadership Attitudes	13	0.238446	0.9065
STEM Career Awareness	4	0.6769153	0.9224

Note. This data set provides the Cronbach's alpha for each scale of the survey.

The sample size is an essential criterion for the level of consistency of items in a group. According to Bonett (2002), "If the sample size is too small, the test will lack power and the confidence interval will be too wide. Sample sizes that are too large are wasteful of resources" (p. 335). The scale reliability coefficient of each scale in this survey indicated an appropriate sample size. Cronbach's alpha showed that the survey reached acceptable reliability ($\alpha > 0.81$). Survey items were worthy of retention, resulting in a decrease in the alpha if fields were deleted. The relatively strong scale reliability coefficient suggested that this survey was valid and reliable—two fundamental elements in evaluating a measurement instrument (Tavakol & Dennick, 2011).

Validity

According to Ghauri and Gronhaug (2005), “Validity explains how well the collected data covers the actual area of investigation (as cited in Taherdoost, 2016, p. 28). Friday Institute for Educational Innovation used pilot T-STEM survey results to edit items based on analysis uniformly across five survey versions. According to Friday Institute for Educational Innovation (2012b), developers strengthened the survey’s validity based on:

> results from factor analysis and confirmed through feedback, four survey questions were dropped that did not load properly on any version. Other items that cross-loaded, or did not load in a consistent manner across all survey versions, were reworded and retained in the survey. Student achievement language was changed to student growth language, and negative or confusing wording was removed. (pp. 1–2)

Revisions of the T-STEM survey’s five scales were tested using exploratory factor analysis. “Each factor performed as expected and no additional changes were found necessary for the survey” (Friday Institute for Educational Innovation, 2012b, p. 2).

“No experiment can be perfectly controlled, and no measuring instrument can be perfectly calibrated” (Kirk & Miller, 1986, p. 21). The collection and analysis of multiple sources of evidence strengthened the validity of this study. Qualitative data collection methods yielded critical information to help answer this study’s research questions. Interviews, fieldwork, and primary source data collection allowed me to draw conclusions based on the intervention’s context and the participants’ ethnography (Kirk & Miller, 1986). The interpretation of qualitative data is arguable more subjective than quantitative data, which leads to the issue of the verifiability of qualitative data analysis (Burnard et al., 2008).

This study utilized a process of constant comparison when analyzing qualitative data. “This essentially involves reading and re-reading data to search for and identify emerging themes in the constant search for understanding and the meaning of the data” (Burnard et al., 2008, p. 431). I searched for findings that were contrary to the main findings. Identifying deviant cases prompted revisions to the study’s literature review and guided iterations to the intervention. The systematic and rigorous analysis of data established trustworthiness in this mixed methods research study.

Participant validation, also known as member checking, is a method used to verify qualitative data. According to Burnard et al. (2008), “Participant validation involves returning to respondents and asking them to carefully read through their interview transcripts and/or data analysis for them to validate, or refute, the researcher’s interpretation of the data” (p. 431). This study employed a variant of participant validation. The study site’s curriculum specialist reviewed interview transcripts then provided input concerning my initial interpretations. Member checking with the curriculum specialist helped ensure that my interpretations accurately represented participants’ views and experiences (Thomas & Magilvy, 2011). Descriptions of how data was collected and analyzed were intended to help readers evaluate this study’s validity and trustworthiness (Burnard et al., 2008).

Roots of the Problem Results

Quantitative Results

Results from the T-STEM survey revealed participants' self-efficacy and beliefs regarding major aspects of STEM instruction. See Appendix D for a complete table of each field's minimum score, maximum, mean, standard deviation, variance, and count. For Student Technology Use and Elementary STEM Instruction, respondents were asked to indicate the frequency at which students engage in specified tasks on a 5-point Likert-scale (*never* = 1), (*occasionally* = 2), (*about half the time* = 3), (*usually* = 4), (*every time* = 5). For the other scales, respondents indicated their level of agreement with survey items on a 5-point Likert-scale (*strongly disagree* (1), *disagree* (2), *neither agree nor disagree* (3), *agree* (4), *strongly agree* (5)). Table 3 shows the summary statistics for each of the survey's seven scales.

Table 3

Summary Statistics

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Math Teaching	32	79.53	11.01	36	99
Science Teaching	32	71.09	8.93	52	87
Student Technology Use	32	17.19	4.73	9	25
Elementary STEM Instruction	32	38.19	6.57	28	51
21st Century Learning	32	63.50	7.81	45	75
Teacher Leadership Attitudes	32	58.00	7.16	42	70
STEM Career Awareness	32	11.25	3.43	8	19

Note. This data set provides the summary statistics for each scale.

Overall, participants' responses indicated moderate to high levels of confidence in teaching mathematics. For example, many teachers agreed with the survey item stating, "I know the steps necessary to teach mathematics effectively" (*M* = 4.19, *SD* = .81). The average response rate for the question, "I am confident that I can teach mathematics effectively" was 4.03 (*SD* = .88). Only three percent of respondents disagreed with the statement, "I understand mathematics concepts well enough to be effective in teaching." Fifty-six and one-quarter percent of survey participants agreed that the teacher is generally responsible for students' learning in mathematics (*M* = 3.47, *SD* = .66). Yet, the survey field asking, "If students' learning in mathematics is less than expected, it is most likely due to ineffective mathematics teaching," received a lower response rate (*M* = 2.63, *SD* = .7). This low average caused a contradiction in the two fields bringing forth the question, what attributes to low student achievement in mathematics if not teaching?

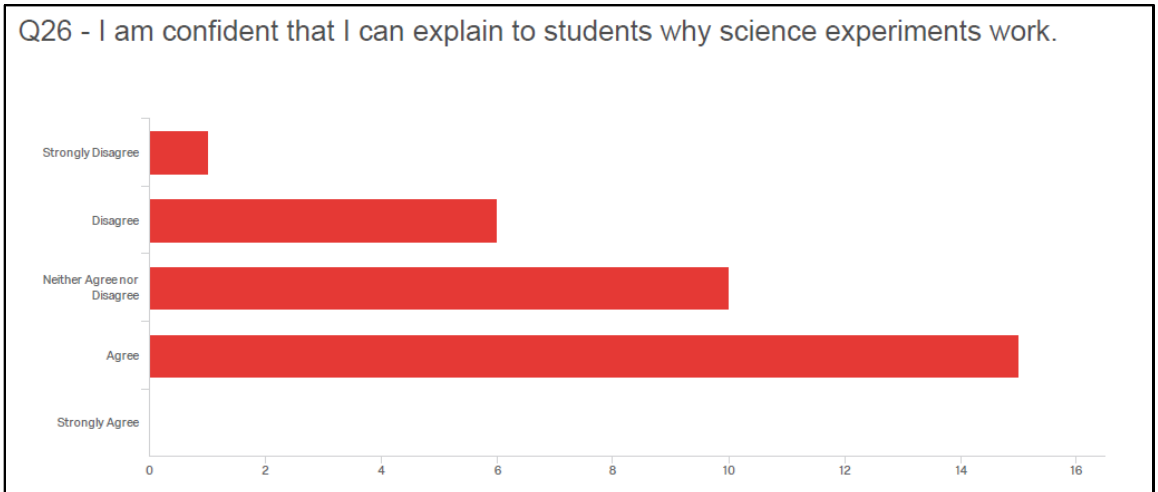
Participants' responses showed relatively high levels of doubt regarding self-efficacy for science teaching and STEM instruction. For instance, when it came to knowing the steps necessary to teach science effectively, the average agreement rate was relatively low (*M* = 3.34, *SD* = .85). Nearly half of the participants neither agreed nor disagreed with knowing the process for teaching science standards.

The majority of teachers did not attribute student achievement in science to teaching practices. The average agreement rate was merely 2.84 for the field "If students' learning in science is less than expected, it is most likely due to ineffective science teaching" (*SD* = .67) Only 28.13% of participants agreed that students' learning in science directly related to their teacher's effectiveness in science teaching. The average agreement rate was 2.88 for the idea that teachers are responsible when students have minimal learning in science (*SD* = .74). There was a positive response rate for the survey field, “I think it is important that teachers take responsibility for all students’ learning” (*M* = 4.16, *SD* = .75). This difference in means between teachers’ responsibility for student achievement in science compared to other content areas indicated that participants had low-self efficacy toward teaching science.

Time and resources are key contextual factors to the implementation of effective STEM instruction. The survey revealed a need for more time and teacher resources for hands-on science. At XYZ Elementary School, teachers perceive insufficient instructional time as a major cause for low student performance in science (*M* = 3.47, *SD* = 1). Overall, teachers held a neutral stance toward having the necessary resources to teach science effectively (*M* = 3.13, *SD* = .96). A lack of sufficient resources may explain why many respondents lack confidence in explaining to students why science experiments work. Figure 4 displays data collected on teachers’ levels of confidence explaining science experiments.

Figure 4

Results for Survey Item Q26

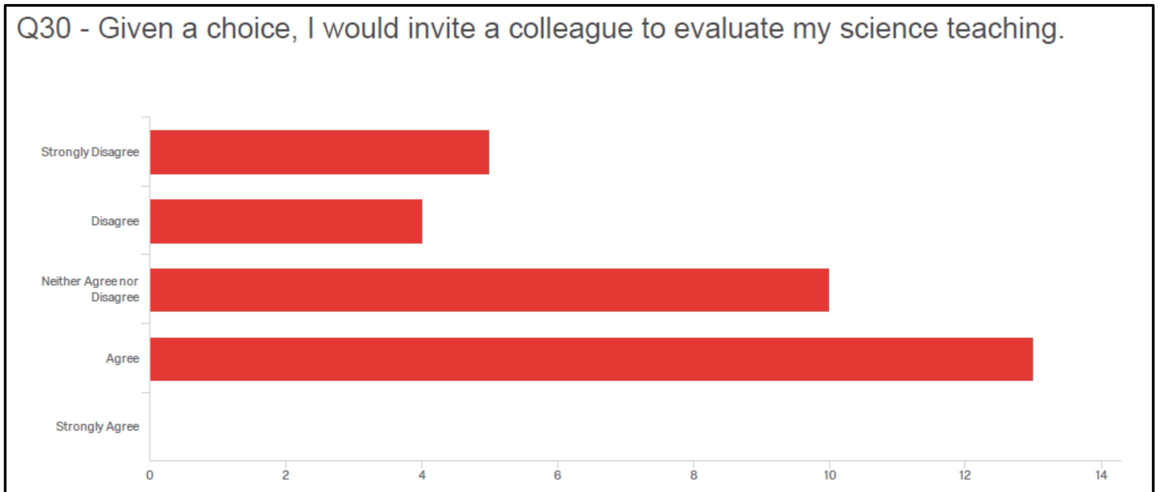


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I am confident that I can explain to students why science experiments work.	1.00	4.00	3.22	0.86	0.73	32

As was indicated in the mathematics section of the survey, most teachers at XYZ Elementary School preferred not to invite a colleague to evaluate their science teaching (see Figure 5). There are many practical and social implications for peer observations and evaluations. According to Arnodah (2013), “Peer Teacher Evaluation embraces characteristics such as collaboration, collegiality and dialogue and so can enhance positive working relationships among teachers” (p. 635). When teachers evaluate each other, the culture of individualism is removed, and trust among teachers is promoted (Arnodah, 2013).

Figure 5

Results for Survey Item Q30



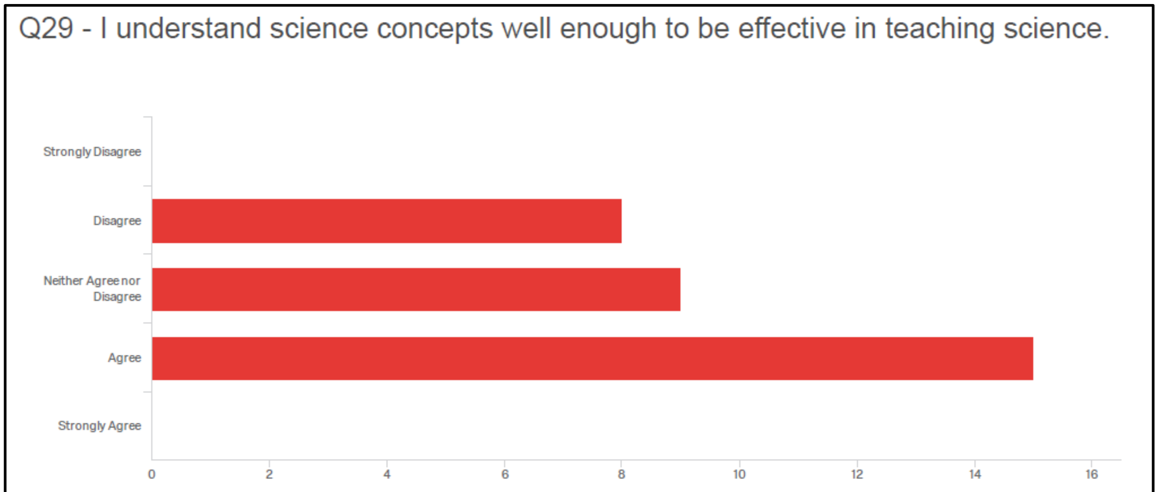
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Given a choice, I would invite a colleague to evaluate my science teaching.	1.00	4.00	2.97	1.07	1.16	32

Note. This graphic depicts teachers' feelings toward peers observing their instruction.

According to survey results, participants' agreement rate on their understanding of science concepts to teach the subject effectively was 3.22 (*SD* = .82) (based on a 5-point Likert-type scale). An item inquiring about the continuous improvement of teaching practices in science received little agreement among respondents (*M* = 3.41, *SD* = 1.03). Data in Table 6 suggested that participants' low self-efficacy in teaching science could be due to a lack of knowledge of science concepts. Evidence showed that participants required more professional development (PD) in science teaching.

Figure 6

Results for Survey Item Q29



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I understand science concepts well enough to be effective in teaching science.	2.00	4.00	3.22	0.82	0.67	32

Teachers at XZY Elementary School believed that PD on content and pedagogy is important. There was an agreement among respondents for the field, “I think it is important that teachers engage in professional development on new teaching strategies” (*M* = 4.16, *SD* = .79). Eighty-four percent of participants thought teachers must learn more about the content they teach. In-house workshops and webinars on STEM instruction can improve teachers’ understanding of science topics. Additionally, time to co-plan science instruction may improve teachers’ self-efficacy in teaching the subject. Eighty-eight percent of teachers agreed or strongly agreed that teachers must collaborate with other educators on STEM instruction design.

According to T. Martín-Páez et al. (2019), “STEM learning is the integration of a number of conceptual, procedural, and attitudinal contents via a group of STEM skills for the application of ideas or the solving of interdisciplinary problems in real contexts" (p. 803). Students can develop STEM proficiency through research, logical reasoning, and problem-solving (T. Martín-Páez et al., 2019). The skills students gain from inquiry-based science instruction can support their academic performance in other disciplines. Increasing students' access to STEM instruction in the early grades has profound implications.

Participants were asked to rate the frequency rate in which students typically engage in STEM instructional strategies. The selected responses were based on a 5-point Likert-type scale (*never* (1), *occasionally* (2), *about half the time* (3), *usually* (4), *every time* (5)). Data indicated students seldom develop problem-solving skills through investigations (e.g., scientific, design, or theoretical investigations) (M = 2.22, SD = .74). The development of problem-solving skills relies heavily on hands-on learning that incorporates many tools to gather data (e.g., calculators, computers, computer programs, scales, rulers, compasses)? The survey indicated that most students at XYZ Elementary School only used data collection tools about half the time or less. Results showed that students infrequently used various tools to gather information (M = 2.5, SD = .75) and make careful observations or measurements (M = 2.28, SD = .62). A pillar of good STEM instruction is for students to make inferences and draw conclusions based on observations and experiments. According to the survey, science instruction at XYZ Elementary did not focus on students' explanations of an experiment's results or investigation (M = 2.06, SD = .79).

Career education can play a pivotal role in students' engagement, performance, and motivation. Exposing students to diverse role models and careers may enhance students' perceptions of scientists and engineers as people who use technology (Buck et al. 2008). STEM instruction offers numerous opportunities for lessons that highlight STEM careers.

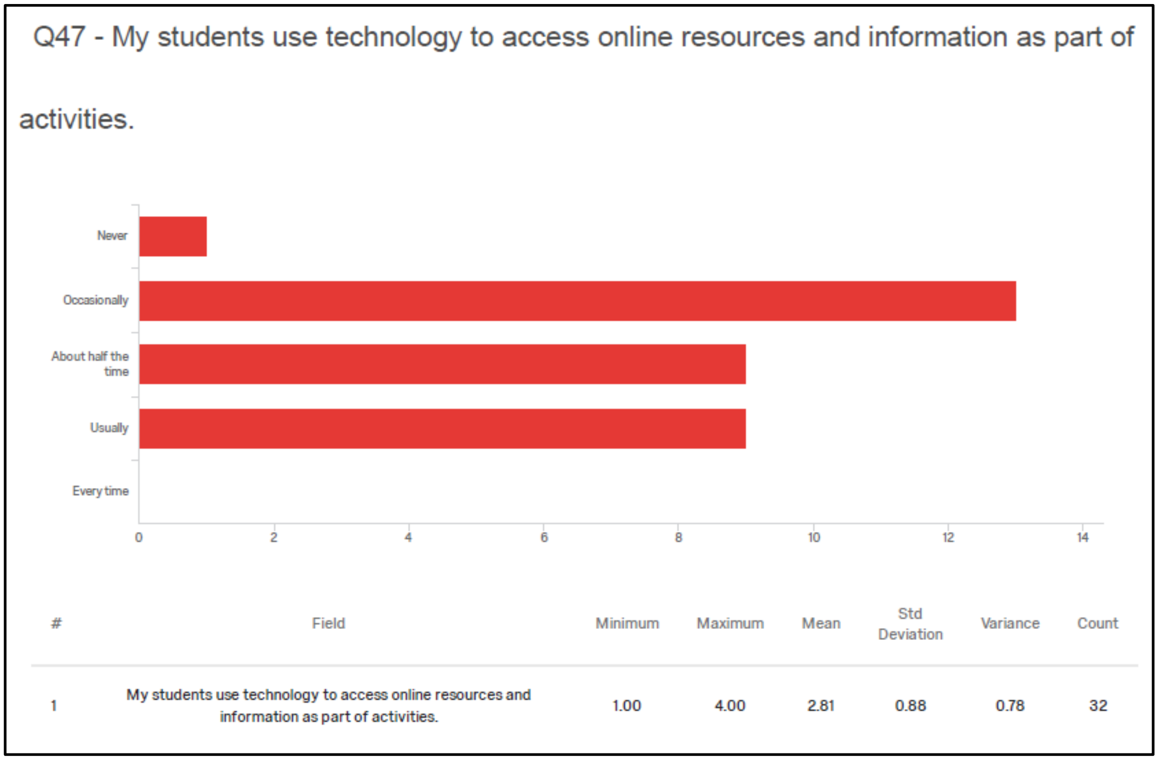
Survey results indicated that students did not learn about careers related to the instructional content (*M* = 2.53, *SD* = .87). The lack of career education at XYZ Elementary could be because teachers did not know enough about STEM careers (*M* = 2.78, *SD* = .99). What's more, teachers did not know where to learn more about STEM careers (*M* = 2.97, *SD* = .95). Exactly half of the participants disagreed with knowing where to find resources for teaching students about STEM careers.

Technology is a significant component of STEM education. Most questions on the Teacher Efficacy and Attitudes Toward STEM Survey's technology scale revealed that students use minimal technology at XYZ Elementary School. For instance, when asked whether or not students use various technologies (e.g., productivity, data visualizations, research, and communication tools), the average frequency rate was low (*M* = 2.94, *SD* = .97 based on a 5-point Likert-type scale).

When it comes to students using technology to access online resources and information as part of activities, the mean frequency was a mere 2.81 (*SD* = .88). Only 28.13% of teachers claimed that their students use technology on a usual basis for gathering information. Fifty percent of participants stated that their students used technology to promote higher-order thinking (*M* = 2.03, *SD* = .88). Data in Figure 7 show the discrepancy in students' utilization of technology during classroom instruction.

Figure 7

Results for Survey Item Q47



Note. This graphic shows the frequency rate at which students used technology to access online resources and information as a part of classroom activities.

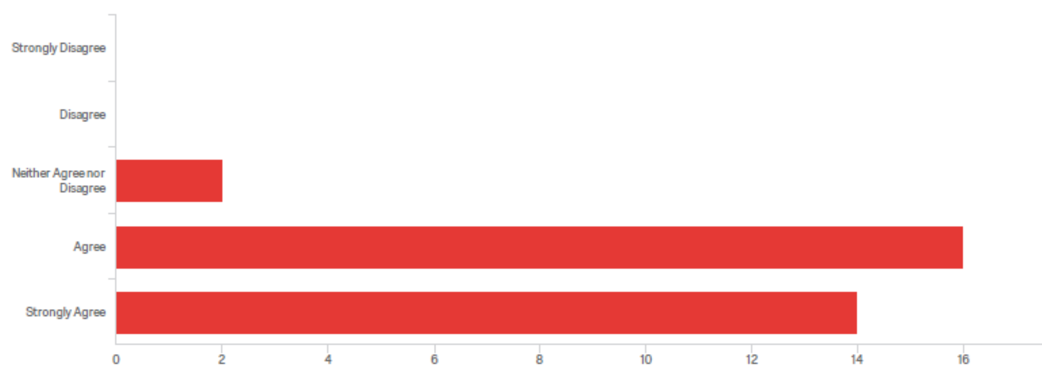
There was a wide range of responses for the survey field, "My students use technology to create new ideas and representations of information" (*M* = 2.13, *SD* = .99, *Min* = 1, *Max* = 5). The low average signifies that most students did not use technology to exhibit their learning or represent concepts in science class. A guiding principle of the Next Generation Science Standards is that students should learn science in three dimensions. "In order to learn science, students must engage in all three dimensions simultaneously, using the different aspects of scientific practice to build scientific knowledge as scientists do" (Wyner & Doherty, 2017, pp. 787–788).

The inquiry process lays the foundation for STEM education. With inquiry-based learning, students explore new ideas to understand, generate solutions, and demonstrate mastery in a visible way (Northern, 2019). The survey indicated that teachers desired students to engage in the inquiry process during classroom instruction. For example, most participants agreed with the statement, "I think it is important that students have learning opportunities to engage in hands-on learning" (*M* = 4.38, *SD* = .6). Data in Table 8 suggest that most teachers believed students need opportunities to take control of their learning through hands-on learning activities (*M* = 4.19, *SD* =.63).

Figure 8

Results for Survey Item Q68

Q68 - I think it is important that students have learning opportunities to engage in hands-on learning.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I think it is important that students have learning opportunities to engage in hands-on learning.	3.00	5.00	4.38	0.60	0.36	32

The average for all other questions within the scale "21st Century Learning Attitudes (Inquiry-Based Learning)" was *M* = 3.97 or higher. Teachers at XYZ

Elementary School wanted opportunities for students to set learning goals, help others, consider multiple perspectives, take risks, produce high-quality work, and make changes when things do not go as planned. To better implement the classroom inquiry process, teachers wanted to experience scientific inquiry for themselves first-hand. Most participants agreed that it is important for teachers to engage in scientific inquiry before implementing the inquiry process in classroom instruction (M = 3.97, SD = .81).

Thoughtful and intentional assessment methods helped teachers measure students' understanding and plan instruction accordingly. There were no common assessments in science at XYZ Elementary at the time of this need assessment survey. Participants agreed that it is important to use a variety of assessment data throughout the year to evaluate student progress. Results indicated that teachers believed in administering common assessments (M = 3.56, SD = 1) and preparing students for state-mandated assessments (M = 3.81, SD = .92). Yet, XYZ Elementary has only one state-tested grade (i.e., third grade in math and reading), so test preparation focuses on those subjects. The study site experienced less "pressure" to prepare students for science assessments since state-mandated science tests are not administered until fourth grade, which is not taught at XYZ Elementary. Students attend a different school in the district for fourth and fifth grades.

Qualitative Results

After the survey was completed and analyzed, I conducted six empathy interviews. Results from the surveys guided the development of interview questions. A semi-structured interview form consisting of questions explored the perceptions of teachers and administrators at XYZ Elementary School. The interviews examined respondents’ understandings and beliefs about STEM education and the use of inquiry pedagogy. Interviews provided me with a better understanding of teachers’ responses to the survey items and factors contributing to the problem of practice.

Interviews occurred at a convenient time and location for the following participants: one elementary school principal, one district-level gifted and talented coordinator, one curriculum specialist, and three regular classroom teachers. The classroom teachers represented grade one, grade two, and grade three. All of the interviewees were employed by the XYZ County School District. Interviews were conducted face-to-face at XYZ Elementary School. The interviews lasted about 20 minutes each. Interviews were recorded using a recording device on a laptop computer. I transcribed interviews in Microsoft Word. Participants’ names have been changed.

I analyzed interview transcripts using general qualitative coding. First, I coded data in small chunks of words that had meaning for the study. Next, these coded chunks were combined into logical categories, which led to overarching themes (Capraro et al., 2016). “The procedure for the analysis of transcripts from interviews involved defining themes that emerged from the data” (Sigurðardóttir, 2010, p. 402). The process of explorative (inductive) coding resulted in identifying nine themes for this study’s first round of interviews (see Table 4).

Table 4

Main Themes from Qualitative Analysis

Theme #	Theme
1	Priorities
2	Obstacles to implementing science instruction
3	Student schema
4	Teacher efficacy
5	Interdisciplinary curriculum
6	Benefits of inquiry-based learning
7	Data-driven instruction
8	Professional growth
9	Benefits of STEM education

Note. This table lists themes derived from coded interview data.

Priorities

One theme that emerged was the interviewees' conception of priorities. Analysis of interviews suggested that XYZ Elementary School prioritized core content classes such as reading and math. These subjects took priority because they are state-tested areas. The federal Every Student Succeeds Act (ESSA) mandates testing for reading and math every year in grades 3–8. The school principal remarked that because the Kentucky Department of Education no longer assesses vocational studies, career education is underemphasized. The gifted and talented (GT) education coordinated stated, "because of the lack of assessment accountability in those areas [math and literacy], it [science] tends to get downplayed as less important, and a lot of teachers sometimes feel like social studies and science are what you do when you have extra time." The curriculum specialist also commented that the teachers are not as driven to teach the content without accountability. Furthermore, both the principal and the curriculum specialist suggested that science and social studies instruction could be improved if integrated into core reading and math classes. This further illustrated the point that core reading and math instruction took priority over other subjects.

Obstacles to Implementing Science Instruction

Obstacles to implementing science instruction became a theme for many reasons. All of the interviewees mentioned that lack of time is a significant challenge to implementing science instruction. When asked what factors attribute to minimal student learning in science, a third grade teacher answered, "At the very end of the day from about 2:15 to 2:50, it's our science, writing, and social studies time." In addition to teaching three subjects in a 35-minute period, the teacher mentioned that the end of the day is also when students are pulled from class for extracurricular activities, so they often forgo science instruction. The principal acknowledged these time constraints. The principal said that he had attempted to adjust the school schedule so students have more science time:

> We've looked at options, possibly with our flex or our response to intervention time. Where if I've got a team of five teachers and I've got two teachers, that would be your intensive and strategic for, let's say, reading. So my students who are below grade level and need more assistance will be going to those two strategic and intensive teachers, and then the other three will have the students

> who are on grade level and above. And we can potentially have more science time there…to get those students to really have science instruction every single day as opposed to a unit once, twice a month depending on how they are progressing. (School Principal, personal communication, January 15, 2020)

In addition to time, I discovered that the lack of resources was another obstacle to teaching science at XYZ Elementary School. The gifted and talented (GT) education coordinator mentioned that teachers often needed class sets of materials, which was challenging to provide. A first grade teacher commented, “Teachers have to pay for that, and sometimes supplies get very expensive.” Access to resources posed obstacles for implementing science instruction at the study site. The first grade teacher said that one way to improve science instruction at XYZ would be to make supplies accessible. This teacher suggested having a centralized space for science supplies. Interview analysis made it clear that the lack of time and resources were major concerns by all interviewees.

Student Schema

A common code from the interview transcript analysis was students’ lack of background knowledge or schema. According to Zhao and Zhu (2012), “People use schemata to organize prior knowledge and provide a framework for future understanding” (p. 112). The principal commented on the high percentage of students who receive free and/or reduced meals at XYZ Elementary School who will never leave the county for months on end. The GT education coordinator noted, “Some kids have no point of reference.” When asked what factors make it harder or easier to teach science, a third grade teacher replied, “A lack of background knowledge from the students makes it difficult." Fisher and Frey (2009) write, "The more you know about a topic, the more likely it will be that you can comprehend what is written about it" (p. 1).

Teacher Efficacy

The fourth theme to emerge from the interview data was teacher efficacy. Qualitative data suggested that most teachers at XYZ Elementary School lack knowledge of specialized science content. According to the district's GT education coordinator, "teachers don't have a solid background in science instruction; it's not a big part of what you get in college." The study site's curriculum specialist proclaimed that teachers' lack of inquiry-based learning as a pedagogical method contributed to minimal student learning in science. The curriculum specialist went on to say that it was "very hard to follow a project-based learning (PBL) that someone else has written," suggesting that teachers struggled with developing inquiry-based instruction. The curriculum specialist also mentioned that teachers needed to see how science instruction works for other schools with similar demographics and scenarios to improve science instruction. It appeared that many teachers at XYZ were not convinced that inquiry-based STEM instruction is possible in the early grades. The GT education coordinator went so far as to say, "When teachers are uncomfortable with content, they tend to avoid teaching it."

Interdisciplinary Curriculum

Another central theme deduced from the interview transcript analyses was the need for an interdisciplinary curriculum. Content areas were generally taught in isolation at XYZ Elementary School. This was evident because many interviewees commented on the need to integrate science into English Language Arts and math instruction. The site's principal suggested improving science instruction using reading class time for discussions and vocabulary activities on scientific topics. One third grade teacher believed that science instruction could be improved at XYZ by incorporating the NGSS into math curriculum maps. According to the school's curriculum specialist, "There is a need to integrate science and social studies into the core math and reading classes in a project-based learning." Classroom teachers also agreed that interdisciplinary instruction presented opportunities for teaching science and STEM careers. For instance, second grade teachers believed that career education could go well in reading classes based on selected texts.

Benefits of Inquiry-Based Learning

Coding analysis revealed another significant theme: the benefits of inquiry-based learning. When participants were asked how hands-on, inquiry-based activities impact student learning, the interviewees shared similar sentiments. Many interviewees described inquiry-based learning using the following terms and phrases: deeper learning, engagement, motivation, real-world connections, and imagination. The GT education coordinator declared, "Inquiry-based activities capitalize on kids' innate curiosity that's already there."

The school's principal agreed with the benefit of inquiry-based learning. He indicated, "With inquiry-based, hands-on learning, the more we can get students to think. The more we can get students to question, the deeper their learning is going to go." Observations and subsequent interviews helped this study determine the degree to which inquiry-based learning occurred at XYZ Elementary School.

Data Driven Instruction

The interviewees shared a common stance on using assessment data to drive instruction. The principal said that teachers should use assessment data to plan instructional activities. “You might do a pre-assessment just to see if the students have any prior knowledge and to kind of get a base of where you can begin—if you can move in to like deeper concepts earlier,” stated a second grade teacher. According to Roberts and Inman (2015), teachers inform their instruction using multiple forms of “assessment” such as pre-tests, learning inventories, and multiple intelligence checklists. One teacher admitted that pre-assessments were not a common occurrence at XYZ Elementary School. The interviewee stated, “I feel like we’ve gotten away from pre-assessment—trying to figure out what do our students know before we go into our instruction. So I feel like personally, I need to get back to doing pre-assessments with my students.”

Formative assessments are monitoring tools between the pre- and post-assessments. The school principal compared formative assessment to cooking a pot of chili:

> It’s kind of like cooking a bowl of chili. You put the chili on, you put the ingredients in, you take a taste, and if it tastes great, then awesome. If it’s not tasting quite up to par, you add different things. Same thing with your lessons; you take a taste of your students’ knowledge with those formative assessments, and then you add more to it before you get that the final product. (School Principal, personal communication, January 15, 2020)

Thoughtful and intentional assessment methods help teachers measure students’ understanding and plan instruction accordingly.

Professional Growth

The eighth theme was professional growth. The interviews revealed a need for faculty at XYZ Elementary School to engage in professional development concerning science pedagogy and the Next Generation Science Standards. A second grade teacher expressed a desire to collaborate with colleagues on the design of science instruction. She stated, “I think it’s easier to teach science when you have a team that might plan together, do science plans together. That way, you have more minds thinking at one time.” A professional learning community (PLC) would be a suitable time for teachers to collaborate on science instruction. According to Sigurðardóttir (2010), “A professional learning community consists of a group of professionals sharing common goals and purposes, constantly gaining new knowledge through interaction with one another, and aiming to improve practices” (p. 397). The principal at XYZ Elementary agreed. He said weekly PLCs would allow teachers to discuss data, evaluate student performance, and co-plan science instruction.

The study site’s curriculum specialist suggested having teachers view examples of proven science units from schools similar in grade levels and student demographics as that of XYZ Elementary. Whether teachers listen to an expert science educator’s advice, review sample science lesson plans, or engage first-hand in scientific inquiry, professional development (PD) must be ongoing. The school district’s gifted and talented education coordinator described PD as a one-time event that causes teachers to feel isolated and overwhelmed. Teachers leave such professional activities with an abundance of information and resources but no time to implement, reflect, and revise. PLCs and other regularly implemented PDs inspire collaborative learning, which has been shown to support better student achievement (Sigurðardóttir, 2010).

Benefits of STEM Education

The final theme derived from the interviews pertained to the benefits of STEM education. There was consensus among participants that science can be integrated with other subjects (e.g.., Math and English Language Arts). STEM is an interdisciplinary approach to learning as it embodies multiple subjects, chiefly: science, technology, engineering, mathematics, and literacy. Furthermore, all of the interviewees agree that technology contains numerous advantages. For example, a first grade teacher at XYZ Elementary believed technology could help students see the world beyond their town. The school's principal stated, "I think technology can take us a lot of places we might not be able to go." Participants believed that STEM education increases student engagement. This method of instruction is hands-on in nature, and concepts are relevant to the real world.

The research site's principal claimed that the school district's central office staff supported science education in the early grades and had allocated funds for STEM instructional plans and resources. Still, XYZ Elementary School leaders and teachers realized many challenges in providing consistent and effective STEM instruction. The fact that these educators acknowledged issues of science instruction and advocated for improvement was a promising indicator that change can happen.

Quantitative and Qualitative Integration Data Analysis

Data from the survey and empathy interviews indicated that science education at XYZ Elementary School had several issues that needed addressing. Teacher self-efficacy was a prominent issue between survey data and interview data. For every survey question in the section Science Teaching Efficacy and Beliefs, the mean score was below four on a

5-point Likert-scale where *strongly agree* (1), *agree* (2), *neither agree nor disagree* (3), *agree* (4), *strongly agree* (5). The coded interviews' central theme was that most teachers at XYZ Elementary lacked ample scientific knowledge *and* confidence in teaching science.

Survey participants and interviewees understood the value of professional growth. For the survey question asking participants to rate their level of agreement about the importance of engaging in professional development on new teaching strategies, 81.25% agreed or strongly agreed. XYZ Elementary School teachers desired knowledge and skills in not only science teaching strategies but also science content. The following survey question received a high agreement rate, "I think it is important that teachers learn more about the content they teach" (M = 4.13, SD = .74). A second grade teacher explained that "some people are kind of scared of especially with the standards are pretty new." It was evident that teachers needed and wanted professional development in STEM education.

There was a high percentage of agreement from survey participants that teachers should collaborate with other educators on STEM instruction design. Yet, interviewees indicated that collaboration in science education is not a regular occurrence. Educators at XYZ Elementary would like more time during PLCs and team planning events to focus on science instruction. The development of science lessons needed to include inquiry-based learning elements—a pedagogical technique that all interviewees valued. The school's curriculum specialist realized that most teachers were not taught using inquiry-based learning as students. Therefore, many teachers felt uncomfortable basing their instruction on an inquiry process. Inquiry-based science instruction must be supported through training and ongoing collaboration.

Many issues related to effective STEM instruction and career education were presented in the data from both quantitative and qualitative methods. Technology, scientific inquiry, career education, interdisciplinary curriculums, and assessments are important factors to STEM education. Despite teachers' low efficacy in teaching science, primarily due to time and resource constraints, teachers realized the benefits of STEM education and its potential to impact student achievement positively.

Acknowledgment of the factors that strongly influence the problem of practice inspired the study's interventions. The analysis of mixed methods data helped finalize the PDSA cycle's planning stage for the intervention's first iteration. The intervention aimed to increase teachers' efficacy toward the implementation of an inquiry-based science curriculum. Chapter 2 of this dissertation analyzed literature in conjunction with the needs assessment data to formulate a theory of action that guided the improvement effort. Implementation, testing, and recording of the intervention comprised the second step of the improvement cycle—do (Donnelly & Kirk, 2015). It is important to note that while this study established a plan and course of action to improve teachers' efficacy toward science instruction, "PDSA cycles do not always have to be linear and may overlap" (Leis & Shojania, 2017, p. 575).

Summary of Roots of the Problem

STEM instruction can be challenging to implement consistently at the elementary school level. This study's analysis of survey and interview data supported this assertion. Significant challenges regarding integrating a STEM curriculum in the early grades included, but are not limited to, lack of instructional time, insufficient resources, school priorities on other subjects, and limited student schema. Results from this chapter's needs assessment survey indicated that many teachers had low self-efficacy toward teaching inquiry-based science instruction. Survey results indicated students seldom used technology or other instruments to gather information. Students infrequently drew conclusions based on observations and hands-on experiments.

Despite participants' lack of confidence in teaching science, they understood the benefits of STEM education in the early grades. Interviewees believed that STEM instruction should be collaborative, hands-on, and relevant to students' lives. Students' interaction with STEM disciplines should not wait until they enter their high school years. According to Clements and Sarama (2016), young students' knowledge of and interest in math and science predicts later success in STEM education. Standards-aligned science instruction ought to begin in early childhood.

Inquiry-based science education should be a core component of every curriculum in grades K–12. The successful integration of the NGSS-supported instruction at the elementary school level is heavily dependent on the classroom teacher. To effectively design and implement inquiry-based instruction that targets the Next Generation Science Standards, teachers at XYZ Elementary School must first experience said instruction. Research suggests that for teachers to feel capable of implementing inquiry-based learning activities in class, they must first consider themselves competent to conduct their own inquiries (Martin & Monte-Sano as cited in Voet & De Wever, 2018). Professional development that immerses teachers in scientific inquiry may positively affect their beliefs toward STEM instruction. Teachers with a strong sense of self-efficacy tend to be better planners, more resilient through failure, and more open-minded (Concordia University, 2018). Preparation, resiliency, and open-mindedness may be what teachers need to challenge misconceptions and remove barriers related to inquiry-based science education in the primary grades.

CHAPTER III: INTERVENTION

Introduction

This study aimed to increase teachers' efficacy toward the design and implementation of an inquiry-based science curriculum. In the previous chapter, I analyzed the root causes of the study's problem of practice, which was a lack of inquiry-based science instruction in the early grades. An illustrated system improvement map represents what was learned about XYZ Elementary School in terms of STEM education (see Figure 9). According to Bryk et al. (2015), the purpose of an illustrated system improvement map is to chart the essential organizational features that are most likely to reveal themselves as the improvement work continues. This chapter's system improvement map "provides a conceptual bridge for moving from the study's root causes to identifying tactical starting points for change" (Bryk et al., 2015, p. 72).

Figure 9

System Improvement Map

Instructional System		Information Infrastructure	
The school schedule allocates insufficient time for teachers to implement science instruction.	There is no curriculum pacing guide for science.	There is no common assessment for science so there is limited data on student learning in science.	The curriculum does not emphasize metacognitive skills where students reflect on and guide their own learning.
Classroom instruction does not embed constructivist learning principles.	Planning periods are not utilized for teacher collaboration on science curriculum development.	There are no STEM coaches in the district. Curriculum specialists' time focuses on math and reading instruction.	In the past, the school did not prioritize science or inquiry-based instructional practices.
Human Resource System		Student Support System	
There is a lack of ongoing professional development on STEM subjects.	Teachers are unprepared to teach one or more STEM subjects.	Students have limited background knowledge and there is poor parental support.	Teachers' have limited knowledge of science topics and scientific processes.
There is minimal collaboration among personnel/employees across the district due to the organization of school buildings.	Teacher-evaluation system does not specifically address science standards or STEM instruction.	Many faculty members have negative perceptions towards inquiry-based teaching.	Gifted students experience STEM and inquiry more often than non-gifted students.
Governance			
The state-required test in third grade measures student learning in math and reading only. Science is only assessed in fourth and seventh grades.		Insufficient resources are available to conduct science experiments.	

Note. Organizational features associated with the present study's problem of practice

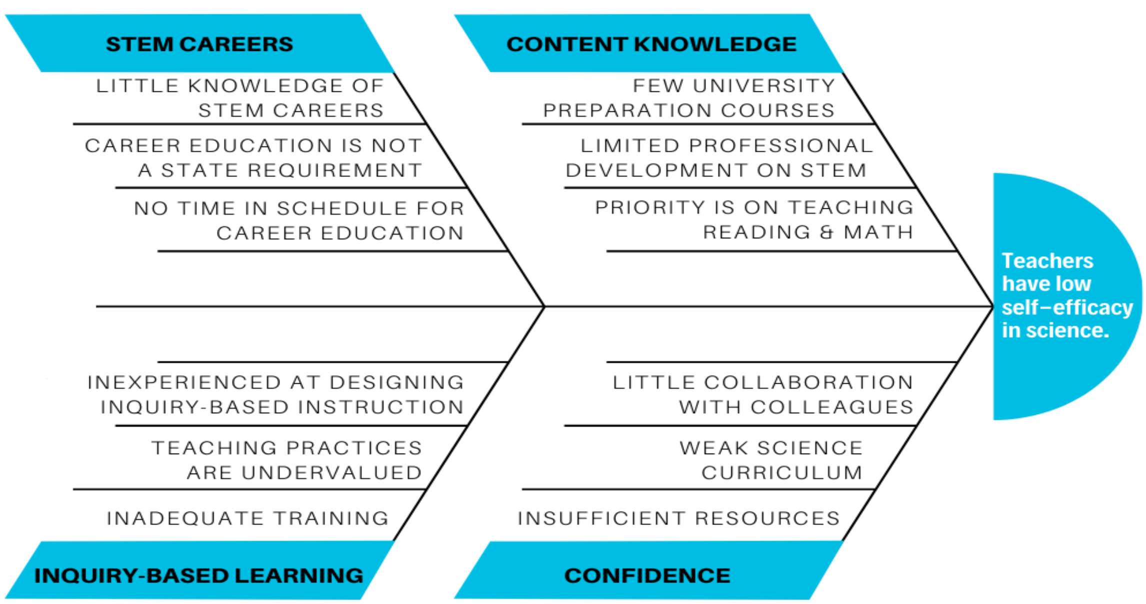
A careful examination of literature, organizational factors, survey responses, and interview data indicated several reasons students infrequently experience science instruction at XYZ Elementary School. One area that this study aimed to improve was teachers' low self-efficacy in designing and implementing inquiry-based STEM instruction.

Intervention Goal

The goal of the intervention is to increase teachers' efficacy toward the implementation of an inquiry-based science curriculum. A fishbone diagram was created to illustrate possible causes for teachers' low self-efficacy (see Figure 10). According to Ilie and Ciocoiu (2010), "The fishbone diagram is an analysis tool that provides a systematic way of looking at effects and the causes that create or contribute to those effects" (p. 1). The fishbone diagram outlines factors that have contributed to teachers' low efficacy in teaching science.

Figure 10

Fishbone Diagram



I investigated different actions to address the issue of low teacher self-efficacy in early childhood science education. Proposed interventions included professional development, mentorships, interdisciplinary curriculum design, and a professional learning community (PLC). A driver diagram was created to organize potential interventions. According to Bryk et al. (2015), a driver diagram "focuses on a small set of hypotheses about key levers for improvement, specific changes that might be attempted for each, and the interconnections that may exist among them" (p. 73). The primary driver decided on for this study was the formation of a curriculum-based PLC. The "Secondary drivers" column notes proposed activities of the PLC while the "Change ideas" column lists expected outcomes (see Figure 11).

Figure 11

Driver Diagram

Aim	Primary drivers	Secondary drivers	Change ideas
To increase teachers' efficacy towards the implementation of inquiry-based science instruction	The school develops a mentoring program for teaching STEM	Teachers analyze inquiry-based learning tasks	Teachers will understand the inquiry process
	The school provides ongoing professional development on Next Generation Science Standards and scientific concepts	The school adopts STEMscopes, an NGSS-aligned curriculum	Teachers will develop a curriculum map and pacing guide to sustain science instruction
	The school forms a curriculum-based professional learning community	Teachers interact with resources and materials needed to teach science	Teachers will have confidence incorporating hands-on STEM resources into instruction
	Teachers design curriculum documents and instructional resources for teaching Next Generation Science Standards	The school adopts instructional coaching as a model for supporting the implementation of inquiry-based science instruction	Teachers will integrate best practices in science instruction
	The school provides ongoing training on inquiry-based learning	The curriculum emphasizes connections between science instruction and other subjects	Teachers will collaborate with colleagues across grade levels

Note. The graphic depicts the primary and secondary drivers predicted to improve STEM education and teacher self-efficacy toward inquiry-based science instruction.

This study's intervention consisted of a curriculum-based professional learning community (PLC). The PLC aimed to promote collective teacher efficacy in teaching science by engaging participants in scientific inquiry using STEM resources, analyzing student data, making instructional decisions, and developing common science assessments.

I created a logic model to help plan, implement, and evaluate the curriculum-based PLC intervention (see Figure 12). A logic model is a "graphic representation of a program showing the intended relationships between investments and results" (Taylor-Powell & Henert, 2008, p. 4). Logic models are usually created during the planning process of a program or project.

Figure 12

Driver Diagram

Inputs	Activities	Outputs	Outcomes	Impact
Teachers collaborate with instructional coaches	Observe teachers' science instruction and provide constructive feedback	Teachers embed elements of inquiry-based learning	Increased student engagement	Increased student achievement
STEMscopes (inquiry-based science curriculum)	Refine a standards-based curriculum for science	Teachers develop a science curriculum map and pacing guide	Science instruction is implemented on a consistent basis	Students are exposed to more science concepts and vocabulary
Next Generation Science Standards	Professional development (PD) on the NGSS and *STEMscopes*	Teachers establish professional growth goals centered on STEM	Teachers' improve their design and implementation of science activities	Students receive high-quality science education
Teachers' knowledge and competence	Teacher training on: • inquiry models • scientific processes	Teachers prepare science experiments that target specific concepts	Students engage in an investigative approach to learning science	Effective and rigorous science instruction
Professional Learning Communities	Teachers interact with resources and materials needed to teach science	Teachers utilize Plan, Do, Study, Act to the continuous improvement of science instruction	Teachers apply new instructional approaches and assessment methods	Collective teacher efficacy on their ability to teach science

Note. Overview of the present study's curriculum-based PLC intervention.

The purpose of a logic model is to help ensure that activities will achieve the desired outcomes (Taylor-Powell & Henert, 2008). This study's logic model was used to evaluate the intervention's relationship to expected outcomes. A primary goal of the intervention was to improve science education at XYZ Elementary School by increasing teachers' self-efficacy levels in designing and implementing inquiry-based STEM instruction. This study anticipated PLC members to become champions for science education, advocating for consistent standards-based science instruction among all teachers.

Review of Literature Supporting the Improvement Initiative

The review of the professional literature in this chapter helped guide the design of this study's curriculum-based professional learning community (PLC). Topics around which the intervention was developed included the 5E Inquiry-Based Instructional Model, professional learning communities, instructional coaching, and professional development (PD). An understanding of these topics was essential to the design and implementation of the study's PLC.

5E Inquiry-Based Instructional Model

XYZ County Schools adopted the 5E Inquiry-Based Instructional Model as its preferred teaching science method at the elementary level. This study's curriculum-based PLC was designed to increase teachers' self-efficacy toward teaching science by supporting their implementation of an inquiry-based learning environment called *STEMscopes*. *STEMscopes* is a phenomena-based program that empowers the Next Generation Science Standards teaching, which the Kentucky Department of Education adopted in 2013. There are numerous resources per unit (called *scopes* in *STEMscopes*) built around the 5E Inquiry-Based Instructional Model. The 5E Inquiry-Based Instructional Model is based upon cognitive psychology, constructivist learning theory, and best practices in STEM instruction (Bybee & Landes, 1990). *STEMscopes* is instantly accessible online and highly customizable for students' individual needs.

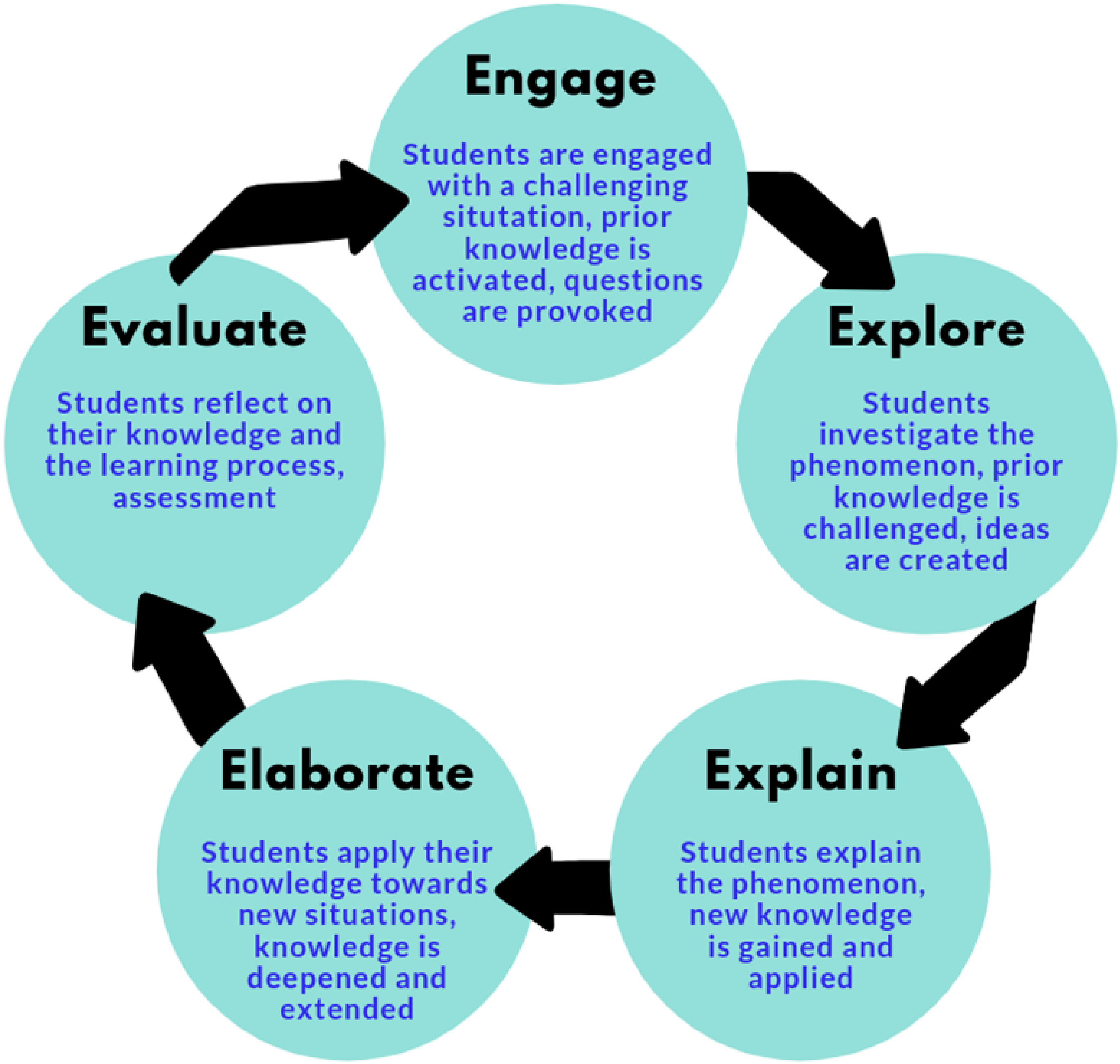
The 5E Inquiry-Based Instructional Model is a type of learning cycle. According to WestEd (2018), an education research, development, and services agency:

> In a learning cycle's simplest form, educators begin by using data to identify a problem, then select a research-based approach to address that problem. Next, they test the approach, collect and examine new data, reflect on the effectiveness of the approach, consider adjustments, and implement again. (p. 1)

Learning cycles guide the instructional process. They systematically arrange teaching materials to improve the quality and quantity of teaching and learning concerning stated instructional objectives (Pangestika & Prasetyo, 2018). The 5E model leads students through five phases of learning that are easily described using words that begin with the letter E: Engage, Explore, Explain, Elaborate, and Evaluate (see Figure 13). The instructional model brings coherence to different teaching strategies, provides connections among educational activities, and helps science teachers decide students' interactions (BSCS Science Learning, 2019). Compared to traditional teaching models, the 5E learning cycle results in greater benefits concerning students' scientific inquiry ability (Bybee, 2009).

Figure 13

5E Inquiry-Based Instructional Model



Note. The *STEMscopes* science curriculum supports the 5E Instructional Model (Duran & Duran, 2004).

The 5E Inquiry-Based Instructional Model is an effective way to design inquiry-based science lessons that enhance student learning. A study by Duran and Duran (2004) investigated the final evaluations of 30 participants who attended a two-week summer institute experience designed to encourage teachers to explore district-adopted inquiry-based science kits. A qualitative analysis of the professional development's final evaluations and participant journals demonstrated a learning cycle's positive impact on classroom instruction. According to P. Williams (2019):

> A focus on content at the expense of process in STEM education (and all education, really) will inhibit student learning, because the important learning occurs through the activities of the process. When the learning of content is necessary so it can be applied, through an activity to a situation, such content is perceived as relevant and so will be learned more effectively and efficiently. (p. 3)

The 5E model serves as a flexible learning cycle that assists curriculum developers and classroom teachers in creating science lessons that illustrate constructivist, reform-based, best teaching practices. A high-quality curriculum is a critical factor in student academic success (Steiner, 2017). A curriculum's effectiveness is largely dependent on the teachers' understanding and ability to use the educational program with intentionality and professional judgment (Hirsh, 2018). Participants in the present study used the 5E learning process to examine science standards and content and develop an inquiry-based science curriculum for each grade level.

Professional Learning Communities

This study's intervention supported teachers' understanding and execution of the 5E instructional model. Participants joined a curriculum-based professional learning community (PLC) that focused on STEM integration. PLCs promote new knowledge and puts it into practice through collaboration and reflection (Hord, 1999, 2004; Stoll &

Louis, 2007, as cited in Sigurðardóttir, 2010, p. 397). According to the Kentucky Department of Education (2020c):

> A professional learning community, or PLC, is an organizational structure by design that meets regularly, shares expertise, and works collaboratively to improve teaching skills and the academic performance of students. The school's curriculum, instructional design, and assessment practices are monitored through the PLC design to ensure teacher effectiveness and, most importantly, student learning. PLCs require the utilization of data from assessments and an examination of professional practice as teachers and administrators systematically monitor and adjust curriculum, instruction, and assessment to ensure the goal of graduating all students are college and/or career ready. (para. 1)

Numerous research studies indicate that professional learning communities are beneficial and impactful on many levels. A correlational study by Sigurðardóttir (2010) examined professional learning communities' relationship with schools' level of effectiveness. The first investigation phase included two Icelandic schools, A and B. School A was the most effective school among 19 selected schools, while school B was the least effective. School C, the intervention school aimed at improving professional earning communities, was one of the less effective schools among the group. According to Sigurðardóttir (2010), intervention for improvement of the professional learning community consisted of four main strands:

- the administrative team joined a study group on the professional learning community;
- all the professional staff engaged in teamwork focusing on student learning;

- an effort was made to define a clear vision for the school;
- and a three-month in-service training program on differentiated learning was offered for all professional staff (pp. 400–401).

The questionnaire survey, Sigurðardóttir conducted at the beginning of the intervention period, was repeated two years later. The total mean score was almost the same before the intervention period. The qualitative data indicated improvements in shared values and vision for School C over the intervention period. Sigurðardóttir reported that teachers' perception of work habits to support collaboration changed significantly. Findings from the study indicated a strong relationship between a school's effectiveness and the teachers' perception of the professional learning community.

For teachers to effectively design and implement a teaching method, they need experience using the pedagogical approach. Many educators have limited to no experience with inquiry-based learning or STEM education. A study consisting of 35 undergraduate students by Schmidt and Fulton (2017) found that elementary pre-service teachers were unfamiliar with an inquiry-based instructional model. "In the context of science education, personal self-efficacy may be reflected in a teacher's confidence about implementing an elementary school science program or an inquiry-based science strategy" (Mintzes et al., 2013, p. 1202). According to Short (2014), past performance endeavors are considered the most influential source of efficacy information because they are based on one's actual experiences.

Teachers need to take full advantage of curriculum materials through study, practice, and reflection. "For an elementary school teacher, an authentic opportunity to successfully practice teaching an inquiry-based science lesson might be expected to contribute substantially to a feeling of self-efficacy" (Mintzes et al., 2013, p. 1203). This "practice" refers to teachers' study and use instructional materials as if they were students—meaning they solve problems, conduct investigations, and think about mistakes students typically make with the material (Hill, 2020). Taylor et al. (2015) engaged teacher participants in a year-long curriculum-based professional development program that modeled lessons and encouraged collaboration around everyday experiences with materials. Participants engaged in activities as science learners, which became the collective experience that improved their pedagogical content knowledge (Taylor et al., 2015). The study's intervention integrated activities in which participants interacted with sources and teaching materials. At group meetings, participants shared their insights on how "practice" with curriculum materials impacted pedagogical content knowledge.

Professional learning communities have the potential to improve teachers' implementation of engaging and challenging instructional tasks. In a study by Smith et al. (2008), 25 Howard University students with STEM majors aimed to learn more about pedagogy, reflection, and demonstration of effective teaching through interdisciplinary seminars, linked courses, teaching experiments, and biweekly PLC meetings. The meetings engaged participants in a hands-on approach to problem-based learning. Consequently, participants used critical thinking skills, enhancing scientific communication skills, and applying classroom lecture concepts to practice. To evaluate the intervention's impact, participants completed a modified version of the Miami University PLC Participant Assessment Survey and the Student Learning Survey for Faculty. Results were compared with sample data from Miami University, which is considered a leader in the learning community movement (Smith et al., 2008). Howard

University faculty rated the impact of the PLC higher than Miami University junior and senior faculty in terms of developing technical skill, effectiveness, and interest in teaching. On a 10-point scale, the study's participants rated collegiality highly (*M* = 7.83) among participants, as were awareness and understanding of teaching methodologies other than lecture (*M* = 8.17) and higher-order thinking skills (*M* = 8.33). Results suggest that professional learning communities effectively impact teaching and learning in STEM disciplines (Smith et al., 2008).

An increase in science teachers' self-efficacy deepens their design and implementation of hands-on, STEM instructional practices. Britton (2010) examined several empirical studies that evaluated the effects of PLCs in STEM disciplines. Britton's research found that PLCs can (a) engage teachers in discussion about science and science teaching or their understanding of it (b) advance teachers' preparedness to teach science and improve their attitude toward it; and (c) increase teachers' focus on students' thinking in science. Krainara and Chatmaneerungcharoen (2019) conducted a longitudinal study that examined the development of teachers' pedagogical knowledge in a 2-year PLC that prompted changes in early grades' science instruction. The study included four science teachers and two university student teachers. Participants collaborated in a PLC that focused on processes of collaborative STEM lesson design. A constant comparative method of analyzing multiple sources of data "showed significant increases in teacher's overall self-efficacy in teaching science, personal efficacy, and outcome expectancy efficacy during the two years" (Krainara & Chatmaneerungcharoen, 2019, p. 6). A notable result from this study was that PLCs increase teachers' expectations for their instructional practices and student outcomes.

In addition to providing a practical setting for planning, implementing, and assessing instruction, PLCs can improve one's content knowledge. Vossen et al. (2019) formed a PLC with six secondary STEM teachers from The Netherlands. The PLC goals were to increase teacher knowledge about how research and design can be connected and how they can communicate this connection to students through instructional strategies. Vossen et al. examined the products participants developed during the PLC to evaluate the teachers' collective knowledge base. The results showed that a PLC in which teachers construct knowledge and instructional strategies together could be a robust system for pedagogical content knowledge (Vossen et al., 2019).

Greater content knowledge does not necessarily mean that a teacher can effectively design and implement quality instruction. "Often, teachers struggle to translate their newly acquired knowledge and skills to their own classroom practices" (Sjoer & Meirink, 2016, p.111). Most teaching training programs are comprised of one-day workshops or even shorter sessions. Teachers are left to their own devices to relate what they learn from training events to their work's specific context and vision. Professional learning communities can give teachers the collaborative environment they need to exchange thoughts on a shared idea.

In a study by Sjoer and Meirink (2016), six primary school teachers had attended 12 teacher workshops. The educators in the study indicated that they wanted follow-up support via a professional learning community. Participants attended five after-school meetings where they collaboratively developed a new science and technology curriculum. Participants struggled with defining the new curriculum. Some teachers favored a teaching guide listing specific topics and teaching materials to too much independence.

In contrast, others felt it more practical to outline the subjects' general learning targets to permit more autonomy in teaching the content (Sjoer & Meirink, 2016). It is typical and even advantageous for team members to believe in a shared vision but possess diverse viewpoints. Fullan (2002) says that leaders should "build relationships with diverse people and groups—especially with people who think differently" (para. 11).

This study's curriculum-based PLC included activities that encouraged discourse and nurtured trust among participants. PLC members needed to feel comfortable sharing opinions and concerns. Yet, there is a difference between honesty and openness. Vostal et al. (2019) write, "Honesty is both truthfulness and alignment of word and deed, while openness is centered in the sharing of relevant, appropriate information" (p. 89). The open exchange of ideas backed with evidence and rationale relies on a culture of mutual trust within the community where teachers' views are respected (Song, 2012). In a study by Mintzes et al. (2013), 116 elementary school teachers participated in grade-level PLCs. "Each community consisted of 4–5 teachers who met biweekly to discuss, analyze, plan, implement and assess inquiry-based science lessons, and the integration of science with English/Language Arts instruction" (Mintzes et al., 2013, p. 1206). The science-based PLC proved to be a powerful experience for the participants. According to Mintzes et al. (2013), the cooperative PLCs' influence seemed to emerge from the emotional and social support that comes with negotiating differences of opinion.

The chief objective of this study's PLC was to increase elementary school teachers' level of self-efficacy in teaching science. According to Mintzes et al. (2013), "Individuals who demonstrate high levels of self-efficacy approach difficult tasks as challenges to be overcome, setting high goals and persisting in efforts to achieve them"

(p. 1202). As referenced in the literature, the results and implications of professional learning communities indicate promising outcomes for this study's intervention. As with any intervention, there were ongoing challenges with this study's curriculum-based professional learning community. For instance, participants' level of enthusiasm sometimes dissipated, the group's sense of cohesion waned, and the infrastructure declined (especially due to the lack of scheduled time for teachers to meet). Yet, despite the challenges, professional learning communities have the potential to improve student learning. Student growth is worth the commitment, time, and struggle associated with working in a PLC.

Instructional Coaching

The integration of instructional coaching helped this study's PLC be an active and sustainable endeavor. "Typically, instructional coaches are there to help teachers who have been asked to seek advice on their practice or who are looking to challenge themselves by learning new strategies" (Wolpert-Gawron, 2016, para. 6). According to Aguilar (2013), "Coaching is a form of professional development that brings out the best in people, uncovers strengths and skills, builds effective teams, cultivates compassion, and builds emotionally resilient educators" (p. 6). Instructional coaching ensures that high-quality teaching practices are realized and implemented. Coaching interactions are goal directive, collaborative, and reflective. Teachers are meant to receive timely, individualized, and meaningful assistance for improving teaching (Teeman et al., 2011). Teeman et al. state that coaching "conversations may focus on management, academic content, instructional strategies, analysis of student work, or a combination of these topics" (p. 687). Instructional coaches are not sages on the stage. The process is collaborative and facilitative. According to Knight and van Nieuwerburgh (2012), "There is broad (but incomplete) agreement that coaches 'do not readily give advice' and that coaching should help learners to come up with their own answers and generate their own questions" (p. 102).

The coaching cycle consists of three stages, which are essential to the collective efficacy of a professional learning community: planning, teaching, and reflecting (Suarez, 2018). Within these phases, coaching actions may include collaborative teaching, modeling lessons, reviewing student work, and analyzing formative or summative assessment data (Zugelder, 2019). Instructional coaching styles depend greatly on the situation at hand. Some cases may be cooperative, whereas other cases may be more directive. "The art of coaching requires understanding when a teacher needs to be the co-constructor of learning and when a teacher needs to lead the self-discovery and analysis of learning" (Zugelder, 2019, p. 182).

While an instructional coach's work may vary from one school to the next, communication will always be an indispensable function of the role. Walkowiak (2016) offers five essential practices for effective communication for instructional coaches in their work with teachers, school leaders, and other educators:

1. The instructional coach and school leaders collaborate to define the role of the coach.
2. The instructional coach establishes trust with teachers at the school.
3. The instructional coach shows value for teachers' ideas.
4. The instructional coach sets very narrow and focused goals for instructional growth.

5. The coach focuses instructional conversations on evidence from students and on learning together as professionals. (pp. 14–16)

Instructional coaching purposefully targets developing teacher expertise by using multiple, simultaneous, and diversified activity centers. Teetman et al. (2011) conducted a descriptive study of 21 ethnically diverse elementary school teachers who represented grades K–6. First, the coach and teacher met to review a planned lesson while focusing on Standards for Effective Pedagogy. Next, the coach observed the teacher's implementation of the lesson while taking extensive field notes for a follow-up discussion. Last, the coach and teacher held a short debriefing session to compare the lesson as designed to the lesson delivered, reflecting on its strengths and areas for improvement.

Teetman et al. assessed participants' growth in the Standards for Effective Pedagogy using a five-point Standards Performance Continuum observation rubric. "Findings demonstrated that target-based instructional coaching, when tailored to teachers' needs, is able to statistically close the pedagogical gap between teachers in the high and low groups over time" (Teetman et al., 2011, p. 691). Professional development activities should be differentiated according to teachers' actual and perceived needs. A coach's situation and contextual factors will never be the same for any two cases. The pathway to understanding a client's need is laid forth with communication. Establishing excellent communication permits a coach to focus on what is most important. Ultimately, instructional coaching aims to improve the learning process and help students make continuous progress.

Instructional coaching supports teachers from across grades and content areas. To support science teaching at XYZ Elementary and the members of this study's PLC, I took on the role of a STEM coach. Research suggests STEM coaching to be an effective method for helping teachers plan and implement instruction. Giamellaro and Siegel (2018) developed a grounded theory to describe how personnel within a school system perceive and co-construct the role of a STEM coach tasked with supporting teachers to implement STEM instruction. Participants communicated their experiences with the STEM coach through interviews and journals. This qualitative data's open coding revealed three broad themes in how participants described the STEM coach: connector, planner, and teacher. Most participants found value in having the STEM coach as a resource, a mediating tool to implement inquiry-based science instruction (Giamellaro & Siegel, 2018). According to Giamellaro and Siegel, the results of their study indicated the STEM coach's role to be a tool to facilitate aspects of high leverage teacher professional development:

- Content-focused for teachers with different content backgrounds,
- internally coherent by facilitating alignment of initiative elements,
- providing individualized feedback,
- modeling of effective teaching practices, and
- supporting collective participation. (p. 34)

The STEM coach's role is best designed by all parties involved, not just the school's administrators. During a coaching cycle, the coach and teachers need agency in how the role of coaching evolves. An instructional coach's interventions should have some flexibility. For each situation, the coach must consider their own strengths and that of the client to bring significant innovation to the partnership.

Instructional coaching can also enhance the instructional practices of seasoned and competent teachers. Jung (2019) formed an instructional coaching partnership with an elementary science teacher who was known for his commitment to providing inquiry-based learning experiences for students. The participant provided instruction that supported students in using and developing academic science language. The study's coaching intervention adhered to partnership principles established from research by coaching expert Jim Knight: equality, choice, voice, dialogue, reflection, praxis, and reciprocity (as cited in Jung, 2019, p. 1016). Instructional coaching aimed to support participants in developing strategies for teaching science academic language. Coded conversations revealed that instructional coaching supported the teacher's successful articulation of language expectations for students and his utilization of "in the moment" scaffolds to support students' language development (Jung, 2019). There are many outcomes of content-specific partnerships. Instructional coaching gives teachers space to communicate classroom needs, support with the integration of strategies and resources, and the capacity to identify and examine successes and challenges.

Despite the impact of coaching on improved teacher efficacy and student outcomes, coaching challenges persist. The list of challenges includes ambiguous definitions for instructional coaching, the tension between coaching and performance management, and the struggle for time and space to permit action (Knight & van Nieuwerburgh, 2012). A remedy for these challenges is to incorporate instructional coaching into a comprehensive professional development program (Teeman et al., 2011).

This study’s intervention incorporated instructional coaching into a professional learning community that focused on developing, implementing, and evaluating a science curriculum.

Professional Development

Instructional coaching and professional learning communities are considered research-based ideas of effective professional development (PD) (Desimone & Pak, 2017). The result of all professional development should be student improvement, but its beginning should recognize teachers’ important roles. After all, “We cannot expect students to change what they do if we are content for teachers to continue doing what they have always done (Harwell, 2002, p. 2). Over the years, there has been a substantial amount of research on teacher professional development. The research shows that professional development can only succeed in settings that support it (Harwell, 2002).

Professional development does more than impart knowledge; it can foster reflective thinking and growth. Six teachers from a Singaporean primary school with midrange results on national assessments were willing to support a PD initiative to improve their instructional practices. The six participants volunteered and committed to working the full year with a university-based research team to change how reading comprehension discussions were led in their classes (Silver et al., 2019). The study’s research teams and teachers met regularly throughout the school year, forming an “innovation team.” Silver et al. noted that the teachers gained knowledge about new facts, concepts, and procedures because of professional development. The participants also became more analytical and evaluative about instructional strategies and their practices.

Irrefutably, the most influential factors of successful professional development are teacher attitudes and beliefs. Initially, teachers in the study by Silver et al. (2019) expressed many concerns about the innovation team. The team's meetings led participants to be less skeptical and favor new strategies in the local context. Teachers who agree with what is presented during PD are more likely to accept the information. But when new information is inconsistent with teachers' beliefs, they will likely reject the information, which is known as confirmation bias (Wexler, 2020). Designers and facilitators of exceptional professional development must be conscious of teachers' beliefs. To change a teacher's negative attitude about a strategy or resource is to change their practice. Data from the study by Silver et al. showed that "teacher understanding and teachers' confidence in their ability to incorporate new models of practice work in tandem, opening up the opportunities for innovation" (p. 563).

The change in teachers' behaviors activated by professional development (PD) should improve student performance (Harwell, 2003). In a study by Killion (2016), participants received face-to-face professional development related to a new science curriculum and its materials. Killion's study tested the causal connection between curriculum materials with curriculum-specific PD and student achievement. The science curriculum developers provided a three-day professional development training in the summer and four one-day sessions throughout the school year. The yearlong PD focused on teachers' implementation of the curriculum and teacher collaboration with the materials. Researchers of the study used multilevel modeling to estimate the effects of the curriculum on students' achievement. The analyses found that "treatment students' performance was positive different from comparison students' performance at a statistically significant (p = .035) level" (Killion, 2016, p. 71). Killion writes, "The outcomes analyses provide evidence that the research-based curriculum accompanied by curriculum-specific professional development produced positive and statistically significant effects on student achievement and teaching practice" (p. 72).

Curriculum-based professional development has a positive impact on students' learning of science. Young and Lee (2005) asked six teachers to implement a kit-based inquiry science curriculum that provides materials and teacher guidance to spur students to construct science knowledge and develop science process skills. The participants received professional development related to the content and processes in each science kit and training on increasing critical thinking through inquiry-based learning. The comparison group was composed of nine student groups that did not use kit-based science and were taught by teachers who had not experienced ongoing science PD. The science achievement of 226 5th graders who engaged in the kit-based inquiry science curriculum supported by professional development was compared with data from 173 5th graders from other districts that did not use kit science materials or have regular PD in science teaching. Young and Lee reported that students in kit-based classrooms scored considerably higher than non-kit classrooms on both the pretest and posttest, even though non-kit classrooms had more minutes of science instruction. Integrating an inquiry-based science curriculum has the highest potential to improve student achievement when coupled with systematic professional development.

Project-based learning (PBL) is a methodology similar to the 5E Inquiry-Based Instructional Model used in this study. During PBL, students use inquiry skills to investigate a problem, topic, or interest. Capraro et al. (2016) conducted a three-year study of sustained professional development with STEM teachers from three urban high schools to examine the implementation of PBL, development of PLCs, and student achievement. In addition to classroom observation data and focus group interviews, student achievement on a state-mandated test was used to evaluate the PD model's effectiveness. According to Capraro et al. (2016), there were three components of their research project:

> (a) PD delivered for a three-year period with 10 set days (60 hr per year, for a total of 180 hr over the course of the study using a fixed set of PD providers, (b) development of professional learning communities, classroom observations of PBL implementation within each school coupled with research-based PD for implementing professional learning communities. (p. 185)

Capraro et al. reported an improvement in mean scores for each of the six categories from baseline observations in the year before the study's inception through the next three years. These findings suggest that high-quality, research-based PD on STEM-oriented PBLs and professional learning communities could lead to student learning gains, as measured by state accountability measures when the initiative is implemented with fidelity. To encourage teachers to integrate a new curriculum, strategy, or resource, they will need not only aptitude but confidence. Curriculum-based PD, where teachers complete activities, explore tasks, examine lessons, and engage with resources, will give them a greater sense of self-efficacy to faithfully implement an intervention (Polly et al., 2017).

Professional development is a significant part of teachers' duties and responsibilities. Under Kentucky Required Statue 158.070, four days of the minimum school term are to be used for PD activities. Twenty-four hours of professional development does not guarantee that an educator or any other professional will achieve mastery in an area. The Kentucky Department of Education's (KDE) webpage for teacher evaluation systems does not use the word "mastery." KDE (2020a) states that "certified evaluation plans should reflect and support Kentucky's commitment to every student being taught by an effective teacher by promoting the vision of continuous professional growth and development of skills needed to be a highly effective educator" (para. 1). With professional learning communities and instructional coaching, teachers will receive the meaningful and sustainable PD they need to improve student achievement.

Leadership Framework

If anything is inevitable in the field of education, it is *change*. Education is an evolving field. There are ever new trends in pedagogy, advances in technology, policy changes, and frequent alterations to procedures and systems at the local level. Leaders must recognize the environmental changes and challenges occurring in their organizations. District and school leaders must use adaptive capabilities to adjust quickly to changing situations (Sharpe & Creviston, 2013). The present study's intervention experienced expected and unforeseen challenges, including scheduling conflicts, waning enthusiasm, and differing district priorities. I employed principles of adaptive leadership during this study to prevent and address potential concerns and deviations associated with a curriculum-based professional learning community (PLC).

"Adaptive leadership is a practical leadership framework that helps individuals and organizations adapt to changing environments and effectively respond to recurring problems" (Mulder, n.d., para. 1). For successful adaptation, leaders must collaborate with their organization members to highlight major issues, challenge established practices, and create widespread engagement (Wong & Chan, 2018). Adaptive leadership leads to a better understanding between all hierarchical layers of the schools and enables everyone to be open to efforts (Mulder, n.d.). I participated in this study's intervention as the PLC facilitator and instructional coach. By taking on these roles, I engaged participants in the active study of curricula and provided teachers with ongoing support in and outside of group meetings.

Similar to that of professional learning communities, much of inquiry-based science instruction is collaborative. Students work with peers, teachers, and other professionals to investigate phenomena and create 3D models during STEM instruction. Woolard (2018) conducted a study to evaluate the adaptive leadership model's effectiveness as a framework for group assignments. The study featured four junior-level undergraduate business management courses and included 48 student groups. Groups engaged in a four-part assignment that taught the management process and embedded a definite system of group interaction, accountability, group reflection, and student engagement. After the academic semester, participants were asked to evaluate the group assignment. Participant feedback expressed overall satisfaction with the adaptive leadership model, which asked students to diagnose the situation, manage self, intervene skillfully, and energize others. Woolard's study found that utilizing the adaptive leadership model as a framework for group assignments yields positive results.

Fittingly, adaptive leadership is a useful model for addressing adaptive challenges. According to Linsky and Lawrence (2011), "adaptive challenges consist of unresolved competing commitments, values, and loyalties that keep organizations (or companies, or schools, of families, or countries, for that matter) locked in place" (p. 11). These kinds of challenges require leaders and their followers to employ new approaches. Such approaches' success depends on an individual's cognitive, affective, interpersonal, and intrapersonal capacities (Drago-Severson, 2009). Adaptive leaders build their team's capacities through training, ongoing support, and, most importantly—reflection.

Adaptive leaders practice metacognition—thinking about one's own thinking. Reflection can lead to greater task commitment, even when unexpected or interfering events occur. A team's ability to tackle adaptive problems requires members to reflect on what is going well and what can be improved. Rolfsen et al. (2014) write, "Opportunities for team adaptation can be utilized only if teams have the chance to use interruptions as triggers for self-evaluation" (p. 337). Self-awareness is partially valuable during adaptive challenges since the problem and the solution frequently lie within an organization's individuals (Heifetz & Linsky, 2002).

Bryk et al. (2015) tell us that "improvement efforts need the goodwill and engagement of the people whose work is the subject of change" (p. 119). Members of the present study's science-focused PLC committed time exploring multiple facets of an issue, investigating new developments, seeking different ways of thinking, and designing thoughtful action plans. Professional learning and growth is an iterative process. It was imperative that participants in my intervention investigated contextual factors and never lost sight of goals. An adaptive leadership style yielded dedicated followers who were unmoved by adversity.

"Although adaptive leadership emphasizes the engagement of the whole team in the change process, the role of positional leaders is still a major determinant of success"

(Wong & Chan, 2018, p. 113). Leaders need to be steadfast in their examination of the contextual factors that affect their organization. As is necessary, leaders must intervene and experiment with making the environment more conducive to change (Wolfe, 2015). Such an environment is one where there is a sense of trust between leaders and followers.

When enacting changes and dealing with challenges, leaders must examine the environmental context as well as their own being. A leader’s awareness of their leadership and management style is vital to promoting understanding and increasing productivity (Tate, 2003). According to Hersey and Blanchard (2013), “Effectiveness is dependent upon the leader, the followers, and other situational factors” (p. 148). Shared responsibility for accomplishing tasks exercises the strengths and resources of multiple team members, which builds a sense of high collective efficacy (Squires, 2015). Adaptive leadership inspired a collaborative culture among this study’s PLC members who were motivated by common goals and agreed-upon processes.

Theory of Action

The present study’s intervention aimed to promote collective teacher efficacy in teaching science by engaging participants in scientific inquiry using STEM resources, analyzing student data, making instructional decisions, and developing common science assessments. My theory of action relied on theoretical concepts, research findings, and useful reports of practice applications. This theory of action is supported with a theoretical framework. I identified three theories that defined and described relationships between the intervention and root causes of the problem of practice:

- the constructivist theory of learning
- sociocultural learning theory, and

- transformational coaching.

These theories comprise the vehicle for generating, testing, and validating actionable knowledge. Actionable knowledge supported practical actions at XYZ Elementary School as well as in other contexts (Mintrop, 2019).

Constructivist Theory of Learning

The constructivist theory of learning assumes that students build knowledge as part of a process of making sense of their experiences. In the constructivist model, teachers introduce foundational concepts and then add increasingly complex concepts as students master the more basic ones (Rolloff, 2010). A primary goal of the model is for students to construct knowledge. According to Seimears et al. (2012), “The construction of knowledge is a lifelong process, and at any time, the body of knowledge individuals have constructed makes sense to them and helps them interpret or predict events in their experiential worlds” (p. 266). This view of learning is quite different from traditional teaching views, where students receive information rather than construct it. Table 5 compares the traditional classroom to the constructivist one.

Table 5

Traditional versus Constructivist Classrooms

Traditional Classroom	Constructivist Classroom
Curriculum begins with the parts of the whole. Emphasize basic skills.	Curriculum emphasizes big concepts, beginning with the whole, and expanding to include the parts.
Strict adherence to a fixed curriculum is highly valued.	The pursuit of student questions and interests is valued.
Learning is based on repetition.	Materials include primary sources of material and manipulative materials.
Teachers disseminate information to students; students are recipients of knowledge.	Learning is interactive, building on what the student already knows.
Teacher's role is directive, rooted in authority.	Teachers have a dialog with students, helping students construct their own knowledge.
Assessment is through testing, correct answers.	Teacher's role is interactive, rooted in negotiation.
Knowledge is seen as inert.	Assessment includes student work, observations, and points of view, as well as tests. The process is as important as the product.
Students work primarily alone.	Students work primarily in groups.

Note. In the constructivist classroom, the focus shifts from teacher to student. Adapted from: Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education, 5*(6), 66–70.

In constructivist instruction, students are not expected to rely on the teacher for how they approach learning. Students are encouraged to use creative methods to tackle assignments and solve problems (Clements & Battista, 1990). The Next Generation Science Standards-aligned instruction takes on a constructivist approach. The goal of science education is for children to convert theoretical knowledge into practice by doing and experiencing the scientific process (Akran & Asiroglu, 2018).

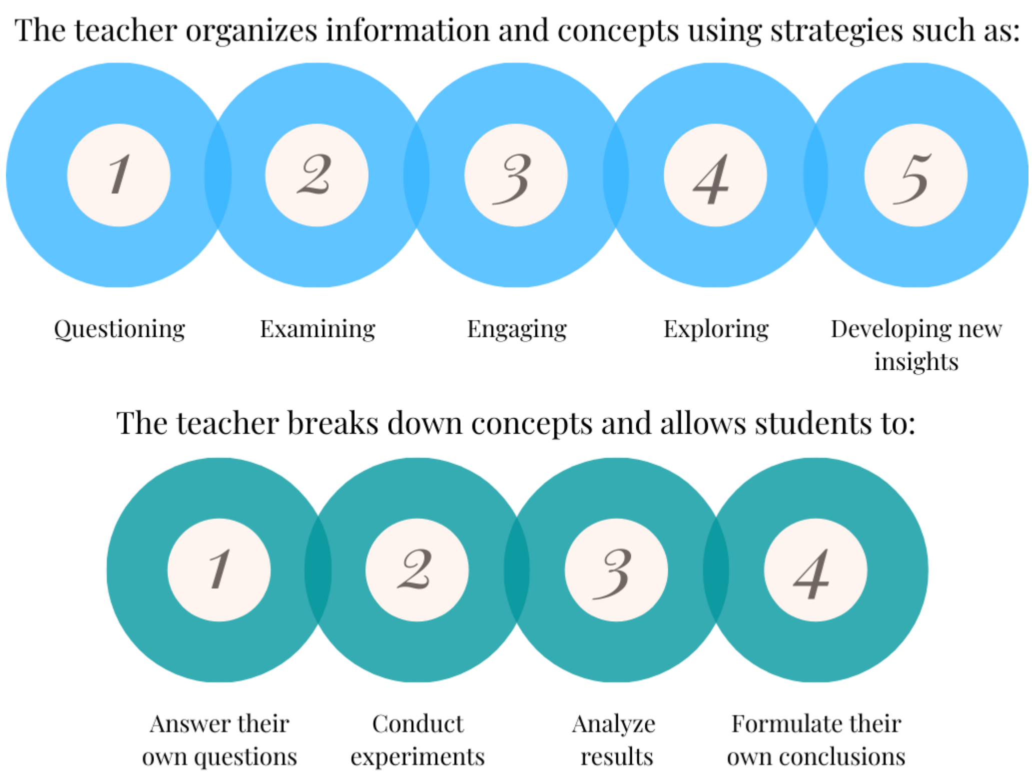
Learning cycles such as the 5E Inquiry-Based Instructional Model focus on constructivist principles through the investigation of phenomena, the use of evidence to support conclusions, and experimental design. The 5E teaching sequence helped inform the design of science instruction at XYZ Elementary School. The 5E Inquiry-Based Instructional Model was also the learning cycle used by the research site's *STEMscopes* curriculum. In a constructivist "learning cycle format, the teacher can create a series of activities that are personally meaningful for students and give students opportunities to practice critical thinking skills" (Bevevino, 1999, p. 275). This study's intervention trained participants in implementing the constructivist theory and the 5E learning cycle during science instruction. The intervention's professional learning community was constructivist in nature. Participants constructed new understandings of teaching science through an ongoing study of the curriculum and the use of instructional materials.

"Using a constructivist perspective, teaching science becomes more like the science that scientists do; it is an active, social process of making sense of experiences" (Seimears et al., 2012, p. 269). Sarican and Akgunduz (2018) used quasi-experimental design (pattern with pretest and posttest control group) to investigate the application of integrative STEM education with all its disciplines together, the academic success in science, and the development of reflective thinking skills geared for problem-solving. The study observed that integrated STEM education increases academic achievement more according to the constructivist approach but has a limited effect on academic achievement. Sarican and Akgunduz concluded that students' academic achievement did not significantly improve because STEM education is process-oriented and evaluated with a result-oriented achievement test. Performance-based assessments in the STEM classroom let students demonstrate their learning while also complying with constructivism principles.

Constructivism makes the premise that students create knowledge, and the teacher is a facilitator (Seimears et al., 2012). I used my roles as the PLC facilitator and instructional coach to create an environment where participants could explore science content. Figure 14 displays instructional strategies to organize information for learners.

Figure 14

Constructivist Teaching Strategies



Notes. Constructivist teaching strategies to organize information (Seimears et al., 2012).

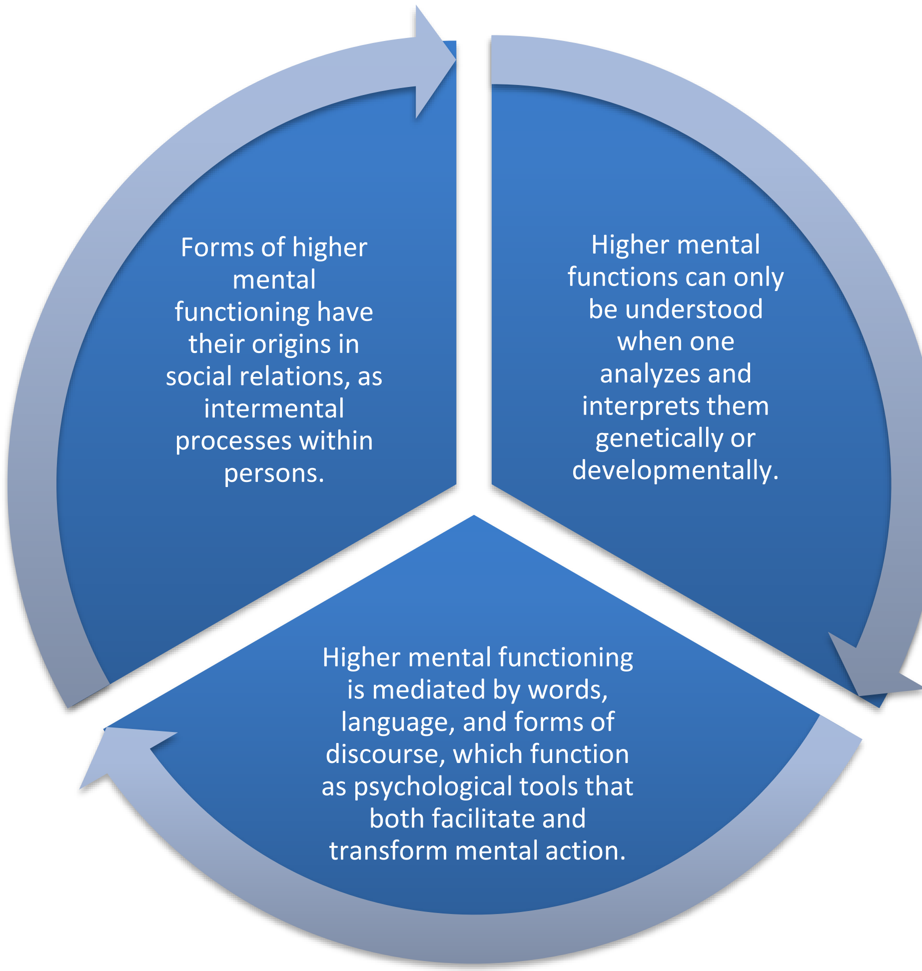
"The traditional teacher-centered method of educational systems has been changed; modern education theory has focused on skills like creative thinking and problem-solving which are today's needs" (Kocadere & Ozgen, 2012, p. 116). Interpersonal skills are also needed in today's world. Students need to be able to work well with others who may come from diverse backgrounds. Coincidentally, the constructivist theory of learning is a social activity. A constructivist learning environment encourages children to discuss ideas (Appleton & Asoko, 1996). Peer-to-peer interaction and collaboration profoundly influence students' learning behavior.

Vygotsky's Sociocultural Theory

Lev Vygotsky, a Soviet psychologist, framed learning as a social process. According to Darling-Hammond et al. (2003), "Vygotsky suggested that knowledge is constructed in the midst of our interactions with others and is shaped by the skills and abilities valued in a particular culture" (p. 126). Vygotsky's sociocultural theory contributed to the development of constructivist theory and curricula (Jaramillo, 1996). According to Vygotsky, "social experience shapes the ways of thinking and interpreting the world" (Jaramillo, 1996, p. 135). Vygotsky claimed that cognitive development occurs first on a social level and later on an individual level (L. Wang et al., 2011). Figure 15 includes three claims that capture the fundamental assumptions of Vygotsky's sociocultural theory (Tappan 1998).

Figure 15

Assumptions of Vygotsky's Sociocultural Theory



Note. Vygotsky's sociocultural theory assumes that higher mental functioning is contingent on social interactions and the accurate matching of instructional strategies to one's developmental capabilities (Tappan 1998).

This research study's professional learning community (PLC) was a team-based intervention that relied profoundly on social interactions. The intervention's curriculum-based PLC was based on the social constructivist paradigm, expressed through sociocultural theory. Participants used the inquiry process to make science instruction social and collaborative for students. Vygotsky's sociocultural theory supported the rationale for this study's intervention and helped guide its development and progress.

Key characteristics of this study's intervention were collaboration and negotiation, contextualization, and ongoing interaction with information (L. Wang et al., 2011). This study's intervention yielded a high level of interaction among participants. By applying the sociocultural theory into research, participants are empowered to collaborate and co-construct new knowledge through dialogue and interactions (L. Wang et al., 2011).

Vygotsky's sociocultural theory plays a vital role in early elementary science curriculum. Curriculum development is more than the identification of course content and learning objectives. The curriculum should be defined by the particular cultural values and theoretical constructs on which it has been based (Edwards, 2003). The science curriculum developed by members of the PLC exhibited a constructivist reading of sociocultural theory. According to Edwards (2003), students' learning of conceptual material occurs through experience, reflection, and the need to engage in active exploration with others. This study's intervention helped participants "build on the ways children learn from each other by creating a learning environment where there are ample opportunities for student-to-student discussion, collaboration, and feedback" (Darling-Hammond et al., 2003, p. 126)

Sociocultural theorists espouse the view that "social interaction among two or more people is the greatest motivating force in human development" (Eun, 2010, p. 401). Vygotsky's sociocultural theory played a pivotal role in the design of this study's intervention. A curriculum-based professional learning community allowed participants to interact, experience, and reflect on an inquiry-based science curriculum and STEM resources.

Transformational Coaching

The transformational coaching model supported this study's participatory and constructivist approach to professional learning and science instruction. According to Crane (2010), "The transformational coaching process provides a useful framework to guide performance coaching discussions in ways that open up communications and build trust" (p. 15). Trust is developed best when coaches know and appreciate their clients' beliefs—the client's cares, concerns, and considerations. Elena Aguilar (2013) puts it matter-of-factly, "There is no coaching without trust" (p. 40). Aguilar (2013) further describes how a coach might damage a client's trust:

> Their trust can be diminished when we don't listen well, when we don't validate their growth, when we don't show enough compassion, when we don't ask for permission to coach, when we push them in direction they're not ready to go, if we speak to their supervisor without honoring the agreements we made. (p. 90)

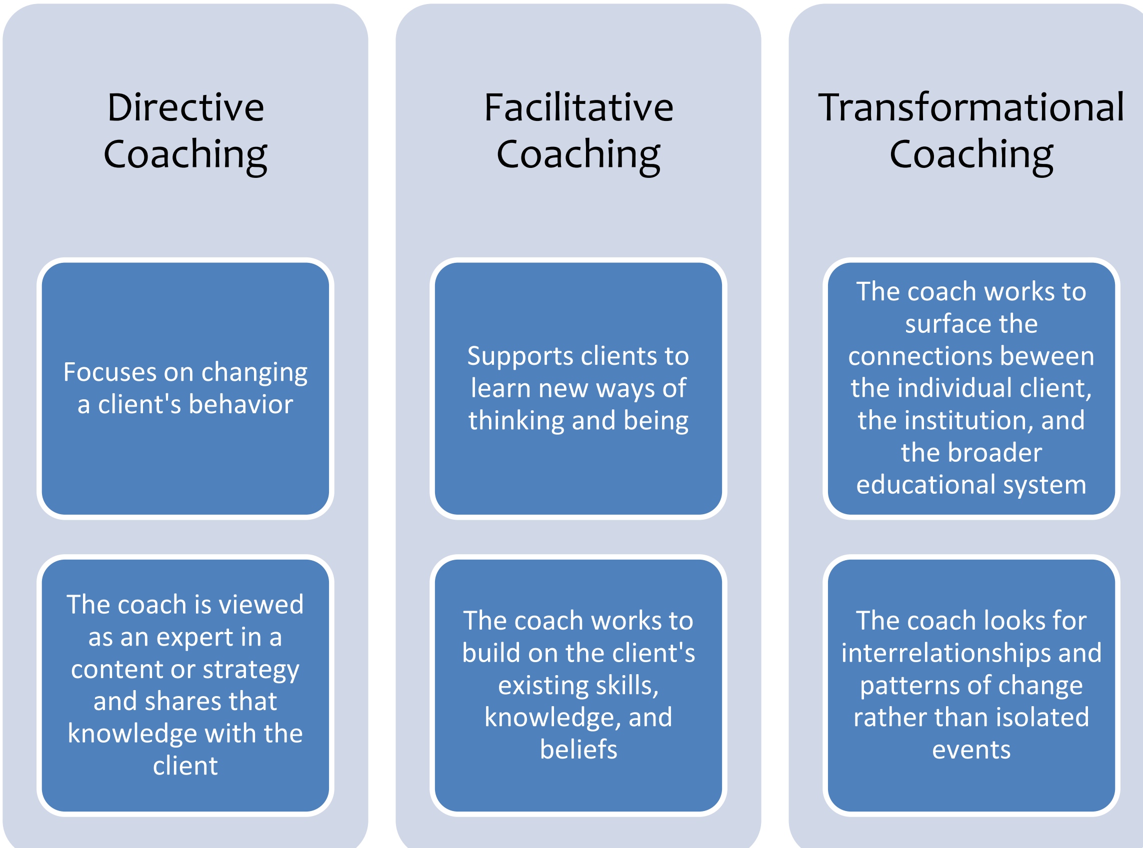
The transformational coaching model follows a holistic approach that focuses on a client's behaviors, beliefs, and ways of being.

"Transformational coaching directly and intentionally attends to ways of being" (Aguilar, 2013, p. 26). Instructional coaches explore the actions, language, nonverbal gestures, and emotions of a teacher and cogitate how these "ways of being" change depending on the context. Transformative coaches urge their participants to consider these changes and their effects (Aguilar, 2013). This particular coaching process helps teachers align behaviors and beliefs to their vision for teaching. The coach and participants must reflect on their missions for science instruction. They must deliberate on their strengths and the ways in which all parties hope to contribute to the group. Studies have shown that specific, ambitious goals lead to a higher task performance level than easy goals or vague goals such as the appeal to “raise student achievement” (Locke & Latham, 2006).

A key difference between transformational coaching to other coaching models is that the transformational coach thinks about systems. Figure 16 illustrates how transformative coaching compares to other popular models. Aguilar (2013) writes, “When we think in terms of systems, we are always looking for the links between the discrete problems that are presented and broader systems that exist now or that may need to be created” (p. 26). Acting as the intervention’s transformational coach, I remained mindful of its root causes and the school’s organizational features, including instruction, information, student support, human resource, and governance. Participants suggested changes to the current system, which supported the integration of inquiry-based science instruction.

Figure 16

A Comparison of Popular Coaching Models

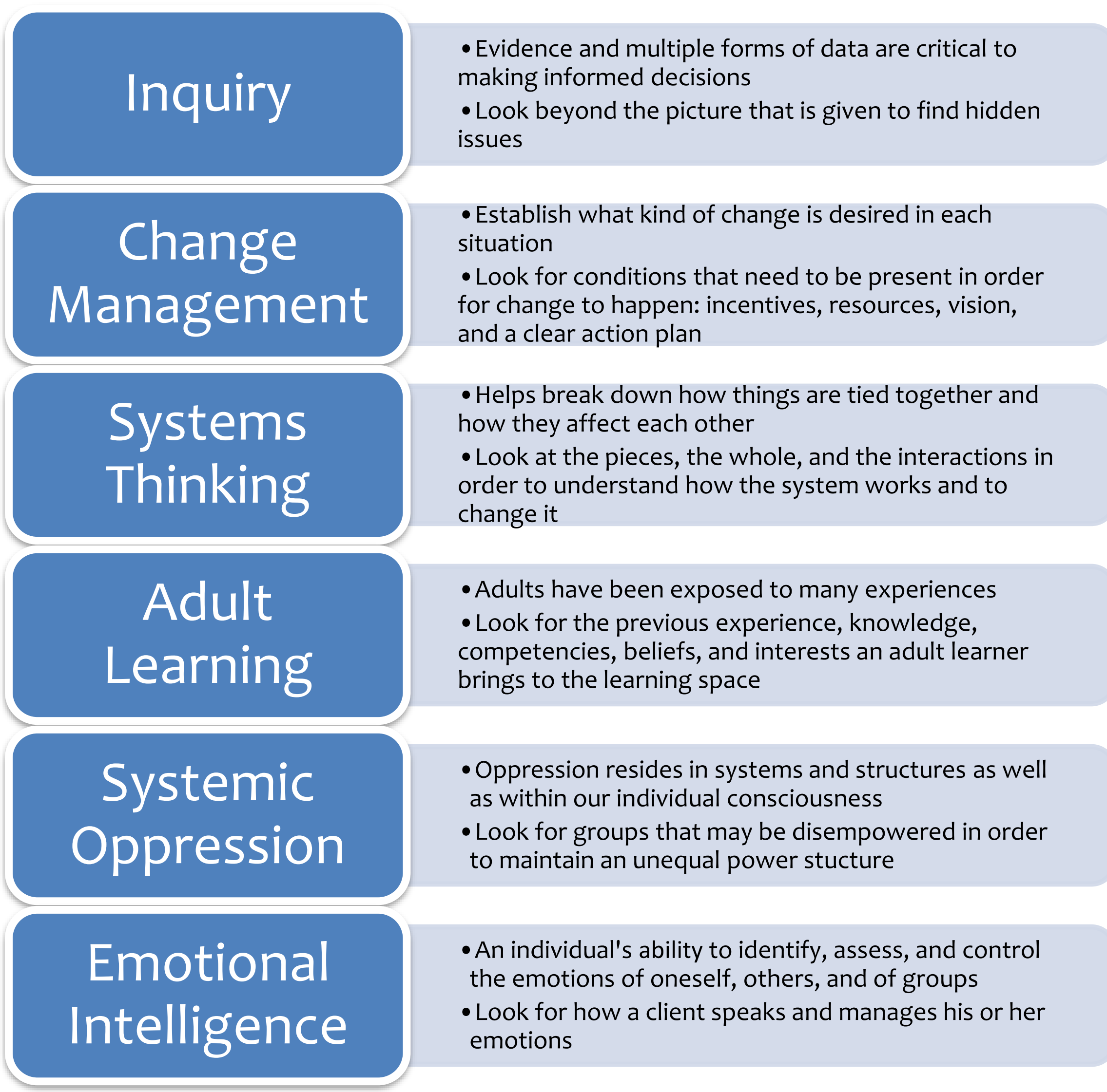


Note. Transformational coaching draws on directive and facilitative coaching to look at the whole rather than single elements. Adapted from: Aguilar, E. (2013). *The art of coaching: Effective strategies for school transformation*. John Wiley & Sons.

There will be many times during transformational coaching when situations are to be viewed in a specific context. Elena Aguilar (2013) received permission from the National Equity Project and Daniel Goleman to base her Coach's Optical Refractor on their work. Coaching lenses are the primary instrument for diagnosing problems from multiple perspectives (see Figure 17). Coaching lenses are based on theories that attempt to understand human and organizational behavior (Aguilar, 2013). Transformational coaches must examine each new situation from multiple perspectives to determine which model and strategies are most sufficient.

Figure 17

Transformational Coaching Lenses



Note. The transformational coaching model uses coaching lenses to understand specific situations and act accordingly. Adapted from: Aguilar, E. (2013). *The art of coaching: Effective strategies for school transformation*. John Wiley & Sons.

“The heart of the Transformation Coaching process is using feedback and dialogue to gain insight—before you launch into action” (Crane, 2010, p. 67). A coach will ask the client a series of questions to explore each lens of the Coach’s Optical Refractor. Not only does dialogue help an instructional coach learn about the client or situation, dialogue also makes a human connection and action possible (Crane, 2010). As a coach for this study’s PLC members, I employed questioning strategies to gain information and reveal participants’ viewpoints.

“Instructional coaching is certainly one of the most unpredictable professions in education; each day brings surprises, new challenges, and successes” (Knight, 2007, p. 19). The Transformational Coaching model was the framework needed to help this study find a starting point, partner with school administrators, build connections, and encourage implementation through collaboration and best teaching practices. Knight (2007) makes a powerful statement about a coach’s leadership:

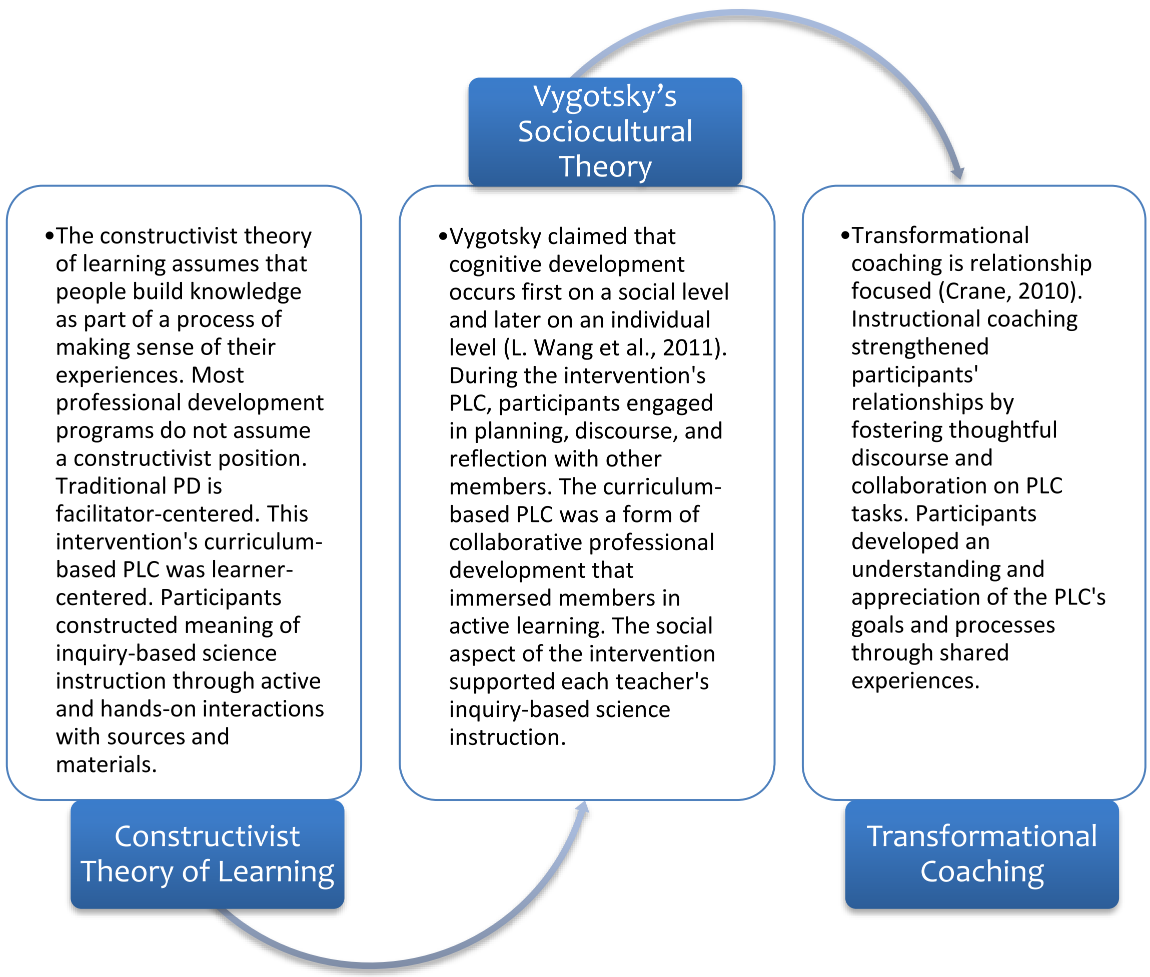
> Instructional coaches need to shape team norms, facilitate school wide implementation of interventions, promote more constructive styles of professional discourse, motivate unmotivated teachers, raise thorny issues, negotiate resolutions to the conflicts that those thorny issues stir up, and stand in opposition to any action or attitude that is not good for children. (p. 197)

For instructional coaches to be transformative, they must also be adaptive leaders.

Three distinct theories comprised this study’s first round of intervention’s theory of action: constructivist theory of learning, sociocultural learning theory, and transformational coaching. Each education theory played a critical role in the intervention’s design, implementation, and modifications. I drew on each theory’s definitions and assumptions to analyze the intervention's results and make a new iteration of the PLC for the second round of implementation. Figure 18 illustrates how the education theories relate to each other and the intervention's curriculum-based PLC.

Figure 18

First Round of Intervention Theory of Action



Note. The study's theoretical framework comprised three education theories that supported the professional learning community's goals and activities.

Intervention Design

Classroom teachers at XYZ Elementary School voiced concerns that they did not have the time, tools, or confidence to teach science and other content-specific subjects such as social studies. The intervention for this study aimed to increase teachers' efficacy toward implementing an inquiry-based science curriculum. I established a curriculum-based professional learning community (PLC) consisting of the school's curriculum specialist and two classroom teachers from each grade level (i.e., first, second, and third grades). The PLC aimed to increase collective efficacy in teaching science by engaging participants in scientific inquiry using STEM resources, analyzing student data, making instructional decisions, developing common science assessments, and offering instructional coaching. As a result of this intervention, teachers at XYZ Elementary School have a greater knowledge of science content and more confidence in implementing inquiry-based instruction.

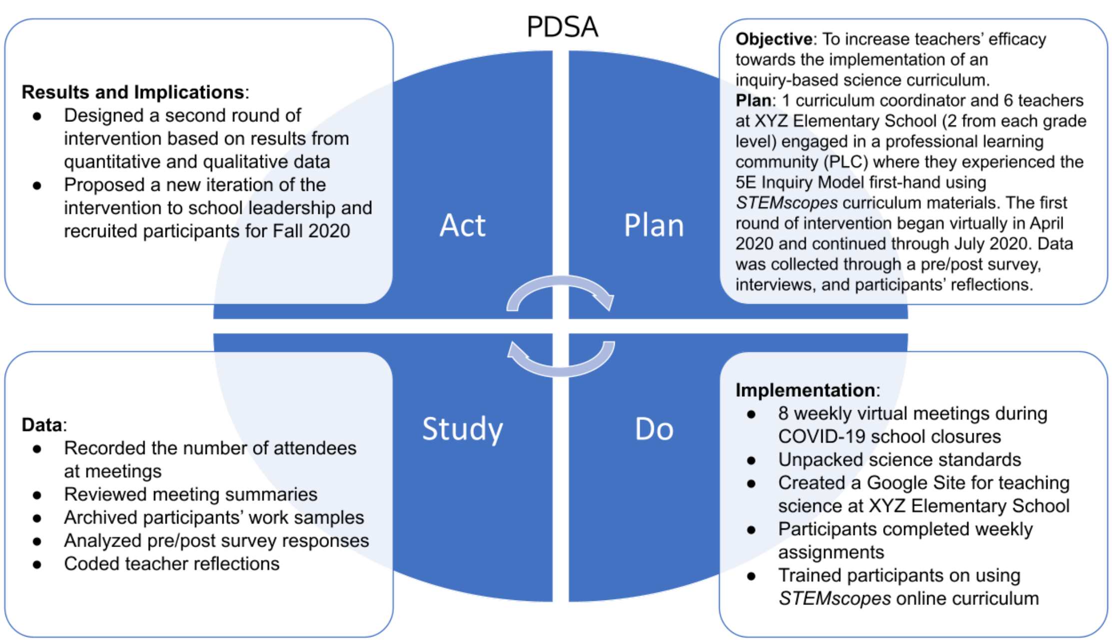
Plan-Do-Study-Act

The Plan-Do-Study-Act (PSDA) Inquiry Cycle was used to control and continuously improve the study's interventions (see Figure 19). According to Bryk et al. (2015), "The heart of the cycle is articulating hypotheses, based on a working theory of improvement, and then gathering data to test them" (p. 121). Due to a sound review of the literature and a well-articulated theory of action, it was decided that a curriculum-based professional learning community (PLC) would be an effective intervention to improve science at XZY Elementary.

Findings from the initial intervention's metrics guided the act step in the PDSA cycle. The 'act' stage focuses on the modifications that should be planned for the next improvement cycle (Crowfoot & Prasad, 2017). According to Donnelly and Kirk (2015), "small incremental changes within a complex system are more likely to be effective in producing overall effective outcomes" (p. 2). Quality improvement is faced with many challenges and calls education leaders to consider different methods, structures, and norms (Bryk et al., 2015). A continual improvement process requires a commitment from the user perspective and the system perspective. "A commitment to using improvement science is a commitment to an iterative pursuit of improvement" (Hinnant-Crawford, 2020, Chapter 8, Section 5, para. 5).

Figure 19

First Round of Intervention Plan-Do-Study-Act Cycle



Note. The Plan-Do-Study-Act is a model for improvement used to plan and monitor the progress of this study's intervention.

Setting/Context

The study took place at XYZ Elementary, a public school in Kentucky. The school site was situated in a relatively rural area. XYZ Elementary serves first, second, and third grades. XYZ County Schools has a building for pre-school and Kindergarten and a fourth and fifth grade building. According to the Kentucky Department of Education’s School Report for the 2018–19 school year, enrollment at XYZ Elementary School consisted of 685 students: 76.2% White, 8.8% African American, 9.1% Two or More Races, 4.4% Hispanic, 1.3% Asian, and 0.3% American Indian or Alaska Native. English Language Learners made up 2.3% of the student body. Kentucky Youth Advocates (2018) declares that 44% of children in XYZ County live in a high-poverty area. According to the Elementary and Secondary Education Act of 1965, XYZ Elementary is labeled a high-poverty school. Nearly 20% of students receive special education services.

This study’s professional learning intervention combined the 5E inquiry model with a STEM education program called *STEMscopes*. XYZ Elementary School had access to the inquiry-based *STEMscopes* curriculum before the study. However, several factors resulted in the ineffectual and inconsistent implementation of science instruction at the study site. For instance, a lack of instructional time created a severe challenge to the regular delivery of science instruction. For the 2019–2020 school year, the school schedule allotted 30 minutes for science combined with writing and social studies (see Appendix B for a sample schedule). Other significant factors that have resulted in limited science instruction for students at XYZ Elementary included a weak science curriculum, insufficient resources, lack of professional development, and low teacher self-efficacy.

District leadership approved this research study and its intervention. The district's superintendent and teaching and learning team at XYZ County Schools sought greater alignment between schools, especially regarding content-specific subjects such as science and social studies. When various parts of the school system align, "the outcomes are more predictable, more efficiently attained, and more likely to be the result that was desired" (Van Clay & Soldwedel, 2011, p. 16). The site's principal encouraged teacher attendance at PLC meetings. School administrators gave me access to lesson plans and instruction for data collection. The first round of intervention began during the Non-Traditional Instruction Program (NTI) in early April 2020 and continued through July 2020.

Participants

Participants included one school curriculum specialist and six classroom teachers (n = 7) who taught first, second, and third grades. The educators were employed at XYZ Elementary School. All participants were Caucasian and female. Five of the six teachers possessed a master's degree. The minimum years of experience teaching in a P–12 setting was five, the maximum was twenty-one, and the median was eight.

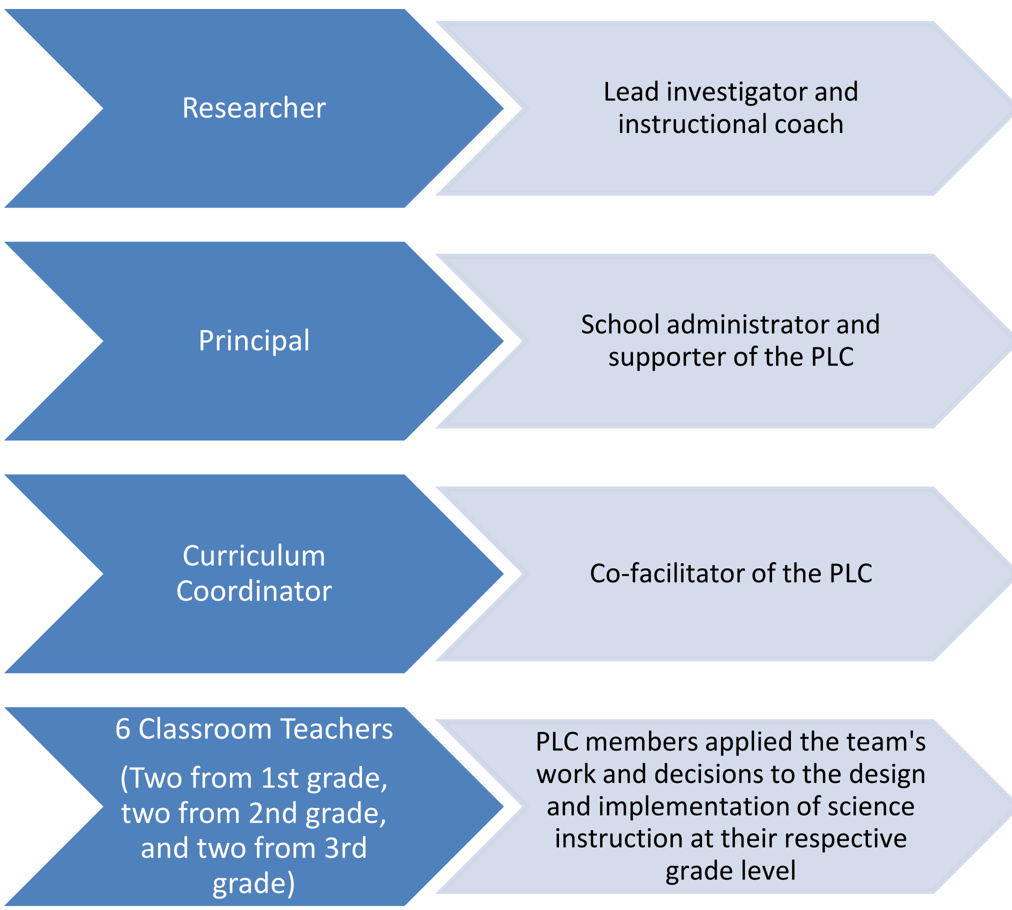
Most participants volunteered to join the study's curriculum-based PLC; one teacher was recruited. It was determined through discourse with school administrators that PLC members were viewed as leaders by colleagues. Participants possessed strong teaching qualities and a commitment to professional growth (See Figure 20). Teachers' autonomous participation, engagement in the PLC's activities, and equitable access to instructional coaching were major priorities of the intervention (Amzat & Valdez, 2017). A report from the National Commission on Teaching & America's Future found that

STEM teachers' practices become more "reform-oriented" from participating in PLCs (Fulton et al., 2010).

I served as the PLC's chief facilitator and instructional coach. I have 12 years of experience as a middle school teacher and elementary school librarian. With two master's degrees in education and National Board Certification, I have sound knowledge of pedagogy and assessment practices most needed in today's classrooms.

Figure 20

First Round of Intervention Participants



Note. The curriculum-based professional learning community's effectiveness was determined based on teachers' level of self-efficacy toward inquiry-based science instruction due to the intervention.

Procedures

As a first step in the intervention, I communicated the purpose and expectations of the curriculum-based PLC with teachers and administrators. Teacher beliefs and practices were measured using a pre- and post-test survey instrument. The 39-item survey was distributed via Qualtrics at the onset of the PLC formation in April 2020 and at the end of the improvement cycle in July 2020.

The first meeting between participants commenced on April 1, 2020, at which time we established norms for the group. During the COVID-19 Pandemic, the curriculum-based PLC met virtually using Zoom video-conferencing software. PLC members met eight times. Each meeting lasted approximately one hour once a week until the end of the 2019–2020 school term on May 12. During summer 2020, the PLC corresponded virtually via email and social media networks. PLC meetings included:

- the design of a Google Site dedicated to science instruction, resources, and assessment,
- the development of grade-level pacing guides,
- the foundation of common science assessments, and
- the training of participants on using *STEMscopes'* online platform.

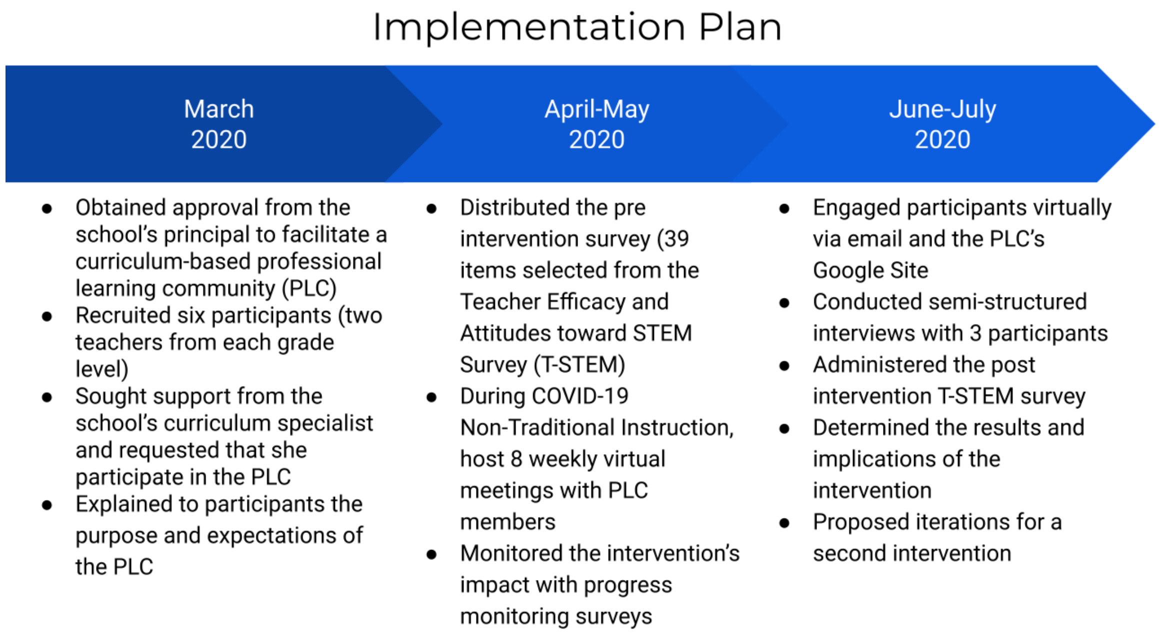
In addition to these primary objectives, “The success of PLCs can be attributed to better understanding of the students, and their needs and motivation” (Phusavat et al., 2019, p. 61). Members of the curriculum-based PLC invested time learning more about the students they served. Teachers considered their students’ background knowledge, socio-economic status, abilities, interests, and other factors pertaining to students’ needs.

The intervention also engaged PLC participants in activities outside of set meetings. For example, participants viewed educational videos, unpacked standards, attended online training sessions, developed sample lessons, completed web quests, curated resources, and other tasks to build their knowledge and skills of hands-on science instruction. Figure 21 displays an overview of the intervention's implementation plan.

I served on the intervention's professional learning community as a facilitator and an instructional coach. As an on-site coach, I helped participants incorporate engaging resources and inquiry-based practices into science instruction. My primary coaching roles were clarifying inquiry-based practices, simplifying STEM resources, and translating the research into on-the-ground strategies (Devine et al., 2013). Coaching focused on "a broad range of instructional issues, sharing a variety of effective practices that might address classroom management, content enhancement, specific teaching practices, or formative assessment" (Knight, 2007, p. 13).

Figure 21

First Round of Intervention Implementation Plan



Note. The PLC was a collaborative initiative that required the assiduousness and cooperation of each team member.

Metrics

The design of the study's interventions was primarily descriptive. The intervention's impact was measured using mixed methods: pre- and post-surveys, summaries, artifacts, and coded reflections. Data from multiple sources (e.g., surveys, documents, and interviews) triangulated the data to increase the research findings' trustworthiness and claims (Krainara & Chatmaneerungcharoen, 2019).

Surveys

Before the curriculum-based PLC meetings commenced, participants responded to items on a revised version of the Teacher Efficacy and Attitudes toward STEM Survey

(T-STEM) for elementary grades. Participants were asked about their perception of teaching and learning in science, STEM instruction, inquiry-based learning, student technology use, and career education. Data from the pre-intervention survey was measured against results from a survey with the same items in July 2020. Mintrop (2019) recommends comparing baseline and outcome using the same metrics to establish that growth did indeed occur due to the study.

The intervention's pre- and post-T-STEM survey contained five scales. I examined the mean, minimum, maximum values of items in each scale. Cronbach alpha reliability coefficients were calculated as an index of scale internal consistency indicating the extent to which items on the survey in a given scale measure the same construct (Gupta & Fisher, 2012). "The closer Cronbach's alpha coefficient is to 1.0, the greater the internal consistency of the items in the scale" (Gliem & Gliem, 2003, p. 87).

The intervention's process and instructional coaching were measured more frequently. Participants were given brief surveys that included both selected responses and open-ended questions. The survey data reflected participants' attitudes toward the intervention and participants' ideas for what the PLC should do next. I used a progress bar to track and display the number of meetings completed. This metric was visible to all participants and school administrators to authenticate the intervention's progress.

Summaries and Artifacts

As a first step in the analysis, I wrote summaries of all the meetings, including the topics discussed and how teachers interacted (e.g., exchanging ideas, discussion) (Sjoer & Meirink, 2016). The summaries provided insight into how PLC members collaborated to design and develop an inquiry-based science curriculum. Artifacts generated in meetings served as additional data sources throughout the intervention. According to Hogan et al. (2009), documents have the power to shape people's practices and conduct. Therefore, this study used curriculum documents, field notes, and assessment tools to supplement data gathered from surveys and empathy interviews.

Interviews

Qualitative interview data were analyzed to further measure the impact of the intervention. I interviewed three participants after the first intervention (see Appendix E). The interviews were semi-structured to explore themes based on each interviewee's comments. I applied the inductive coding method to data from interview transcripts to interpret and define any emerging themes. "Both inductive and deductive content analysis processes involve three main phases: preparation, organization, and reporting of results" (Elo et al., 2014, p. 1). Inductive content analysis includes "open coding, creating categories and abstraction" (Elo & Kyngäs, 2008, p. 109). Because of this process, themes emerged around teachers' beliefs and attitudes toward science instruction and the inquiry process.

Validity of First Round of Intervention

To further increase the PLC's trustworthiness and its work, I constructed an intervention dashboard in Google Slides (See Appendix F). "Dashboards are visual display mechanisms used in an operationally oriented performance measurement system that measures performance against targets and threshold using right-time data" (Kerzner, 2017, p. 263). A dashboard is a reporting system that shows participants and stakeholders how the project is going. This study's dashboard was created on a single table in Google Slides and contained data from the intervention's metrics. The dashboard served many purposes, such as communicating progress toward goals, calling attention to problems, justifying decisions, galvanizing participants, and indicating future steps needed to successfully implement inquiry-based science instruction.

Ethical Considerations

The methods, procedures, and metrics were designed to guarantee the quality and integrity of results. Mixed methods provided both quantitative and qualitative data. Participants were provided with sufficient information about the purpose of the intervention as well as its commitments. The intervention included two teachers from each grade level at XYZ Elementary School. The participants served as ambassadors who shared the PLC's decisions and products with colleagues. Participants' identities were kept confidential. The study and its intervention received approval from Western Kentucky University's Institutional Review Board (IRB), a body of the Office of Research Integrity. The IRB examines the methods and protocol of proposed studies to ensure that the research is ethical. See Appendix G for this study's IRB approval form.

Limitations of First Round of Intervention

The intervention was designed specifically for the project's goals, participants' needs, and the contextual factors at XYZ Elementary School. Results of the intervention's impact were restricted to a group of participants who taught first, second, or third grades at the research site. Replicating this study with teachers at the intermediate and secondary levels may be desirable for future research on curriculum-based science PLCs (Kleickmann et al., 2016).

For this phase of the study, I collected quantitative and qualitative data from teachers who joined the intervention's PLC. I did not collect data on teachers' instructional quality and self-efficacy without involvement in the PLC. Future research should include data from participants who undergo different forms of professional development on inquiry, STEM curriculum materials, and science standards.

In this study, one facilitator for inquiry-based science teaching scaffolded teacher learning. I planned each meeting's agenda, developed tasks, and presented pertinent information. Future research should include multiple experts facilitating the PLC meetings and examine the effects of expert scaffolding.

This study used mixed methods to determine the intervention's results and conclusions. Quantitative survey data provided numerical evidence of the PLC's impact on teacher attitudes and instruction quality. Qualitative interview and artifact data provided insight into participants' thoughts and feelings. Multiple sources of data presented a clearer picture of the intervention's outcomes and needed iterations. However, accurate measurements may not be possible until well after the project is complete (Kerzner, 2017). Administrators at the study's school site can execute additional data collection methods to ensure that participants are well supported and motivated.

Summary of the Intervention Design

The curriculum-based professional learning community (PLC) attempted to clarify underlying connections between teachers' self-efficacy beliefs toward inquiry-based science instruction and their experiences before, during, and after participating in the PLC. Participants analyzed STEM tasks, managed resources, and designed instructional units. This study's PLC was a type of professional development that incorporated instructional coaching practices. The intervention's design aligned with aspects of several highly-regarded theories: adaptive leadership, constructivist theory of learning, sociocultural learning theory, and the transformational coaching model. These theories validated the intervention's design and supported the analysis of quantitative and qualitative data collected.

Applied science is mainly about testing and learning. Results and interpretations from the intervention led to new knowledge and eventually to improvement. “The science of improvement is not being applied until systems thinking is incorporated into improvement methods and activities” (Perla et al., 2013, p. 182). Participants and other stakeholders understood how resources, time, training, curriculum, and pedagogy fit in the “big picture” of STEM education. It takes time to develop a structure of systems. Implementation of the curriculum-based professional learning community was a step in the right direction.

Results of the Intervention

One concern of design-based school improvement is making connections between the study's intervention and outcomes (Mintrop, 2019). This study incorporated metrics to inform stakeholders of the project's status (Kerzner, 2017). An intervention cannot be measured effectively without metrics capable of supplying complete or nearly complete information (Kerzner, 2017). I used data from the study's metrics to make corrections in small increments. Metrics were used to measure the intervention's impact on teachers' self-efficacy toward science and the intervention process (e.g., meetings, tasks, resources).

Surveys

Participants completed a survey before their engagement in the curriculum-based PLC and at the end. The survey consisted of items from the Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) for elementary grades, which was sanctioned by its developer, The Friday Institute for Educational Innovation at North Carolina State University.

Six classroom teachers and one curriculum specialist at XYZ Elementary School participated in the first intervention. The T-STEM survey asked participants about their perception of teaching and learning in terms of teaching efficacy, science teaching outcome expectancy beliefs, student technology use, STEM instruction, and STEM career awareness. Pre-intervention survey results were used to develop PLC activities and tasks that nurtured participants' understanding of science concepts and their ability to implement inquiry-based science instruction.

The survey was delivered using a digital form generated in Qualtrics, an online survey tool. The study examined the mean, standard deviation, and difference between modified actual and preferred scores (t-test and effect size) for each survey's designated scale.

The Cronbach alpha reliability coefficient is an index of scale internal consistency, which indicates the extent to which items on the survey in a given scale measure the same construct (Cronbach, 1951; Gupta & Fisher, 2012). Tables 6 and 7 display the scale reliability coefficient for three of the four scales in the pre- and post-intervention surveys. The STEM Career Awareness scale had but one item and, thus, no scale reliability coefficient.

Table 6

Pre-Survey Cronbach's Alpha

Scale	*Number of Items*	*Average Interitem Covariance*	*Scale Reliability Coefficient*
Science Teaching	15	. 1154195	0.8429
Student Technology Use	7	. 3793651	0.8824
Elementary STEM Instruction	31	.3371795	0.8771
STEM Career Awareness	1	N/A	N/A

Note. This data set provides the Cronbach's alpha for each scale of the pre-intervention T-STEM survey.

The scale reliability coefficient of three scales in the pre-intervention survey indicated acceptable reliability ($\alpha > 0.81$). The strong scale reliability coefficient suggested that the pre-intervention survey was both valid and reliable.

The post-intervention survey consisted of the same scales as the pre-intervention survey. However, some items were removed from the post-intervention survey to focus data analysis on critical components of the intervention's goals of increasing elementary school educators' self-efficacy in teaching inquiry-based science instruction. The modification maintained a relatively large-scale reliability coefficient for applicable scales, as exhibited in Table 7. The removal of three items from Student Technology Use weakened that particular scale's reliability.

Table 7

Post-Survey Cronbach's Alpha

Scale	*Number of Items*	*Average Interitem Covariance*	*Scale Reliability Coefficient*
Science Teaching	12	. 1601732	0. 9003
Student Technology Use	4	. 5436508	0. 7908
Elementary STEM Instruction	13	. 3079976	0. 9201
STEM Career Awareness	1	N/A	N/A

Note. This data set provides the Cronbach's alpha for each scale of the post-intervention T-STEM survey.

Pre-Intervention Survey Results

Results from the T-STEM survey revealed participants' self-efficacy and beliefs regarding STEM instruction before the intervention. Appendix H is a table of each field's minimum score, maximum, mean, standard deviation, variance, and count. For Student Technology Use and Elementary STEM Instruction, respondents were asked to indicate the frequency at which students engage in specified tasks on a 5-point Likert-scale (*never* (1), *occasionally* (2), *about half the time* (3), *usually* (4), *every time* (5)). For the other scales, respondents indicated their level of agreement with survey items on a 5-point Likert-scale (*strongly agree* (1), *agree* (2), *neither agree nor disagree* (3), *agree* (4), *strongly agree* (5)). Table 8 shows the summary statistics for each of the survey's four scales.

Table 8

Summary Statistics for Pre-Intervention Survey

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	7	56.14	5.55	48	63
Student Technology Use	6	17.33	4.59	13	26
Elementary STEM Instruction	6	38.17	8.06	28	48
STEM Career Awareness	6	3.67	1.03	2	5

Note. Summary statistics for each scale of the pre-intervention T-STEM survey.

The pre-intervention T-STEM survey confirmed findings from the needs assessment survey administered to all classroom teachers at XYZ Elementary School in December 2019, as described in Chapter 2. Stacked bar charts, a visualization method for presenting multiple attributes of data, were generated for each survey scale (see Figures 22–26). Visualization charts can enhance users' understanding of the underlying data (Howorko et al., 2018). According to Heiberger & Robbins (2014), "Diverging stacked bar charts provide an effective way to communicate summaries of data collected with Likert and other rating scales" (p. 29).

Figure 22

Pre-Intervention Data for Personal STEM Teaching and Efficacy Beliefs Scale

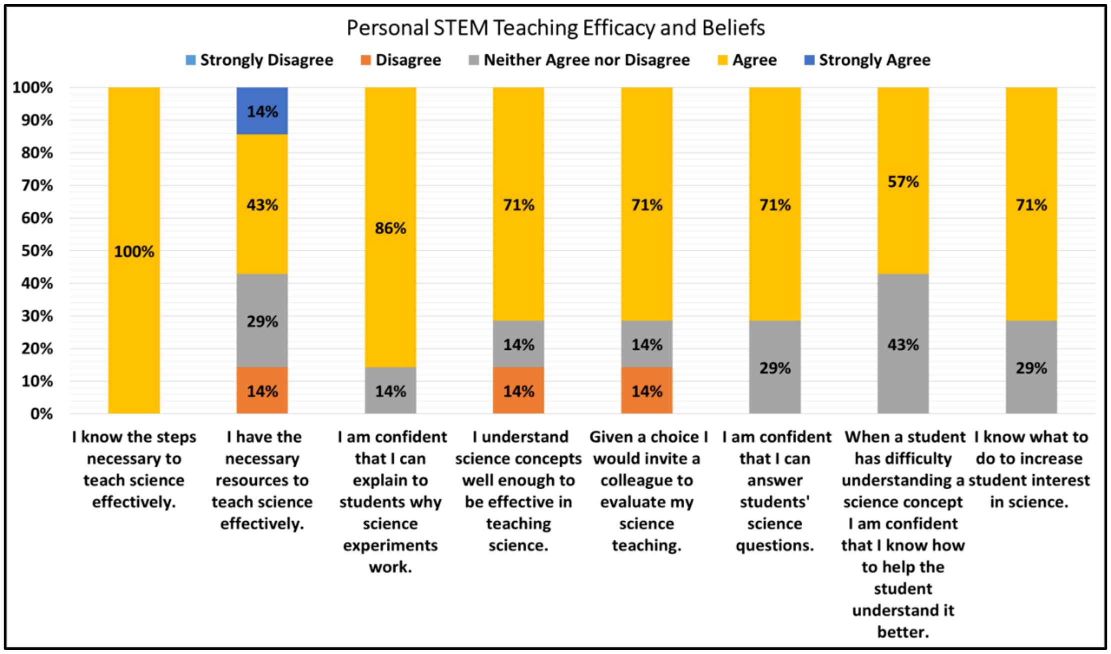


Figure 23

Pre-Intervention Data for STEM Teaching Outcome Expectancy Beliefs Scale

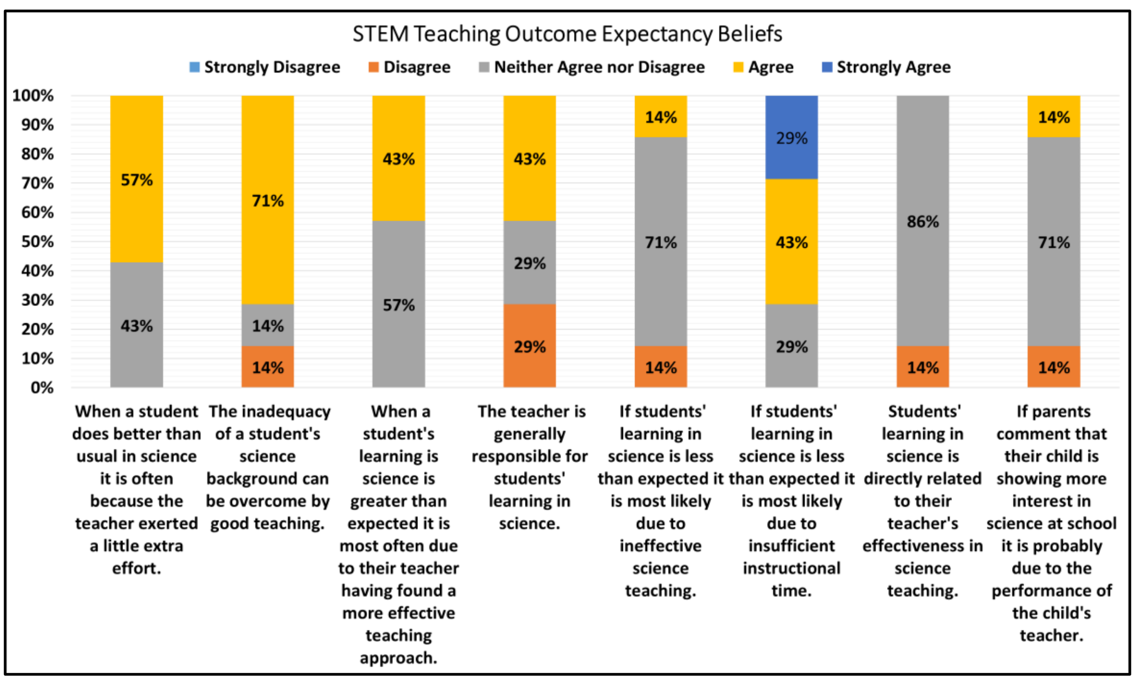


Figure 24

Pre-Intervention Data for Student Technology Use Scale

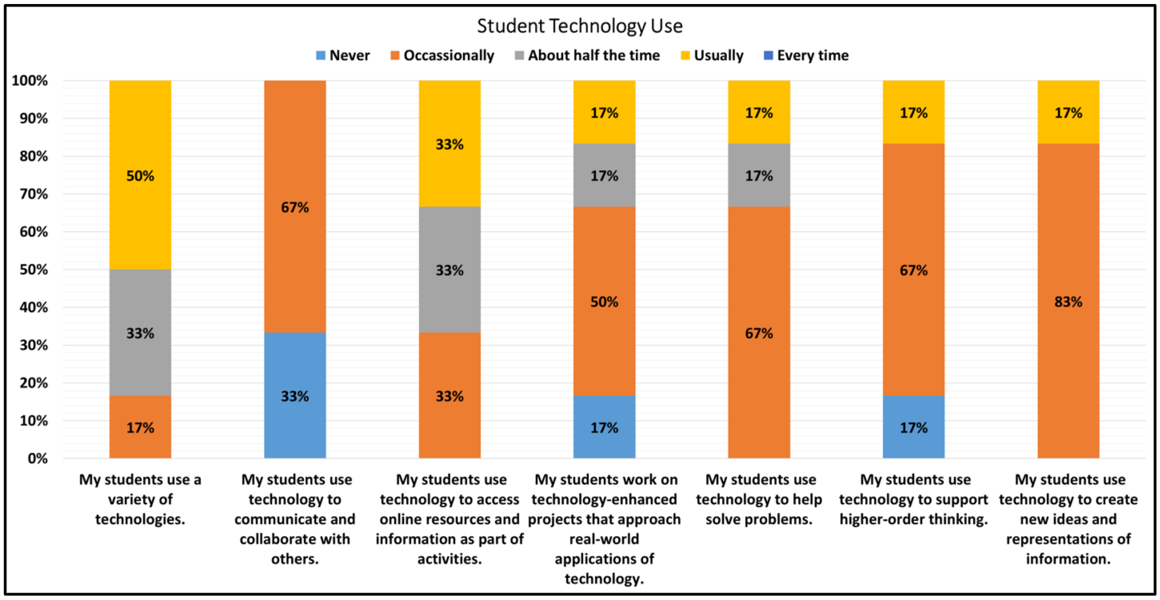


Figure 25

Pre-Intervention Data for STEM Instruction Scale

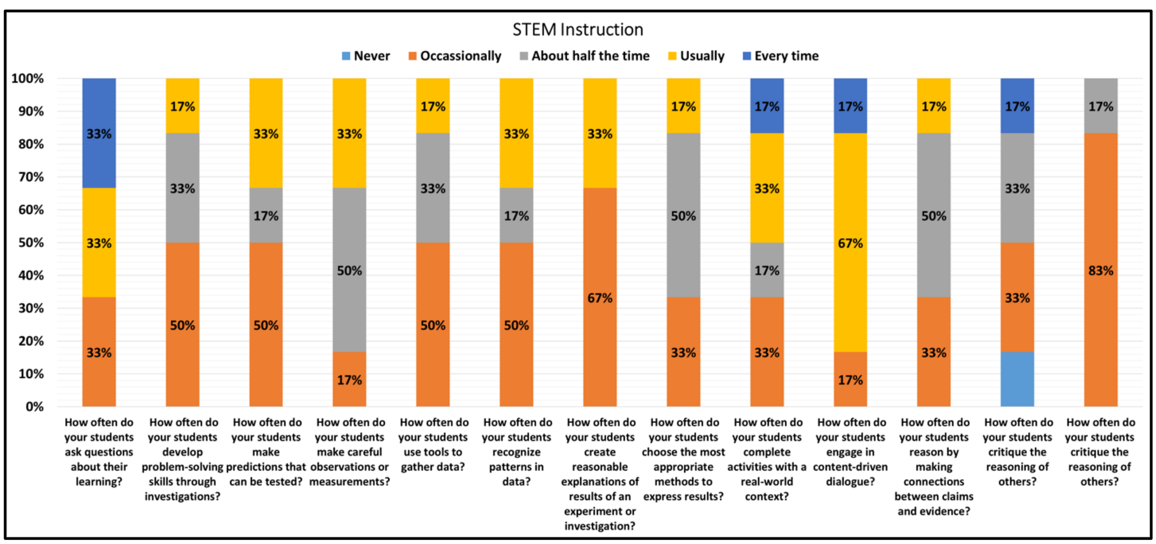
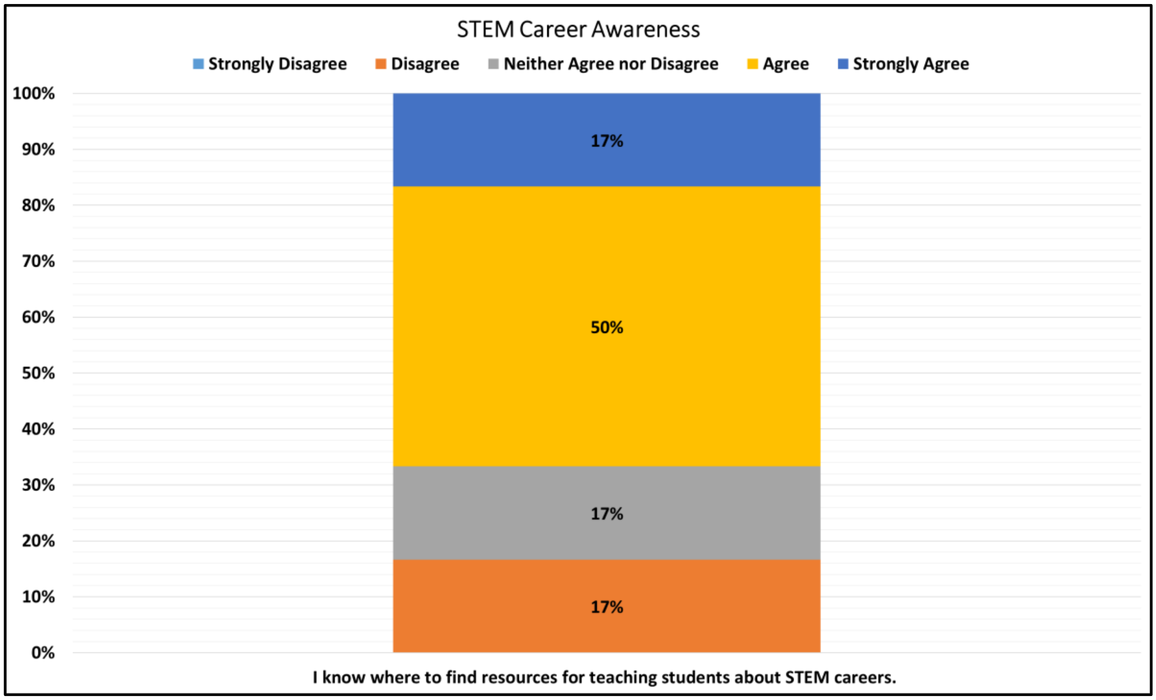


Figure 26

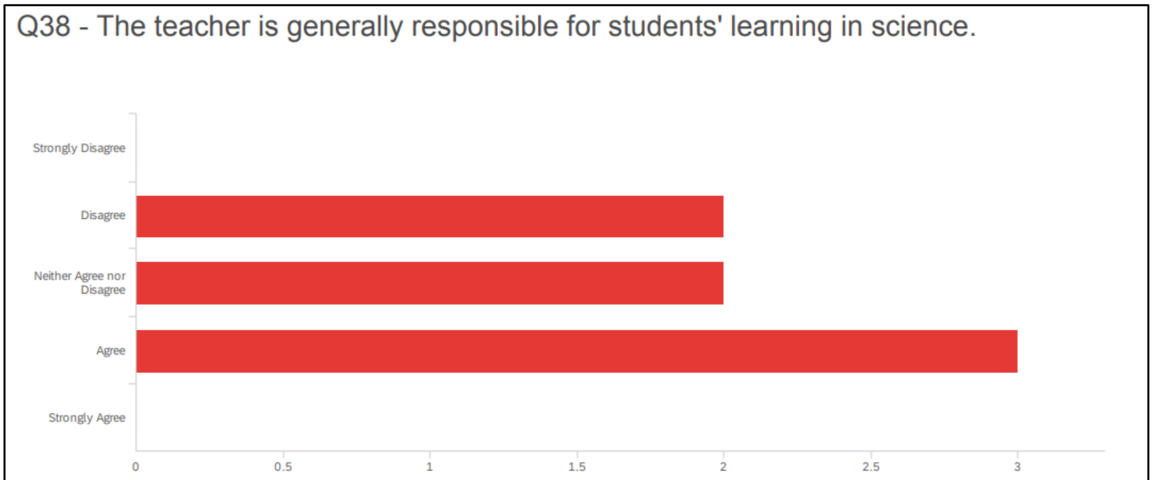
Pre-Intervention Data for STEM Career Awareness Scale



Overall, participants' responses indicated moderate efficacy levels in their knowledge of science content but moderate to low efficacy levels concerning their effectiveness in teaching science. For example, there was a high agreement rate for the question, "I know the steps necessary to teach science effectively" (M = 4, SD = 0). Participants were generally neutral toward the statement, "The teacher is generally responsible for students' learning in science" (M = 3.14, SD = .83) (see Figure 27).

Figure 27

Results for Survey Item Q38



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The teacher is generally responsible for students' learning in science.	2.00	4.00	3.14	0.83	0.69	7

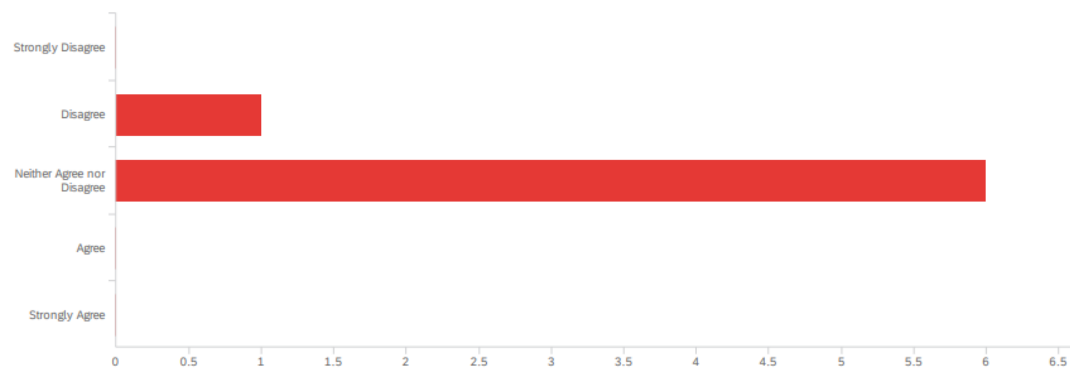
Note. This graphic depicts participants' attitudes toward teachers' responsibility for student outcomes in science.

Additional fields from the survey supported the finding that participants had low self-efficacy in impacting student learning in science. For instance, only one participant agreed that if students' learning in science is less than expected, it is most likely due to ineffective science teaching. The majority of participants (71.43%) neither agreed nor disagreed with this statement. When asked if students' learning in science is directly related to their teacher's effectiveness, 85.71% neither agreed nor disagreed, and one participant disagreed (See Figure 28). According to Nadler et al. (2015), "few researchers have examined how participants interpret the midpoint when responding to questionnaire items" (p. 75). It is believed that participants understood the salient point of each survey field, so their selection of the midpoint response (i.e., neither agreed nor disagreed) likely indicated low confidence levels.

Figure 28

Results for Survey Item Q41

Q41 - Students' learning in science is directly related to their teacher's effectiveness in science teaching.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2.00	3.00	2.86	0.35	0.12	7

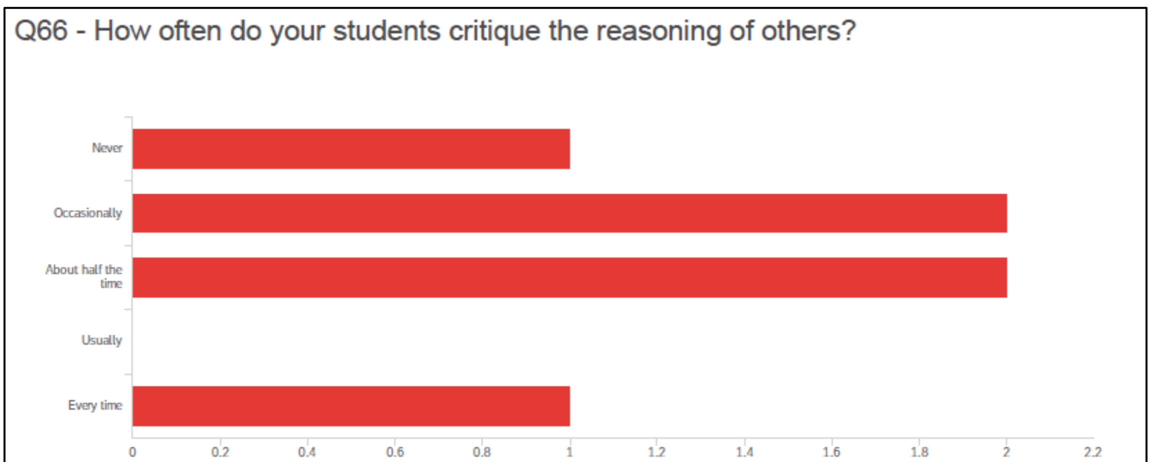
Note. An overwhelming number of respondents did not agree that students' learning in science is directly related to the teacher.

A series of survey items asked respondents about how much time their students use technology and engage in problem-solving activities. Results for items in the Student Technology Use and Elementary STEM Instruction scales showed minimal student engagement in best practices for STEM education. Four out of six respondents indicated that students use technology less than half the time to solve problems (M = 2.5, SD = .76) and engage in real-world applications (M = 2.33, SD = .94). Yet, when asked, "How often do your students complete activities with a real-world context," the frequency was much higher (M = 3.33, SD = 1.11). These findings suggest that participants valued instruction with real-world connections but needed support in engaging students in authentic learning.

An essential element of STEM instruction is for students to use evidence to support their learning claims. Eighty-three percent of respondents indicated that students engage in content-driven dialogue more than half the time. However, 66.67% specified that students occasionally (less than half the time) create reasonable explanations of an experiment or investigation results (M = 2.67, SD = .94). This discrepancy between student dialogue and reasoning incited the design of PLC activities that focused on higher-order learning. See Figure 29 for survey results on how often students at XYZ Elementary critique the reasoning of others. The large variance in responses to this field suggests ambiguity among participants regarding higher-order thinking activities.

Figure 29

Results for Survey Item Q66



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students critique the reasoning of others?	1.00	5.00	2.67	1.25	1.56	6

Progress Monitoring Surveys

Progress monitoring surveys are formative evaluation tools. A meta-analysis of experimental evidence suggests that monitoring goal progress is an effective self-regulation strategy and has a vital role in shaping goal attainment (Harkin et al., 2016). I used data to inform and improve the intervention's implementation.

I administered two progress monitoring (check-in) surveys at different periods of the intervention. The surveys consisted of two open-ended items and five selected-response items based on a 5-point Likert scale (*strongly disagree* (1), *agree* (2), *neither agree nor disagree* (3), *agree* (4), *strongly agree* (5)). The fields in each progress monitoring survey may have been distinct, but they addressed the intervention's critical priorities. Tables 9 and 10 show how each selected-response item from the progress monitoring surveys aligned to the T-STEM survey fields.

Table 9

Fields for Progress Monitoring Survey #1

Progress Monitoring Field	T-STEM Survey Field
The Science Squad PLC has helped me to better understand the steps necessary to teach science effectively.	I know the steps necessary to teach science effectively.
The Science Squad PLC has helped me to know about resources that will support my science teaching.	I have the necessary resources to teach science effectively.
The Science Squad PLC has increased my understanding of science concepts.	I understand science concepts well enough to be effective in teaching science.
The Science Squad PLC has improved my ability to connect science concepts to real-world phenomena.	How often do your students complete activities with a real-world context?

Table 9 (continued)

The Science Squad PLC has helped me write questions that will engage students in deeper levels of thinking.	How often do your students ask questions about their learning?
Open-Ended Items on the Progress Monitoring Survey	
How has the Science Squad PLC helped you learn?	
What should the Science Squad PLC do differently to help you learn better?	

Note. Progress monitoring survey items align with fields from the T-STEM survey.

Table 10

Fields for Progress Monitoring Survey #2

Progress Monitoring Field	T-STEM Field
The Science Squad PLC has increased my confidence in helping students understand science concepts.	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.
The Science Squad PLC offered strategies that will help my students engage in content-driven dialogue.	How often do your students engage in content-driven dialogue?
The Science Squad PLC has improved my skill in seeing and hearing students' ideas and reasoning as connected to science (as opposed to being off-topic).	How often do your students engage in content-driven dialogue?
The Science Squad PLC has supported my design of instruction that will allow students to solve problems through investigations.	How often do your students develop problem-solving skills through investigations (e.g., scientific, design or theoretical investigations)?
The Science Squad PLC provided information and activities that enhanced my ability to use *STEMscopes* (an online, inquiry-based learning environment).	How often do your students develop problem-solving skills through investigations (e.g., scientific, design or theoretical investigations)?
Open-Ended Items on the Progress Monitoring Survey	
What have you found to be the most valuable part of the Science Squad PLC?	
What is one thing you would have changed about the Science Squad PLC?	

The results of the progress monitoring surveys conveyed that the intervention's design was beneficial to participants. Table 11 exhibits the summary statistics for the quantitative items on the first check-in survey. See Appendix I for the complete data set. The mean score for each field rounds to the number 4, which signified high levels of agreement on statements about the actions and goals of the PLC. Responses to the open-ended items were also favorable. One teacher commented that the PLC "helped me understand how the curriculum is set up in the science documents and become more comfortable in using it." The intervention led members through tasks that supported their design of grade-level curriculum maps.

Table 11

Summary Statistics for Check-In Survey #1

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
The Science Squad PLC has helped me to better understand the steps necessary to teach science effectively.	7	3.71	.76	3	5
The Science Squad PLC has helped me to know about resources that will support my science teaching.	7	4.14	.38	4	5
The Science Squad PLC has increased my understanding of science concepts.	7	3.86	.69	3	5
The Science Squad PLC has improved my ability to connect science concepts to real-world phenomena.	7	4.14	.69	3	5
The Science Squad PLC has helped me write questions that will engage students in deeper levels of thinking.	7	4.14	.69	3	5

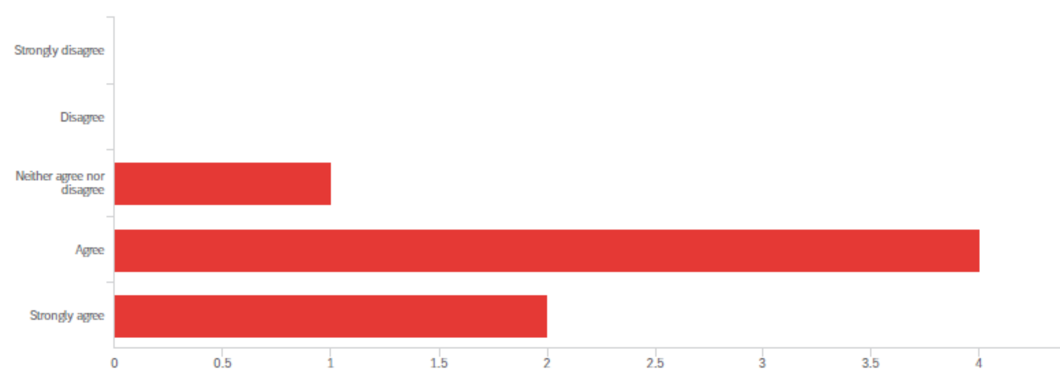
Note. Summary statistics for each item on the first check-in survey.

Another participant stated, “The Science Squad has connected me to more resources to better enhance my understanding of the standards. It has also helped me find resources to better engage my students.” The PLC included weekly activities where participants complete tasks that often focused on using resources to support standards and the 5E Inquiry Model. Figure 30 shows how participants’ knowledge and use of resources during the intervention improved their ability to connect science concepts to real-world phenomena. A participant remarked, “I have enjoyed the phenomenon activity to tie science content to real-world examples. I also enjoyed learning of the crosscutting concepts for questioning.”

Figure 30

Results for Progress Monitoring Survey Item Q4

Q4 - 4. The Science Squad PLC has improved my ability to connect science concepts to real-world phenomena.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	4. The Science Squad PLC has improved my ability to connect science concepts to real-world phenomena.	3.00	5.00	4.14	0.64	0.41	7

Note. Results indicated that the PLC increased participants’ understanding of science concepts and knowledge of resources.

The second progress monitoring survey had a different set of questions from the first tool (see Table 12). The survey received high scores on all items. See Appendix J for the complete data set. Respondents agreed or strongly agreed with every field except for one who professed neutrality on the idea that the PLC stimulated the design of problem-based instruction (Q4). Every participant commented that collaboration was the most valuable part of the PLC. For instance, one teacher said:

> I have found that having a team of people from different grade levels to be the most beneficial. I feel like I have lots of people that I can bounce ideas off of, learn from, etc. I also found that all of the resources are very beneficial for planning science in the future.

The intervention gave teachers a unique but much-needed opportunity to collaborate across grade levels. No matter the iteration of the study's PLC, there should be theory and practices around dialogue, collaboration, and shared goals.

Table 12

Summary Statistics for Check-In Survey #2

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
The Science Squad PLC has increased my confidence in helping students understand science concepts.	7	4.43	.53	4	5
The Science Squad PLC offered strategies that will help my students engage in content-driven dialogue.	7	4.71	.49	4	5
The Science Squad PLC has improved my skill in seeing and hearing students' ideas and	7	4.57	.53	4	5

Table 12 (continued)

reasoning as connected to science (as opposed to being off-topic).					
The Science Squad PLC has supported my design of instruction that will allow students to solve problems through investigations.	7	4.43	.79	3	5
The Science Squad PLC provided information and activities that enhanced my ability to use *STEMscopes* (an online, inquiry-based learning environment).	7	4.57	.53	4	5

Note. Summary statistics for each item on the second check-in survey.

Post-Intervention Survey Results

After the first intervention, participants responded to items also on the diagnostic survey instrument. The results suggest an increase in teachers' attitudes and efficacy toward STEM education (Science Teaching scale M_{pre} = 42.71; M_{post} = 48.57). On the other hand, results showed no significant change in instructional practices or student engagement with technology (Student Technology Use scale M_{pre} = 10.33; M_{post} = 11) and the inquiry process (Elementary STEM Instruction scale M_{pre} = 36; M_{post} = 39.86). Table 13 presents the summary statistics for each of the post-intervention survey's four scales. See Appendix K for the complete post-intervention survey data set.

Table 13

Summary Statistics for Post-Intervention Survey

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	7	39.71	4.39	34	45
Student Technology Use	7	11.00	3.21	7	16
Elementary STEM Instruction	7	42.71	7.43	36	55
STEM Career Awareness	7	2.71	0.76	2	4

Note. Summary statistics for post-intervention.

The post-intervention T-STEM survey results show an increase in participants' agreement rates with items on the instrument. Figures 31–35 use a stacked bar chart to display data collected on a 5-point Likert scale (*strongly disagree* (1), *strongly agree* (5)).

Figure 31

Post-Intervention Data for STEM Teaching Efficacy and Beliefs Scale

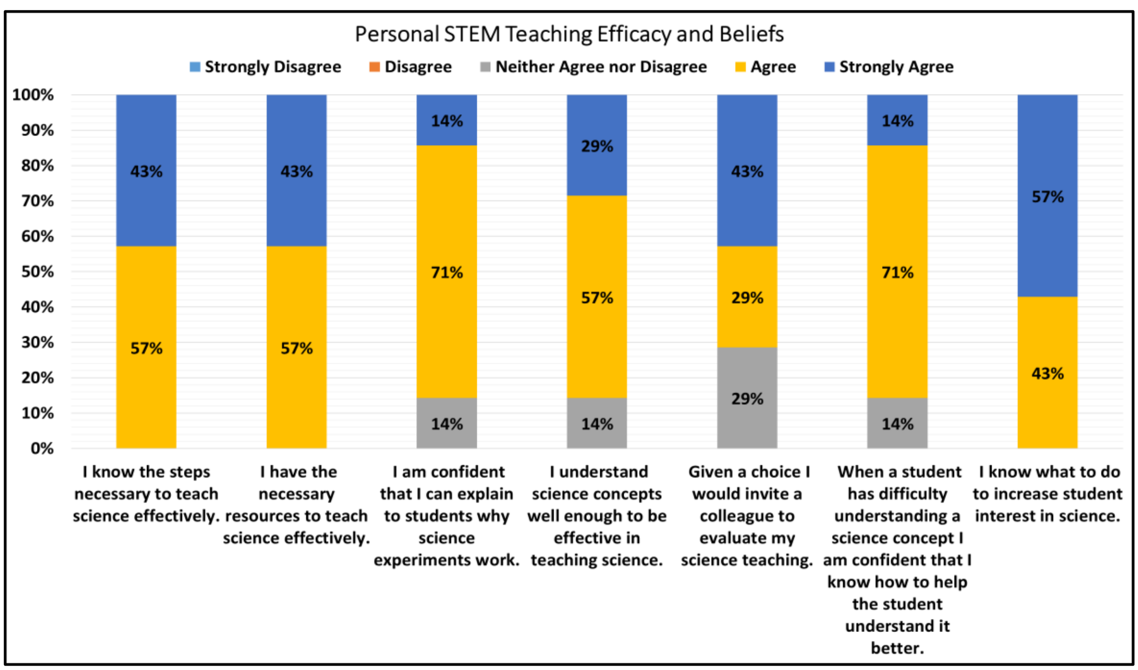


Figure 32

Post-Intervention Data for STEM Teaching Outcome Expectancy Beliefs Scale

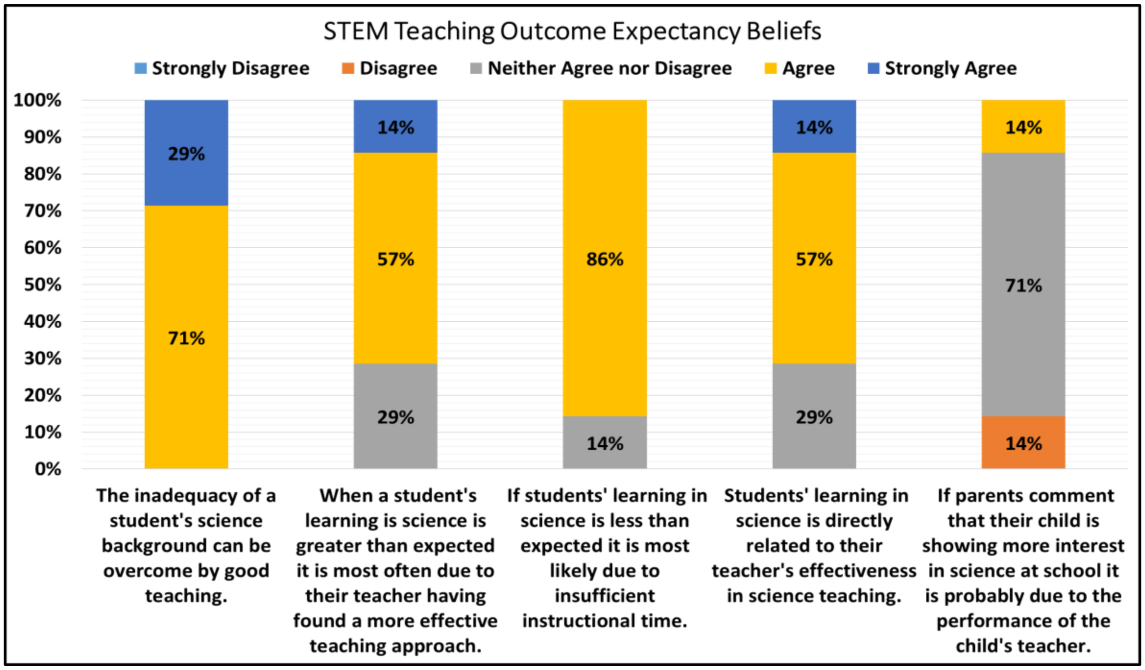


Figure 33

Post-Intervention Data for Student Technology Use Scale

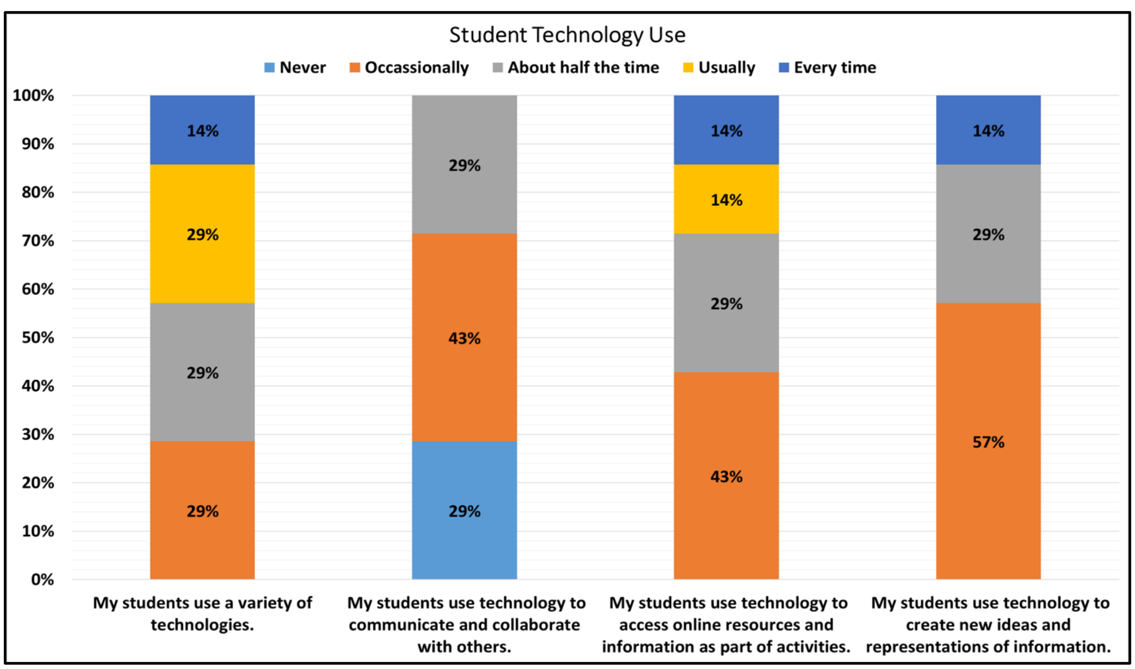


Figure 34

Post-Intervention Data for STEM Instruction Scale

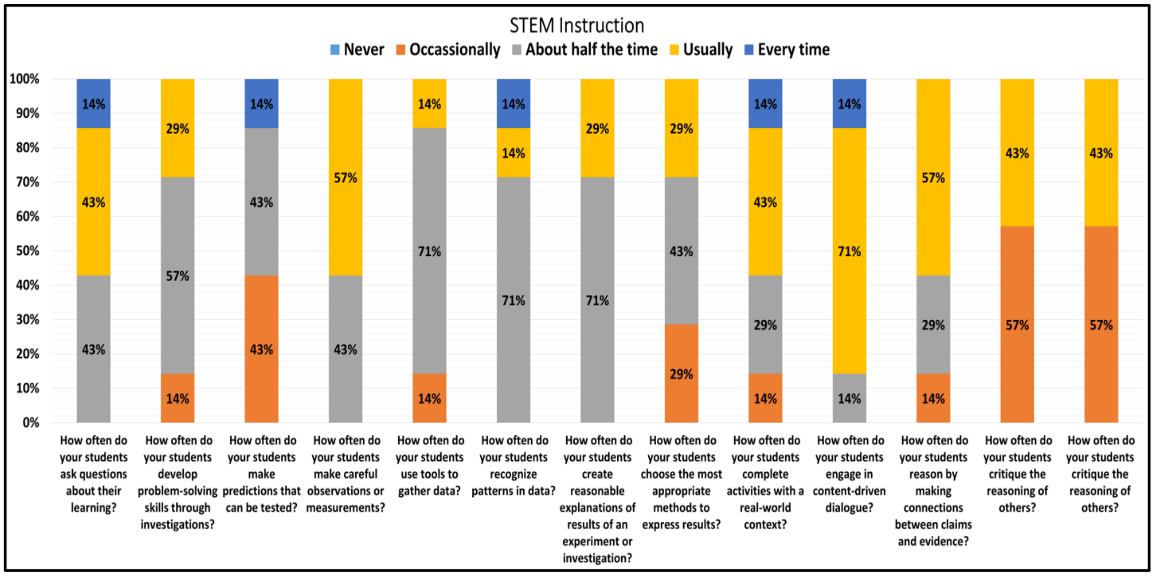
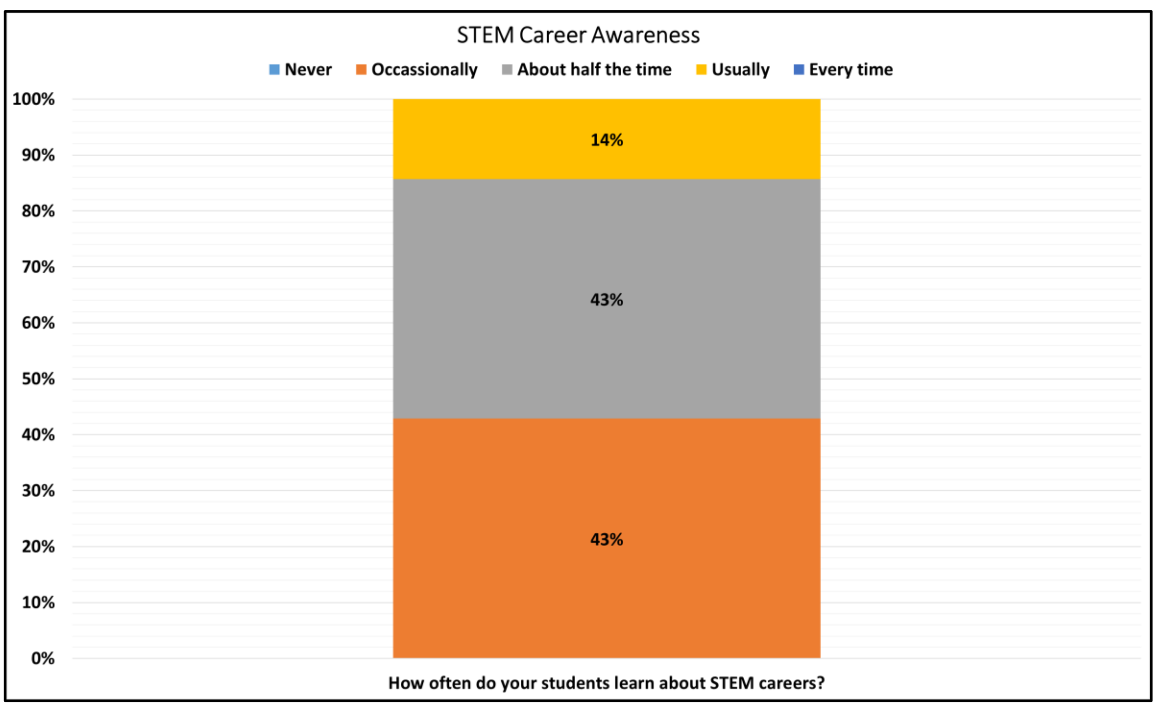


Figure 35

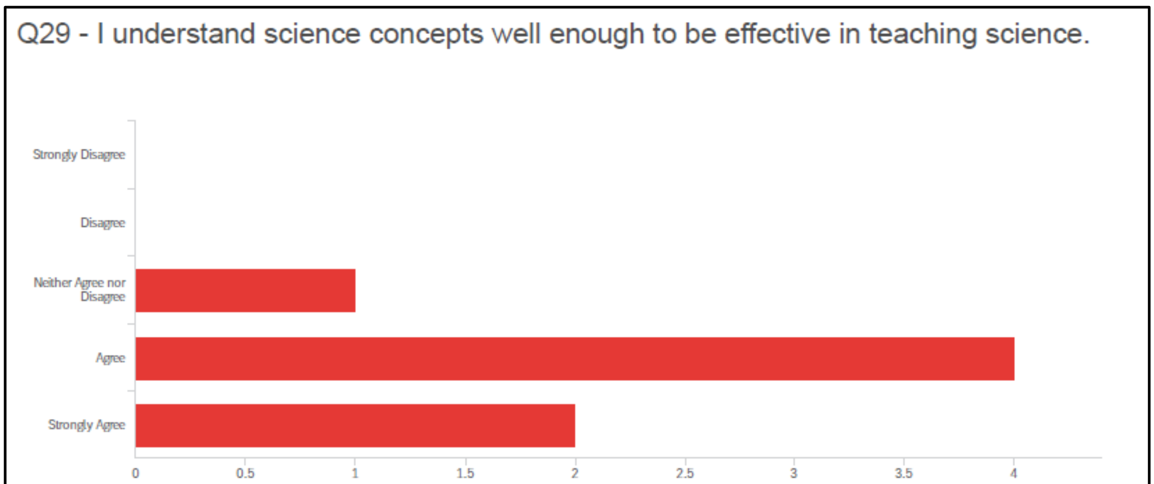
Post-Intervention Data for STEM Career Awareness Scale



Post-intervention T-STEM survey results showed gains in teacher efficacy toward STEM instruction. The Science Teaching scale's mean scores increased from *M* = 39.71 on the diagnostic survey to *M* = 56.14 on the post-intervention survey. The Science Teaching scale directly correlated to this study's goal of increasing teachers' efficacy toward inquiry-based science pedagogy. Figure 36 shows the level at which participants agreed with the testimonial, "I understand science concepts well enough to be effective in teaching science" (*M* = 4.14, *SD* = .64). The needs assessment survey had a mean score of 3.22 (*SD* = .82) for the same field.

Figure 36

Results for Survey Item Q29



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I understand science concepts well enough to be effective in teaching science.	3.00	5.00	4.14	0.64	0.41	7

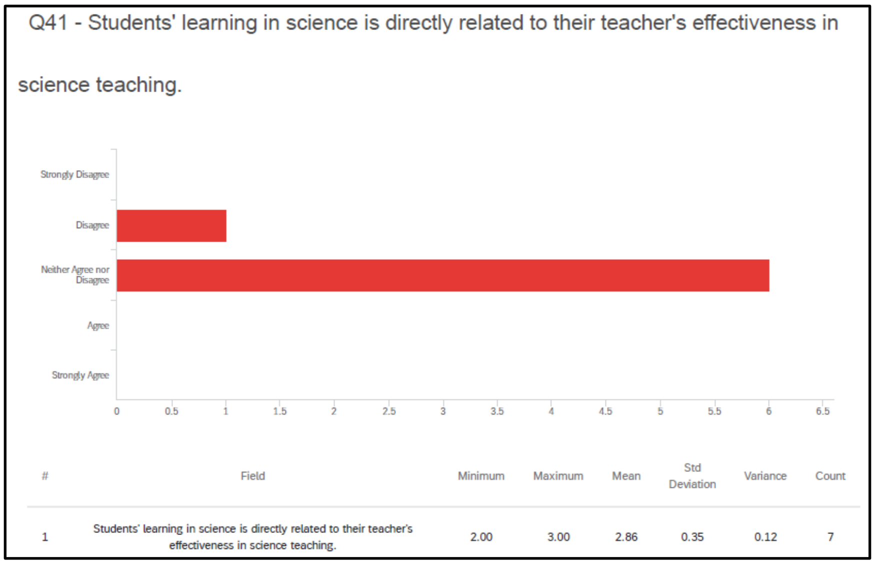
Note. After the intervention, two participants strongly agreed that they had the knowledge needed to teach science effectively, and none disagreed with the field.

This study's professional learning community (PLC) engaged participants in activities involving inquiry-based science instruction through innovative resources. As a result of the intervention's constructivist approach to learning, participants felt better prepared to increase student interest in science. On the pre-intervention T-STEM survey, no one selected "strongly agree" to the field "I know what to do to increase student interest in science." Four of the seven respondents selected "strongly agree" for this item on the post-intervention survey; the remaining marked "agree." Panels A and B in Figure 37 exhibit pre- and post-survey data for participants' perceptions toward the direct link between student learning and teacher effectiveness.

Figure 37

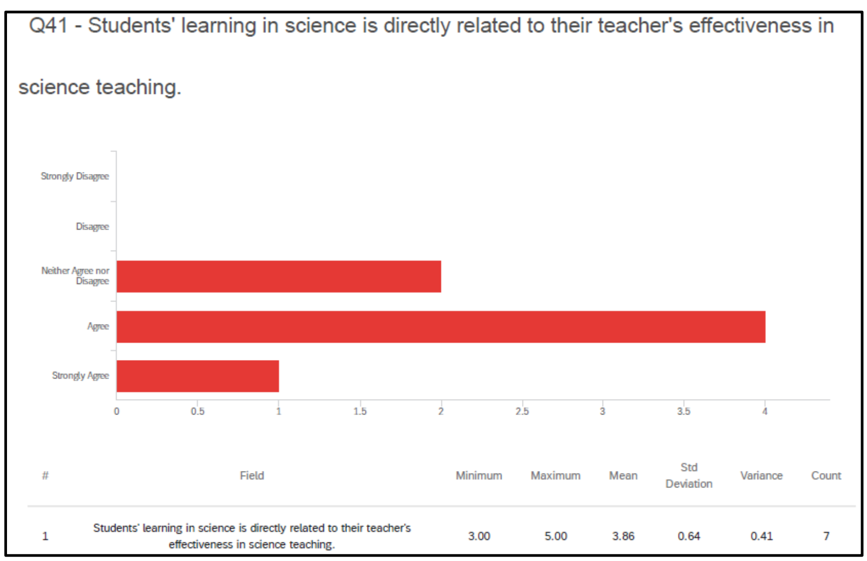
Pre- and Post-Survey Results for Item Q41

A



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2.00	3.00	2.86	0.35	0.12	7

B



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	3.00	5.00	3.86	0.64	0.41	7

Note. Post-intervention survey data in Panel B for item Q41 illustrated the PLC's impact on participants' self-efficacy toward science teaching.

Survey data show minimal gain in teachers' implementation of inquiry-based science teaching. Despite the growth in participants' confidence levels in teaching science, two participants remained disinclined for a colleague to observe their classroom teaching. The COVID-19 Pandemic presented challenges to participants' efforts in engaging students in STEM instruction. Pandemic learning conditions made co-teaching and peer observations difficult to implement during this stage of the study.

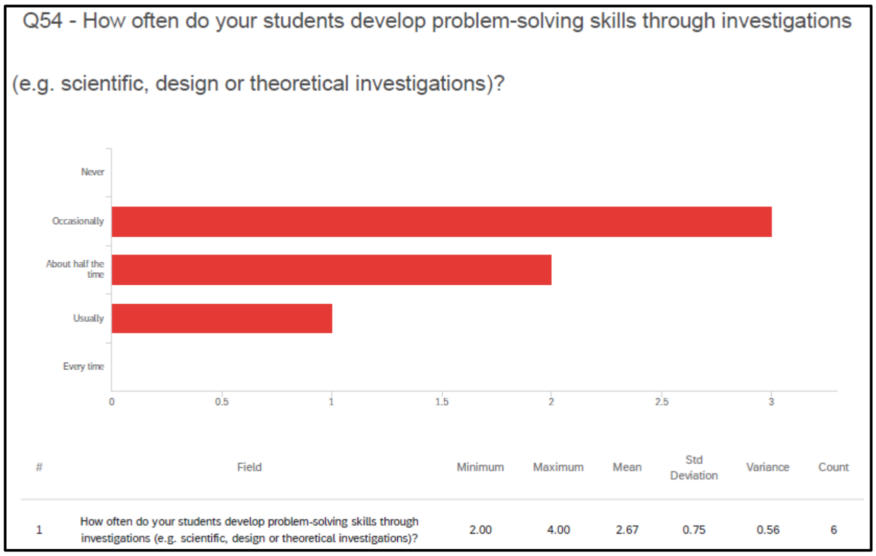
The post-survey items contained in the Student Technology Use scale and Elementary STEM Instruction scale asked for the frequency at which students performed specific tasks on a Likert-scale (*never* (1), *occasionally* (2), *about half the time* (3), *usually* (4), *every time* (5)). A series of survey items asked respondents to indicate the frequency at which students use technology during instruction. On a five-point scale where five represents the highest frequency levels, numerical values were low. For instance, 57.14% of the participants responded that students develop problem-solving skills through investigations about half the time. Panel A in Figure 38 shows pre-intervention results for the survey field on students' problem-solving skills, whereas Panel B contains post-intervention data.

Hands-on learning and exploration is a major tenet of inquiry-based science instruction. Revisions to the intervention further supported teachers' STEM instruction design with instructional support and collaborative team teaching.

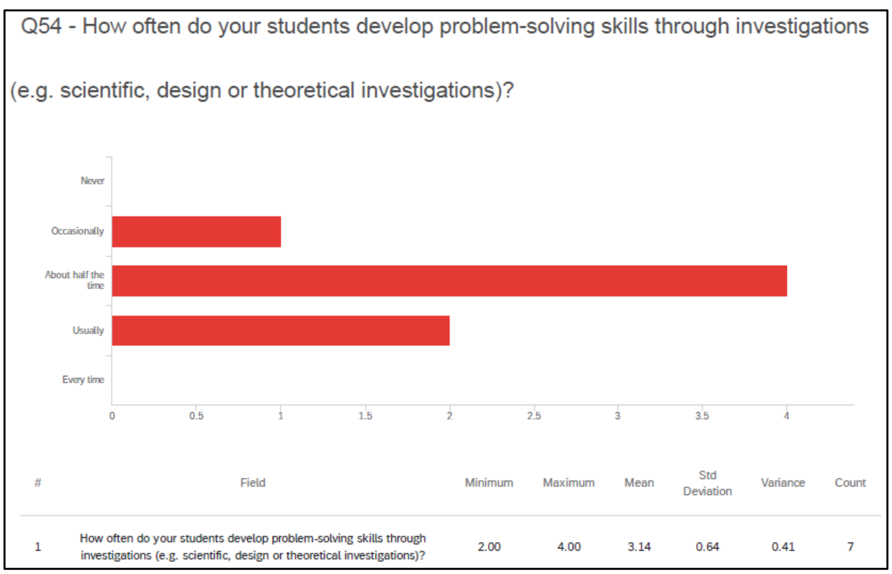
Figure 38

Pre- and Post-Survey Results for Item Q54

A



B



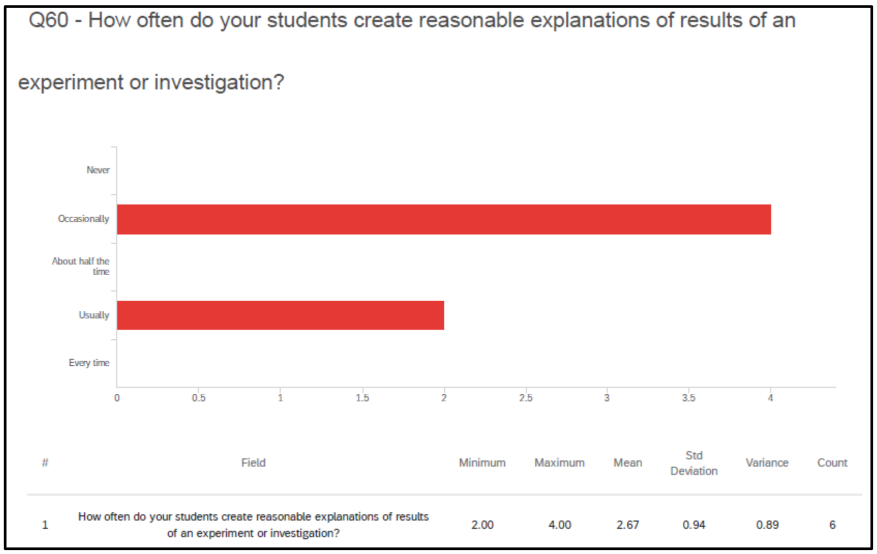
Note. Post-intervention survey data in Panel B showed minimal growth. The broad range of responses indicated the need for teacher training on constructivist teaching strategies.

The mean for most fields in the scales associated with classroom instruction (e.g., Student Technology Use and Elementary STEM Instruction) is near the middle mark (*M* = 3). Ideally, students would engage in inquiry-based STEM strategies more regularly than “about half the time.” The intervention’s PLC made strides in increasing participants’ knowledge of science concepts, positively impacting students’ understanding of content. As a result of the intervention, students had more opportunities to create a reasonable explanation of an experiment’s results. Figure 39 confirms how participants’ instruction started to prioritize evidence-based investigations and student-generated claims.

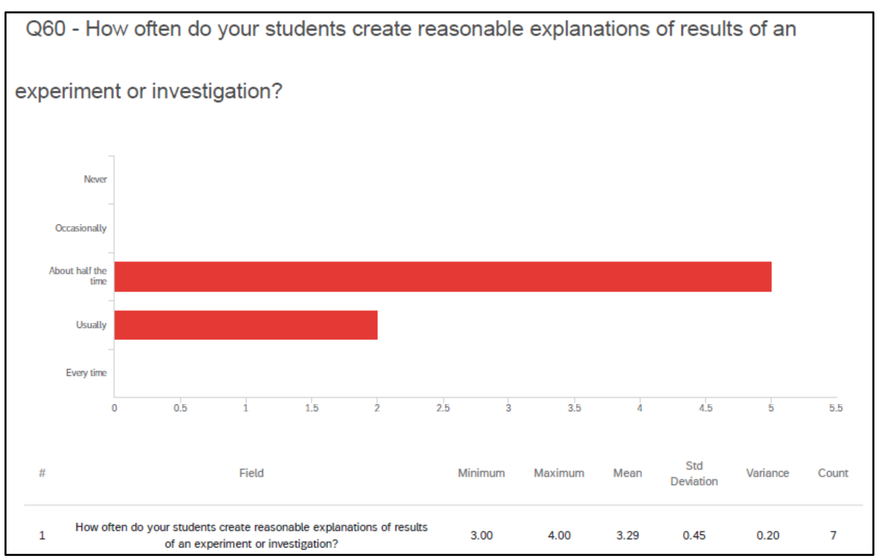
Figure 39

Pre- and Post-Survey Results for Item Q60

A



B



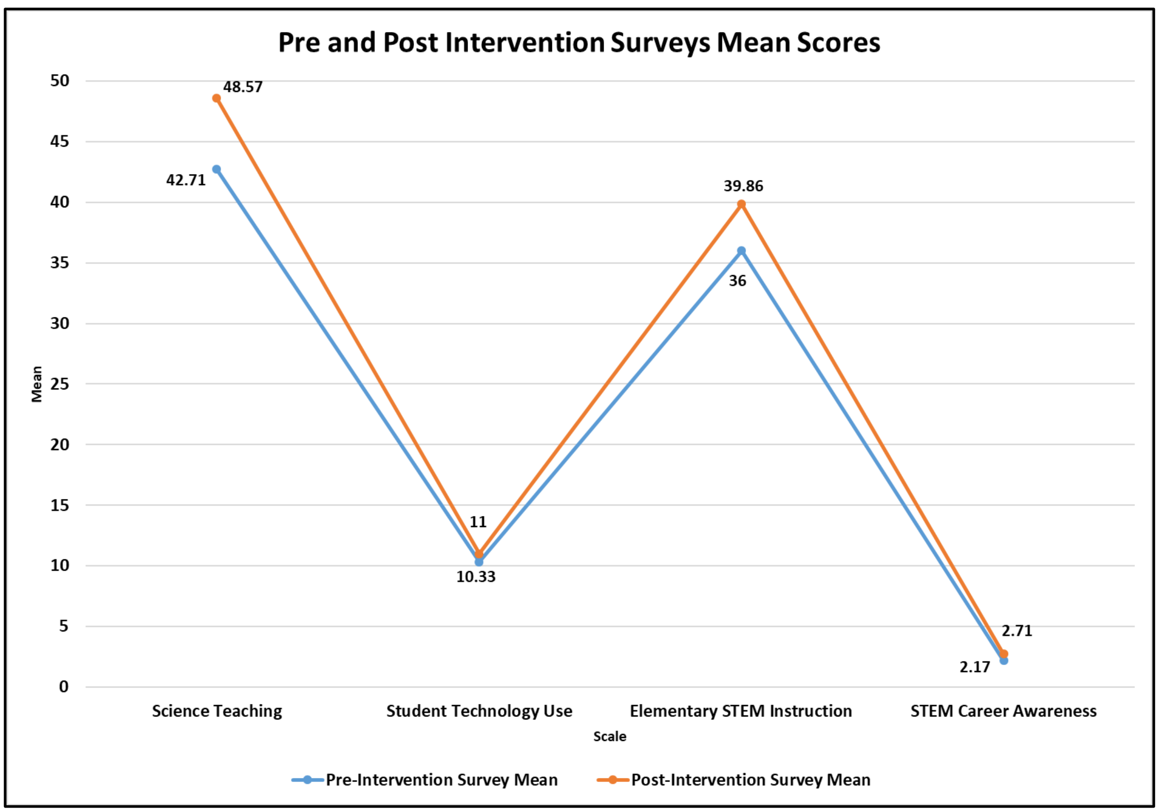
Note. Post-intervention data in Panel B for item Q60 indicated an increase in teachers' implementation of investigative classroom activities.

Pre- and Post-Intervention Survey Results

The post-intervention T-STEM survey included 29 variables for four scales. To measure the impact of this study's curriculum-based PLC, I compared pre- and post-survey descriptive statistics. Figure 40 shows a double line graph depicting each scale's mean scores for items in both the pre- and post-PLC surveys. The increase in mean scores for each scale indicated improved teacher efficacy, student technology use, instructional practices, and STEM career awareness.

Figure 40

Double Line Graph of Means for Scales in Pre- and Post-T-STEM Surveys



Note. Double line graph of mean scores from pre- and post-intervention survey responses.

A comparison of mean scores for each scale provided evidence of the intervention's impact. The largest increase in mean scores from the pre- to post-intervention survey was for the Science Teaching scale. The Science Teaching scale measured participants' efficacy toward teaching science and their beliefs on student outcomes. The scales titled Student Technology Use and Elementary STEM Instruction experienced an improvement in mean scores from the beginning to the end of the intervention. However, the gains were lower than those made by the Science Teaching scale.

A variety of factors affect the practices that teachers employ in the science classroom. Training, support systems, resources, instructional coaching, and ongoing collaboration were reviewed before the next intervention. Iterations to the intervention concentrated on participants' implementation of inquiry-based science instruction. In addition to survey results, qualitative data provided insight into the science-focused PLC's effects on teachers' self-efficacy and instructional practices.

Post-Intervention Interviews

I interviewed the school's curriculum specialist and three teachers after the intervention's implementation cycle, one teacher from each grade level. Interview questions related to participants' views on the intervention (see Appendix E). Interviewees responded to questions regarding their understanding of science concepts, knowledge of resources, and familiarity with the school's inquiry-based science curriculum *STEMscopes*. I coded interview transcripts for recurring themes. Content analysis allowed me to explore concepts and themes not recognized by a predetermined theme (Akran & Asiroglu, 2018). Empathy interviews provided insight into what worked well during the improvement cycle and what modifications were needed. Table 14 lists five overarching themes determined as a result of general post-intervention qualitative coding. Five themes emerged from the post-intervention interviews—collaboration, vertical alignment, integration of resources in STEMscopes, instructional procedures, and scope and sequence.

Table 14

Main Themes from Post-Intervention Qualitative Analysis

Theme #	Theme
1	Collaboration
2	Vertical alignment
3	Integration of resources in *STEMscopes* (science curriculum)
4	Instructional procedures
5	Scope and sequence

Note. This table lists themes derived from coded interview data.

Collaboration

The most prevailing theme that emerged from post-intervention interviews was the participants' appeal to collaboration, especially across grade levels. At XYZ Elementary School, teacher teams were based on grade levels. There were few, if any, opportunities for teachers to collaborate on the design of instruction and analysis of data with colleagues from different grade levels. Participants were so enthusiastic about the intervention's vertical PLC they gave the team a catchy name, The Science Squad. One interviewee responded that the most valuable part of The Science Squad PLC was "sharing ideas, helping each other look at things differently."

Vertical Alignment

A major theme around collaboration was vertical alignment. Simply put, vertical alignment is when one course or grade level prepares students for the next lesson, course, or grade level. A third grade teacher shared how the "[The Science Squad] PLC was and still is a great resource for me because not only can I go to other teachers that are in my grade level. But I can also go to teachers below and umm above my grade level." When various "parts [of the system] are aligned, the outcomes are more predictable, more efficiently attained, and more likely to be the result that was desired" (Van Clay & Soldwedel, 2011, p. 16).

Integration of Resources in STEMscopes

The PLC guided participants on the deconstruction of science standards. According to one classroom teacher, the PLC process "opened my eyes to that you really have to unpack standards to understand what they're wanting from you and your students." A greater understanding of science concepts increased teachers' confidence in using the school's science curriculum, *STEMscopes*. Members of the PLC received training on the features and structure of *STEMscopes* using various methods, including a scavenger hunt, guided tour, tutorials, and hands-on STEM challenges.

Participants explored resources that extended beyond *STEMscopes*. They found that the integration of *STEMscopes* with other materials fosters cross-curricular connections. A third grade teacher remarked that "The Science Squad [PLC] also opened my eyes to different resources that we can use to also implement with *STEMscopes*. *STEMscopes* does not have to be a stand-alone content."

Interviewees referenced a particular PLC activity that illustrated the theme of resource integration in the current science curriculum. The activity asked participants to find an image or photograph a phenomenon that relates to a science standard. Participants used various sources to locate examples of phenomena that could anchor science content in the classroom. Interview data insinuated that integrating diverse resources with *STEMscopes* was vital in improving science instruction at XYZ Elementary School.

Instructional Procedures

Another theme revealed from interview data focused on instructional procedures. Despite teachers' gains in efficacy teaching science, participants expressed concerns about designing daily instruction. One group member suggested that the intervention's next steps would be to hold "science work sessions periodically." The first phase of the intervention attempted to refine the science curriculum map for each grade level. Contingencies such as COVID-19 and limited opportunities to meet synchronously hindered the development of curriculum documents. In the second round of intervention, the priority moved from teacher efficacy to curriculum scope and sequence.

Scope and Sequence

This study's virtual PLC shifted participants' focus from isolated science activities to a coherent and cohesive curriculum. A member of the group commented that the curriculum-based PLC helped her "to see the scope and breadth of the standards—that mastery is something built over time not mastered after one instructional sequence." Due to specifications in the school setting's daily schedule, science time was scarce.

Science was taught every other week for approximately 30 minutes a day. In the next cycle of this study, the PLC considered instructional practices that incorporated more science during reading and math classes. A statement from one of the participants illustrated this idea. The teacher asserted, "I wish we could have so much more time or find a way with either science or social studies or both to [connect] the content with reading material. So it's not just so compartmentalized like now we're doing reading, now we're doing science, where students can kind of start building connections between content areas and material. So that would definitely be a next step for improving for sure."

Qualitative and quantitative data supported the idea that the study's PLC impacted teachers' understanding of science content, resources, and standards. According to the school's curriculum specialist, "This PLC brings science in elementary back to life with goals of embedding and breaking down the content and resources to place a more equitable focus back on science in hopes of a more balanced curriculum." Data also showed that other improvements to inquiry-based science instruction were needed. A member of the PLC eloquently pointed to potential revisions to the intervention, "Next steps would be designing, revising units with common assessments either formatively, summatively or both."

Challenges

The COVID-19 Pandemic closed XYZ County Schools' facilities to students and staff on March 16, 2020. The closure was anticipated to last until April 10, 2020. Unfortunately, school doors ceased to open for the remainder of the 2019-2020 school term. The closing of schools in hopes of preventing the further spread of Coronavirus was accompanied by a plethora of unforeseen consequences, such as an exacerbation of inequalities in educational outcomes due to non-school factors (Lancker & Parolin, 2020) and a decrease in the quality of education.

Due to COVID-19 school closures and safety guidelines from the Centers for Disease Control and Prevention, this intervention's participants could not meet in person. Therefore, all meetings were held virtually via Zoom video-conferencing software. Virtual meeting platforms make constructivist, hands-on learning activities difficult. Participants engaged in interactive and creative activities, but they could not use hands-on instructional materials such as science kits. I demonstrated strategies and tools for online learning that aligned with aspects of inquiry-based learning to address this challenge.

Remote communication and collaboration also posed a challenge to instructional coaching. I had fewer opportunities to meet with participants one-on-one to offer support and provide feedback. In addition to weekly live video conferences, the intervention utilized several communication tools (e.g., e-mail group, Google Site) to contact and update participants. These asynchronous communication tools encouraged ongoing discussions among team members. Limitations of asynchronous communication include lack of immediate feedback, length of time necessary for discussion to mature, and feelings of social disconnection (Branon & Essex, 2001). According to Branon and Essex, synchronous communication supports team decision-making, nurtures community building, and helps alleviate technical or logistical issues. Therefore, a hybrid format of synchronous and asynchronous communication tools bolstered greater collaboration and instructional coaching.

Conclusion Based on First Round of Intervention

This study's vertical, science-based PLC was beneficial in many ways. In just eight weeks, participating teachers felt more confident teaching science and had a firm grasp of techniques that cut across subjects. PLC activities allowed participants to complete tasks and create products that they shared with colleagues at subsequent meetings. Participants identified connections between literacy, math, reading, writing, and science and tied them back to standards and resources to make the most of their time with students.

Findings from the first round of intervention data indicated improvements in STEM teachers' self-efficacy. PLC's are also known for increasing STEM teachers' instructional attention to students' understanding and teachers' use of diverse modes of engaging student problem solving (Fulton et al., 2010). Yet, quantitative and qualitative data suggested that participants' implementation of inquiry-based STEM instructional strategies was mostly unchanged. The outcome resulted from many factors, COVID-19 school closures being especially detrimental. This study's participating teachers lacked sufficient opportunities to apply all they had learned and experienced in the PLC to their classroom instruction. Had the intervention occurred under normal circumstances, teachers may have engaged students in a constructivist approach to science more frequently.

The many challenges and contingencies surrounding science education in the early grades call for curriculum reform. In the subsequent phase of this dissertation's research, participants experienced a second round of intervention. Iterations to the curriculum-based PLC were based on the first round of intervention's mixed methods data, contextual factors, professional literature on individual agency and collective efficacy, and applied educational learning theories.

CHAPTER IV: REVISION

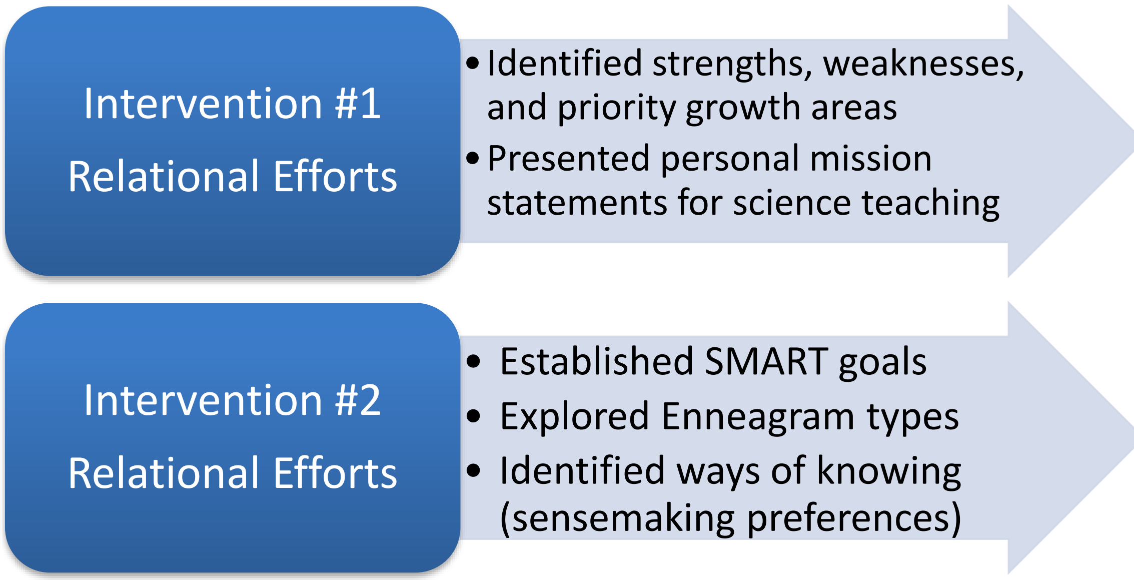
Introduction

Continuous improvement is a cyclical process. This dissertation's primary intervention to improving the lack of inquiry-based science instruction at XYZ Elementary School was a curriculum-based professional learning community (PLC). The curriculum-based PLC supported and monitored instructional design and assessment practices to increase teacher efficacy and effectiveness. The intervention aimed to support teachers in designing and implementing constructivist-based science instruction for all students at XYZ Elementary. The results in Chapter 3 influenced fundamental changes to the intervention. Iterations to the science-focused PLC centered on task behaviors *and* relationship behaviors.

Both interventions focused on human relations to build trust and promote a collaborative culture. In the first round of intervention, participants met virtually once a week for eight weeks. Participants shared a sense of purpose by presenting personal science teaching mission statements. Each group meeting began with an overview of the PLC's goals and a discussion of team progress or setbacks. The revised intervention improved participants' relationship behaviors by specifying goals and exploring individual personalities and preferences. This study's emphasis on human relations inspired a culture centered on collaboration. Figure 41 illustrates key changes to the intervention associated with relationship behaviors.

Figure 41

Revisions Focused on Relationship Building

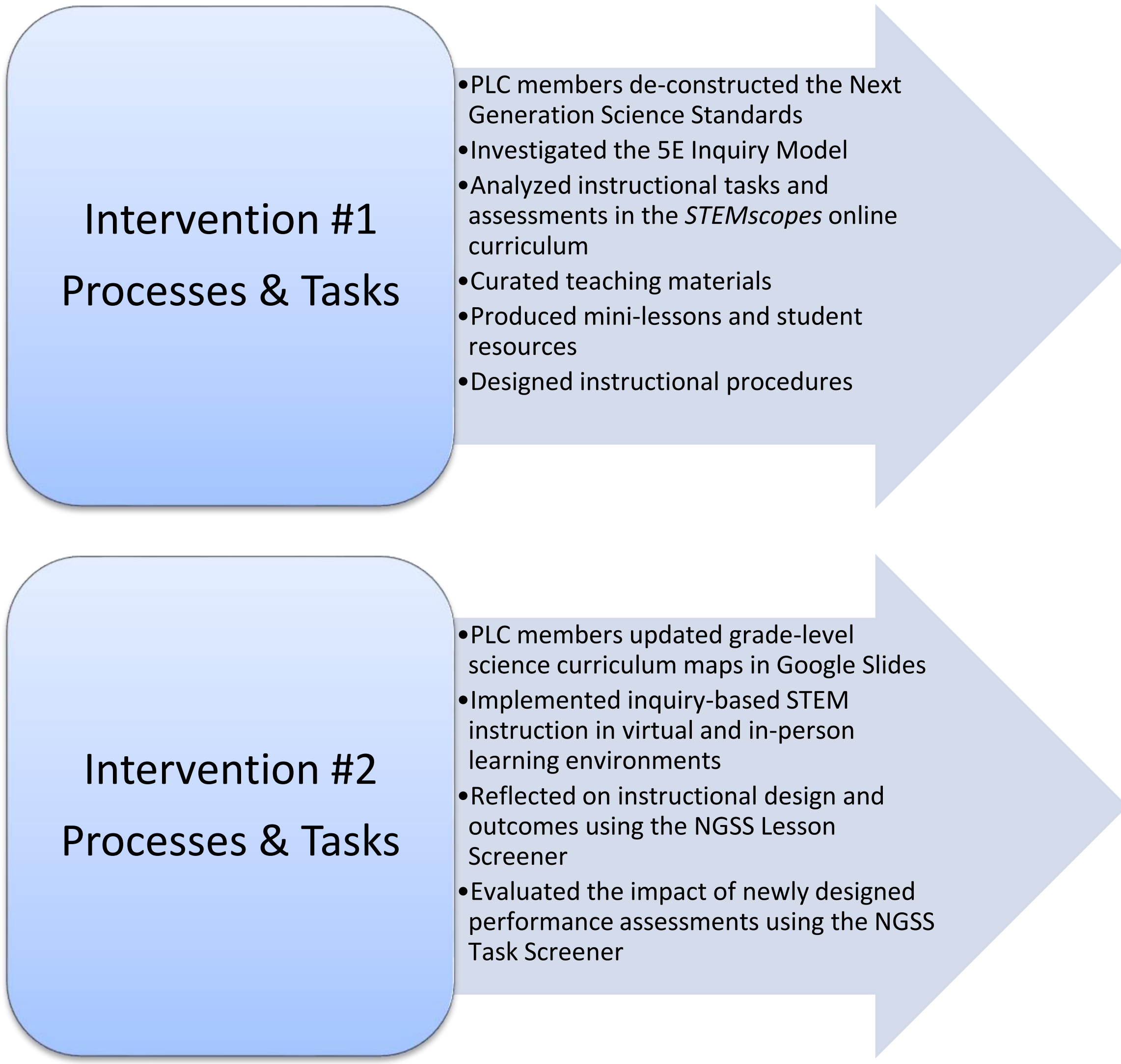


Note. Strategies used in both rounds of intervention to improve participants' relationships.

This study's emphasis on human relations influenced participants' task behavior. Trust, safety, and respect undergird any growth-enhancing culture (Drago-Severson & Blum-DeStefano, 2018). The support and challenge participants experienced in each iteration of the intervention increased collaboration and continuous learning. Changes to the intervention's inputs also affected task behavior. Revisions to technical and structural inputs included hybrid meeting sessions, co-teaching, instructional coaching, assessment development, and curriculum mapping. Constructivist learning theory buttressed the second intervention's inputs. Participants were immersed in designing and implementing an inquiry-based STEM curriculum. Figure 42 displays revisions to the PLC process and instructional coaching strategies.

Figure 42

Revisions Focused on Improving Processes and Practices



Note. Strategies used by both rounds of intervention to improve PLC outputs.

Revisions made to this study's intervention improved participants' self-efficacy levels in teaching inquiry-based science and increased the frequency at which students experienced STEM instruction. The mean score of each scale in the post-intervention T-STEM survey increased. Quantitative data indicated improvement in participants' attitudes toward designing science instruction through the 5E Inquiry-Based Instructional Model. Data also showed increases in students' interactions with technology tools and STEM instruction best practices. The intervention's focus on collaborative professional learning supported participants' design of what became XYZ Elementary School's first-ever science common assessments. Participants used the Next Generation Science Standards (NGSS) screening tools to corroborate the effectiveness of assessment tasks and instructional procedures. Members of this study's curriculum-based professional learning community (PLC) included administrators, coaches, and teachers from every grade level. The vertically-aligned PLC established a cohesive front on science instruction improvement without losing sight of members' individual needs, skills, and goals. Personalized coaching and ongoing collaboration fostered collective efficacy around science education and promoted participants' sense of individual agency.

According to the 2020 Impact Kentucky Survey, 48% of teachers at XYZ Elementary School agreed that they give input into their professional development (PD) (Kentucky Department of Education, 2020b). Participants in the first phase of the PLC volunteered to be part of the intervention. Though this intervention was not for official professional development credit, the PLC's availability was filled quickly by teachers representing all grade levels. Evidently, teachers at XYZ Elementary desired more ownership of their professional learning. This study's intervention promoted participants' efficacy toward designing and implementing standards-based science instruction.

Teachers' professional learning experience changed throughout the PLC's implementation and modifications. This chapter describes the study's approach to continuous improvement through subsequent iterations of this intervention. Revisions to the intervention were based on the analysis of formative and summative data, a review of the literature, and amendments to the study's theoretical framework. The concept of improvement science guided this action research project. As described in this chapter, findings from the first round of intervention and its iteration conveyed how, under what conditions, and for whom the intervention works (Hinnant-Crawford, 2020).

Input from staff and quantitative survey data, described in Chapter 2, revealed that teachers did not have the time, tools, or confidence needed to teach science with fidelity. The intervention's first iteration consisted of a virtual PLC with two teachers from each grade level at XYZ Elementary School and its curriculum specialist (n = 7). I facilitated PLC meetings and provided instructional coaching to support participants. The curriculum-based PLC's main goal was to improve teachers' self-efficacy in teaching science.

The PLC engaged participants in the practice, analysis, and reflection of inquiry-based learning to enhance students' science education in grades 1–3. XYZ Elementary closed its facilities to students and staff on March 16, 2020, due to the spread of the Coronavirus. Despite all of the issues caused by the 2020 COVID-19 Pandemic, I found an opportunity to partner with teachers in making remote learning more useful and engaging. The intervention began with an open invitation to elementary educators to join a science-focused PLC. The group met eight times via video-conferencing software for one-hour sessions. The PLC maintained its purpose of increasing teachers' efficacy but grew organically based on participant need and collaborative input.

Post-intervention interview data indicated that vertical alignment was a beneficial outcome of the virtual PLC. Rarely do teachers at XZY Elementary School have the opportunity to plan instruction with colleagues from different grade levels. Traditionally, standard planning periods are available for teachers who are on the same grade-level team. To advance the PLC's effort to align the science curriculum vertically, I created a Google Site for elementary school (i.e., grades 1–5) education. The website contained information on standards, a bibliography of resources, tutorials on using the *STEMscopes* curriculum, professional learning modules, and strategies for embedding the inquiry process. Participants contributed to the science teaching website by posting links to resources and recommending tools to support data collection and student assessment.

Since PLC members could not meet in person in Spring 2020 because of COVID-19, there was a need for virtual support systems. Participants joined an online group in Schoology, XZY Elementary's learning management system, to stay connected. The platform housed hyperlinked documents, meeting agendas, and links to recorded PLC meetings. Schoology has a discussion board where members posted questions, uploaded resources, and shared lesson plans. The addition of a Google Site and Schoology group to the PLCs' virtual landscape maximized collaboration potential.

Discourse between participants revealed that participants believed they knew the steps to teach science. According to quantitative data from check-in surveys, participants agreed that the Science Squad PLC helped them better understand the steps necessary to teach science effectively (M = 3.71, SD = .7 on a 5-point Likert scale). However, PLC activities showed that most teachers adhered to a conventional approach to teaching science, contrary to the 5E inquiry process.

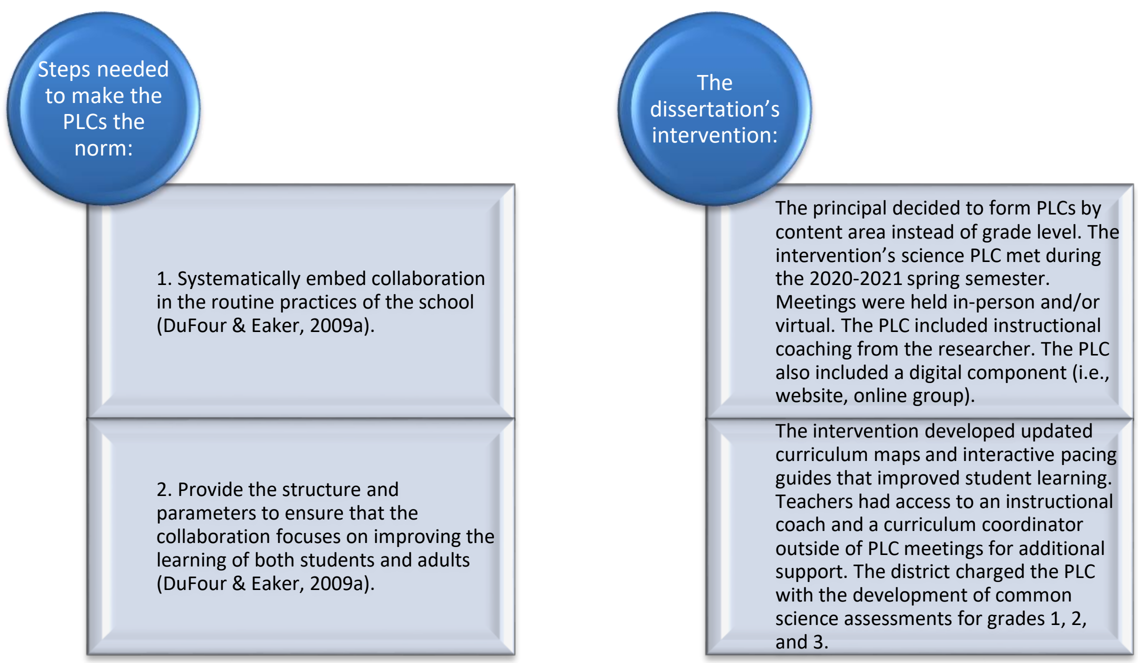
Anecdotal notes concluded that the Gradual Release of Responsibility (GRR) model was widely used at XYZ Elementary to teach science. GRR is scaffolded instruction that moves instruction from whole group delivery to student-centered collaboration, then independent practice. Modeling, guided practice, and independent work from the GRR model help students' develop foundational skills. "Unfortunately, most current efforts to implement the gradual release of responsibility framework limit these interactions to adult and child exchanges" (Fisher & Frey, 2013, Chapter 1, Section 2, para. 4). GRR is often known as the "I do, we do, you do" model. STEM teaching practices and the NGSS call for peer collaboration and student-led investigations. According to Dole et al. (2019), "The true magic happens when teachers provide just the right balance of scaffolding and getting out of the way so students can show their stuff" (p. 252). The discovery of teachers' preferred instructional delivery method led to PLC work associated with constructivism and sociocultural learning theory.

Sociocultural thinking shifts the pedagogical focus from the teacher to the student. Sociocultural learning theory emphasizes peer collaboration where students co-construct understandings. Sociocultural theory's premise is that learning happens best through experience, metacognition, and group-oriented exploration (Edwards, 2003). Sociocultural theory is a driving force behind inquiry-based instruction. An inquiry-based learning environment encourages learners to question, investigate, and communicate conclusions. The PLC focused its efforts on the 5E Inquiry-Based Instructional Model. Participants practiced using phenomena to engage students with real-world content. They designed instructional procedures that emphasized student observations and questioning. PLC members brainstormed formative assessments to monitor students' learning of essential topics.

Quantitative and qualitative data from the first round of intervention, described in Chapter 3, suggested participants' self-efficacy levels toward a constructivist approach to teaching increased—an important goal of this dissertation. A critical byproduct of the intervention was the advancement of the organization's culture. The PLC concept became the norm at XYZ Elementary School. Figure 43 shows how the intervention meets the two steps DuFour and Eaker (2009) claim are needed for a collaborative culture.

Figure 43

This Intervention's Role in Making PLCs the Norm at XYZ Elementary



Note. The steps needed to make the PLC concept the norm in schools are cited from: DuFour, R., & Eaker, R. (Eds.). (2009a). *On common ground: The power of professional learning communities.* Solution Tree Press.

The effects of this study's PLC reinforced the school principal's commitment to teacher autonomy and agency. When asked what would support teachers best in developing and teaching science instruction, the school's principal responded:

> Support from myself and our administration team. And making sure they know it is perfectly okay that, yes, absolutely take time to do this. It is very, very important. And giving them the freedom to go about and to teach it. I think autonomy is very, very important for our teachers that we shouldn't have someone breathing down our neck to tell them that they need to do x, y, and z. Teachers need that autonomy. We need autonomy to lead in the classroom, lead in the building, and it's okay to make mistakes, mess up, no big deal. You know, learn from it, punt the ball, pick it up…and go again. (School Principal, personal communications, September 11, 2020)

The intervention impacted school culture in other ways. The intervention showed the value of cooperative learning when it is ongoing, subject-based, and school-wide. The intervention was the first virtual learning community ever created at XYZ Elementary School. The impact of the PLC concept supported the creation of the site's first social studies-specific learning community. I facilitated weekly virtual meetings with members of the social studies PLC for eight weeks in Spring 2020. The social-studies-focused vertical team met again in July and August 2020. The team included teachers from XYZ Elementary School *and* the district's intermediate school (grades 4–5).

Before this study's science-based PLC intervention, STEM instruction and the inquiry process were not school-wide priorities. Now, compelling and supporting questions are listed on lesson plan templates. XYZ Elementary School teachers began the process of developing content-based instructional units. The interdisciplinary units integrated writing and science or social studies into what previously had been solely reading instruction. The shift to using a cross-curricular and constructivist approach to teaching has inspired potential changes to the school's schedule.

The assistant principal (Vice Principal, personal communication, September 22, 2020) discussed two scheduling options. Option number one included a 90-minute integration of reading, writing, and science or social studies. Students would continue to receive an additional 45-minute reading flex period. Option number two included a 60-minute reading core class for all students. There would be a 75-minute period of supplemental reading instruction for students who score below benchmark on the STAR reading test or 75 minutes of integrated content-based literacy for students who score at or above benchmark on the standardized reading assessment. There were strengths and weaknesses to both alternative schedules, but "talk" of changes to integrate more science instruction is a sign of improvement.

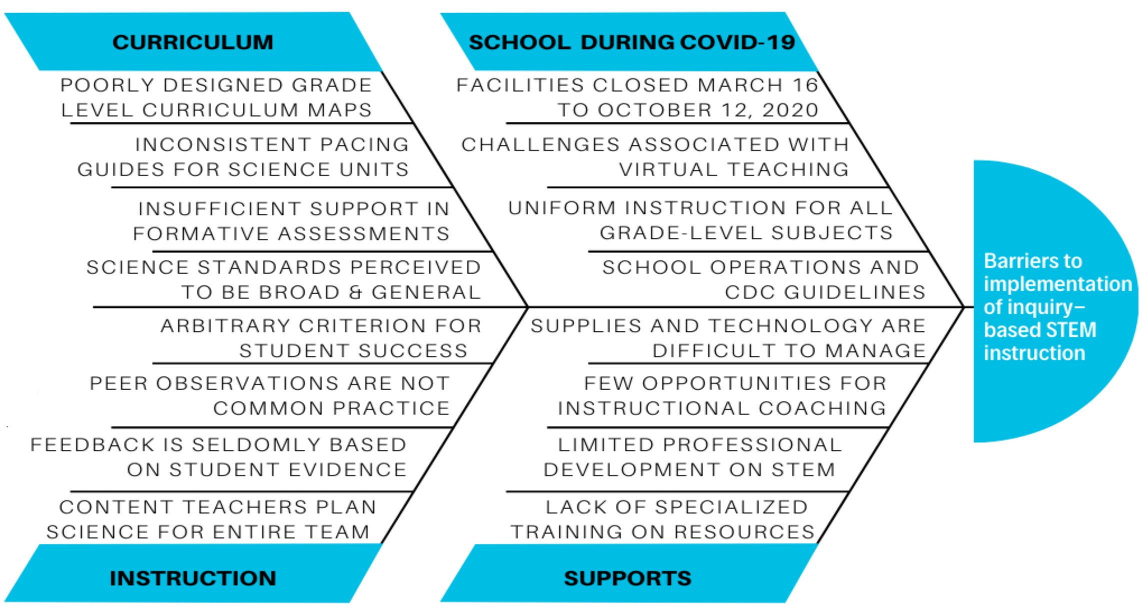
In one way or another, culture impacts every aspect of an organization, from task commitment to belief systems. This study engendered lateral collaboration among teachers and school administrators. Culture evokes teachers' energy to perform tasks and follow the organization's norms (Owens & Valesky, 2014). The PLC intervention formed norms among participants that centered on collaboration and inquiry-based learning.

Data from the post-intervention survey and interviews indicated that teachers needed additional support to implement inquiry-based STEM practices. Factors surrounding the COVID-19 Pandemic, non-traditional/remote instruction, in particular, hindered participants' capacity to apply new strategies, resources, and the inquiry process to classroom instruction. Interview data and field notes from the first round of intervention exposed the reasoning inquiry-based STEM instruction was infrequently implemented at XYZ Elementary School. A comment from an interviewee corroborated the impact of the curriculum-based PLC. The participant stated, “I think we all knew we needed to work toward the why, but there seemed to be little knowledge of the how.”

Possible causal factors to this problem are exhibited in the fishbone diagram in Figure 44. I generated the figure after careful analysis of qualitative data and contextual factors associated with COVID-19. The fishbone diagram represents vital factors that contribute to the lack of inquiry-based STEM instruction at XYZ Elementary School (Bryk et al., 2015).

Figure 44

Factors that Hinder Implementation of Inquiry-Based STEM Instruction



Note. Fishbone diagram depicts factors that inhibit the implementation of inquiry-based science instruction in the early grades.

A driver diagram illustrates a theory of action (Hinnant-Crawford, 2020). Drivers guide and direct the direction of an improvement effort (Bryk et al., 2015). There is often a need for a research study to focus on secondary and primary drivers during an intervention. Both drivers illustrate elements of the system that influenced the study's goals (Hinnant-Crawford, 2020).

The purpose of this research was to increase teachers' efficacy in the implementation of inquiry-based science instruction. This study's intervention (i.e., a curriculum-based PLC and instructional coaching) was the primary driver, highlighted yellow in the diagram (see Figure 45). The first round of intervention concentrated on the orange-highlighted drivers of the diagram. These drivers activated collaborative vertical planning and the ensuing increase in teachers' attitudes toward inquiry-based STEM education.

Figure 45

Driver Diagram

	Primary drivers	Secondary drivers	Change ideas
	The school develops an instructional coaching program for teaching STEM	Teachers analyze inquiry-based learning tasks	Teachers will understand the inquiry process
	The school provides ongoing professional development on Next Generation Science Standards and scientific concepts	The school adopts STEMscopes, an NGSS-aligned curriculum	Teachers will develop a curriculum map and pacing guide to sustain science instruction
Aim To increase teachers' efficacy towards the implementation of inquiry-based science instruction	The school forms a curriculum-based professional learning community	Teachers interact with resources and materials needed to teach science	Teachers will have confidence incorporating hands-on STEM resources into instruction
	Teachers design curriculum documents and instructional resources for teaching Next Generation Science Standards	The school adopts instructional coaching as a model for supporting the implementation of inquiry-based science instruction	Teachers will integrate best practices in science instruction
	The school provides ongoing training on inquiry-based learning	The curriculum emphasizes connections between science instruction and other subjects	Teachers will collaborate with colleagues across grade levels

Note. Detailing this study's driver for productive persistence.

As described in Chapter 3, findings from the intervention prompted revisions in the second round of intervention. My analysis of survey data and interview transcripts validated teachers' need for more support with implementing and assessing science instruction. The targeted drivers for the second phase of the intervention are highlighted blue in the diagram. The curriculum-based PLC's second iteration aimed to increase participants' interactions with instructional resources and further support instructional coaching. Instructional coaching was provided "intensive and differentiated assistance to teachers so that they are able to incorporate research-based instructional practices into their teaching" (Devin et al., 2013, p. 1126).

Students' return to the school building in the 2020–2021 term promised more opportunities for participants to integrate the inquiry process in science class. The school's reopening also presented opportunities for teachers to interact with each other in person. Participants continued to engage in the PLC's online components established in the first round of intervention. A hybrid professional learning format offered timely instructional coaching that was based on student outcomes.

According to Bryk et al. (2015), "the aim in developing a working theory of practice improvement is not to be exhaustive; it is to carefully choose a few secondary drivers that we believe might function as key levers for productive change" (p. 76). Effective change and continual improvement rely on multiple iterations of a reform effort. The specific drivers targeted throughout both rounds of intervention amplified the outcomes and sustainability of standards-based science instruction at XYZ Elementary School.

The change in teachers' behaviors activated by professional development (PD) can positively impact student learning (Harwell, 2003). For all the benefits and outcomes associated with professional development, PD has its challenges. Teacher professional development does not guarantee changes in practice. Despite the PD hours educators receive every year, there seems to be a gap between well-known best practices and what occurs in most classrooms (Schmoker, 2006). According to Schmoker, instruction is not closely observed or supervised. Most teachers sense they are "doing a good job" and do not perceive a need for extensive professional development.

Piaget (as cited in Wall, 2018) "theorized that individuals construct personal meaning and understanding when they experience cognitive disequilibrium by encountering information that does not align with their existing schemas" (p. 31). Teachers need access to colleagues' instruction so they can observe inquiry-based learning strategies in action. Therefore, peer observations and data analysis became part of this study's curriculum-based PLCs in the second round of intervention. Cognitive disequilibrium was needed for some teachers to challenge their underlying assumptions about inquiry-based science instruction. Otherwise, participants would have maintained the status quo in their conceptual structures (Wall, 2018).

Revisions to this study's curriculum-based PLC were designed to further increase teachers' efficacy in science instruction. Improved levels of self-efficacy in teaching science depended on participants' experiences engaging with resources and implementing instruction. In its second round of intervention, the PLC prioritized supporting participants' implementation of inquiry-based science instruction.

Revision Goal

The curriculum-based PLC allowed participants to pause and think about science education differently with new information. The first cycle of the intervention focused on unpacking the Next Generation Science Standards, exploring resources, understanding 3D learning tasks, and using the *STEMscopes* curriculum. The revised intervention focused PLC activities on instructional planning, curriculum mapping, and assessment practices. An influential but straightforward question guided revisions to the intervention: *How can teachers use this with students next week?*

Accountability structures contributed to the group's ongoing learning with the intention of collective responsibility (Wild et al., 2018). Activities participants engaged in during the revised intervention included:

- sharing knowledge and experience
- creating SMART goals to clarify expectations and heighten inspiration
- designing standards-based science units for each grade level
- restructuring scope and sequence documents for science
- implementing instructional procedures that follow the 5E Inquiry-Based Instructional Model, a constructivist approach to teaching.

A critical goal of the intervention was to update the science curriculum map based on science standards, resources, and inquiry-based learning. The team modified the current pacing guide for teaching science based on information from the curriculum map and classroom instruction evaluation. Teachers from the same grade level taught roughly the same lessons simultaneously, which provided a foundation for the group to discuss their experiences and insights (Wild et al., 2018, p. 310). Participants exercised agency over pacing and modifying the curriculum.

During the first cycle of the intervention, I acted mainly as the PLC developer and facilitator. My role in the revised intervention focused more on collaborative lesson planning and instructional coaching. I offered alternative perspectives and new ways of thinking on standards-based science teaching and let participants draw their own conclusions. Discussion and activities ensued from participants' concerns, needs, and priorities. As an instructional coach, I modeled and allowed participants to learn from one another. Effective and sustainable PLCs enable the giving and receiving of meaningful feedback. This study's PLC provided numerous feedback opportunities based on instructional design, assessment, and classroom evidence.

Literature Review

Helen Keller said, "Alone we can do so little, together we can do so much" (Goodreads, n.d.). Professional learning communities (PLCs) create a collaborative working environment that nurtures cooperation, personal growth, and emotional support (DuFour & Eaker, 2009b). DuFour and Eaker identified four building blocks of a PLC: mission, vision, values, and goals. These elements are essential to the initiation and sustainability of any school reform effort. Revisions to this study's intervention focused on building collective teacher efficacy by creating a collaborative learning culture.

The intervention's PLC and instructional coaching efforts focused on improving teachers' attitudes toward inquiry-based science instruction. The theories, processes, tools, and strategies used in the iterated intervention helped participants create new habits of professional practice. Collaboration was at the core of the intervention's practices, from mapping the curriculum to developing common performance tasks. I approached this chapter's review of literature through the lens of collaborative learning. An examination of a portion of the literature on school culture, goal-setting, collective efficacy, and systems change influenced this study's design and implementation. The intervention instituted a collaborative learning culture that promoted participants' mastery of collective inquiry, continuous improvement, and action orientation.

Culture

School improvement is mediated through the learning environment's culture and climate (Hallinger & Heck, 1998). Yeol (2020) presents a well-articulated definition of organizational culture:

> Organizational culture refers to the assumptions, beliefs, values, norms and customs, habits, and rituals that the members of the organization share in the process of adapting to the external environment and solving internal problems. (p. 208)

A school's culture, directly and indirectly, affects organizational effectiveness and student achievement (Fullan, 2007; Yeol, 2020). A single leader nor a sole intervention is insufficient to sustain school improvement efforts. Teaching and learning are transformed through an organization's *culture*.

Cultural change is not an easy task by any means. Changing organizational culture is different from structural change, such as passing legislation or adopting a new procedure. Cultural change often alters long-held assumptions and habits of people in an organization (DuFour & Fullan, 2013; Owens & Valesky, 2014). The process of cultural change may be complicated, but it is achievable. There is no set formula to follow. According to DuFour and Fullan, cultural change involves finding out what works, what does not, and making adjustments based on the findings. The iterative process of cultural change requires commitment. The process of professional learning communities is based on a commitment to continuous improvement. PLCs have the potential to generate systemic change and build the collective capacity of personnel. DuFour and Fullan write that PLCs “unleash energy and draw in the vast majority of people who begin to make fundamental changes never before thought possible” (p. 8).

The PLC process can drive an entire system (DuFour & Fullan, 2013), especially when participants actively engage in specific cultural facets. Yeol (2020) categorizes school culture into four divisions: hierarchy, group, rational, and innovation. This study actuated innovation by seeking new teaching methods in an exploratory fashion. Schools with an innovation culture actively respond to changes in the learning environment. This study’s intervention addressed many contingencies throughout its duration. For instance, the COVID-19 Pandemic resulted in school closures, the shift to online learning, and new means for synchronous and asynchronous professional development. PLCs are more than “innovation” to be implemented. PLCs support and maximize innovation when they become a core and lasting component of the organizational culture (Louis, 2006).

Members of this study’s curriculum-based PLC entrusted colleagues to complete activities for the common good. For instance, participants worked cooperatively to make inquiry-based science teaching possible for students attending class online. Teamwork and mutual respect strengthened the group culture of this study’s PLC. This intervention established itself on three fundamental pillars: trust, cooperation, and flexibility. Participants’ flexibility in the problem-solving process emboldened group and innovation dimensions of the school’s culture (Yeol, 2020).

It is widely accepted that leaders must first identify the existing school culture before implementing change (MacNeil et al., 2009). The culture at XYZ Elementary School centered on instruction for reading, math, and writing. Science, social studies, and the humanities were overshadowed by the core subjects, as is common in most primary schools. Students at XYZ Elementary take the K-PREP state assessment for reading and math only. Most professional development opportunities for teachers at the school focus on the core curriculum (i.e., reading, math) rather than content subjects (e.g., science). The accountability associated with core subjects may prevent teachers from engaging in new school enterprises such as subject-based PLCs.

A school culture short of trust and respect for teacher professionalism will diminish collective inquiry (Carpenter, 2015). An assessment of an organization’s culture revealed existing assumptions and targets. Understanding the factors that comprise a school’s culture is critical to the design and initiation of organizational improvement.

Facets of an organization’s culture are developed over time to a point where they are part of the day-to-day business (Owens & Valesky, 2014). Daily routines found in many schools hinder its focus on building the collective capacity of educators. Maloney and Konza (2011) present a case study of 20 elementary school educators who took part in a professional learning community intending to develop a shared vision of early childhood education within a culture of collaboration. The PLC met four times over six months. Despite participants’ enthusiasm for the learning project, interest soon waned.

> For some teachers, engaging in collaboration and communal discourse was regarded as an encroachment of their valuable time and compelled them to

> prioritize what they felt was important on a day to day basis. (Maloney & Konza, 2011, p. 84)

Teachers' level of devotion toward a school improvement initiative such as a curriculum-based PLC depends on many factors. Individuals of the organization must perceive tasks as pertinent to their position's roles and goals. Otherwise, existing norms (usually of the managerial kind) will supersede the doings of school-wide reform. Efforts to promote a culture of collaborative, professional learning must focus on individuals. Each person needs to feel as if they have something to gain and something to contribute.

This dissertation's curriculum-based PLC was fashioned to give "power" to its members. Participants' attitudes, concerns, and priorities guided the design and implementation of the PLC. The use of questions, the application of authentic feedback, and the opportunity to self-reflect roused participants' assumptions about inquiry-based science instruction. As teachers' confidence in the constructivist teaching approach improved, so did their attitudes toward collaboration and innovation. While immediate gains in teacher-efficacy may harvest acceptance and support, "one must be careful to communicate the complexity of changing a culture as well as the extended timeline" (Louis, 2006, p. 485).

Developing a collaborative learning culture is a complex and long-term process (Louis, 2006). PLC design should be defined as a sequence of steps but a shift in beliefs and aspirations (K. Garrett, 2010). Particular aspects of school culture are instrumental to the effectiveness and sustainability of PLCs. MacNeil et al. (2009) measured the cultural dimensions of Texas schools that earned *Exemplary* ratings from the state education department. The study reported healthier climates for *Exemplary* schools compared to those ranked *Acceptable*. Results of an Organizational Health Inventory completed by 1,727 teachers "suggest that the dimensions *Goal Focus* and *Adaptation* describe aspects of school health and culture that are crucial to the academic success of students within the school" (MacNeil et al., 2009, p. 81). The success of collaborative and continuing professional development is contingent on goal-oriented behaviors and adaptability. Participatory goal-setting and shared adaptive leadership are essential to a school culture where collaboration, collective inquiry, and continuous improvement are the norm (Carpenter, 2015).

Goal Setting

Leaders and followers must share common goals and have the tools necessary to execute improvement plans with purpose and motivation. The first step is not action; the first step is understanding (Gardner, 2013a). Leaders and followers must know the organization's mission—its reason for being. The organization's vision or where it wants to be in the future should be confirmed by personnel, then articulated to stakeholders. The mission and vision statements are the basis for devising goals and objectives that help an organization realize and fulfill its purpose (MacLeod, 2012).

Studies have shown that specific, ambitious goals lead to a higher level of task performance than do easy goals or vague goals such as the appeal to "raise student achievement" (Locke & Latham, 2006). There are presently no actionable goals regarding STEM education at XYZ Elementary School. This study used SMART principles of goal-setting to influence goal-directed behavior among participants. SMART is a well-established tool that organizations can use to devise and attain goals. According to Rubin (2002), SMART goals should be Specific, Measurable, Attainable, Relevant, and Time-bound. “The introduction of specific, measurable goals is among the most promising yet underused strategies we can introduce into school improvement efforts” (Schmoker, 1999, Chapter 2, Section 1, para. 6). Members of this study’s PLC converted shared priorities into SMART goals (See Table 15).

Table 15

Alignment of SMART Goals to Science Curriculum

Priority Issue	SMART Goal
Use phenomena to anchor science lessons, spark student interest, and foster a sense of curiosity and wonder in our students.	The Science Squad will create a HyperDoc of phenomena for each science standard that will anchor students’ interest in learning goals and sustain students’ motivation to investigate responses to compelling questions.
Integrate ELA standards into the science curriculum and embed science topics during core reading class.	The Science Squad will compile a collection of literacy strategies for students to use when engaging in science sources (i.e., texts, graphs, observations, computations).
Administer alternative forms of assessments to gain insights into students’ progress on achieving the NGSS performance expectations.	Science Squad members will develop a common performance-based assessment for each grade level’s first science unit.
Model best practices of three-dimensional learning so that students can communicate their understanding of a phenomenon using data, information, and an explanation of the underlying science concept that produced the evidence.	The Science Squad will script one mini-lesson for each grade level that incorporates compelling and supporting questions to prompt the investigation of claims that are supported with evidence and explanations (C-E-R: Claim, Evidence, Reasoning).

Note. Agreed upon priorities by participants were crafted into SMART objectives.

According to Lawlor and Hornyak (2012), the utilization of SMART goals within the classroom can enhance student learning outcomes. Lawlor and Hornyak “conducted a comparison of Management Fundamental classes from 2010 to 2011 on a major project required for the class to determine if students can improve their performances by requiring them to utilize SMART goals early in the semester" (p. 259). Results indicated that when compared to the class that did not utilize SMART goals, the group that began the project sooner enjoyed the assignment, revised their goals as new information became available, approved of their team members, and provided a high-quality presentation. Leaders, staff, students, and stakeholders who use data-driven goals can challenge existing paradigms, generate lively discourse, and improve teaching and learning (O'Neill, 2000).

Specific and relevant learning goals have been shown to result in higher performance than long-term performance goals. Latham and Brown (2006) studied the application of goal setting theory on student self-efficacy and satisfaction with an MBA program. Entering MBA students who established specific learning goals (e.g., master specific course subject matter) had higher GPAs at the end of the academic year than students who set vague goals such as "give my best effort." Setting specific and challenging goals requires one to acquire knowledge before tasks can be performed correctly, which leads to higher performance than setting abstract goals (Latham & Brown, 2006). Locke and Latham assert that specific learning goals enhance metacognition where individuals identify, plan, monitor, and evaluate progress toward goal attainment.

Teachers and stakeholders should be involved in the goal-setting process. When followers collaborate with leaders in establishing the organization's expectations, they will behave reasonably, act helpfully, and do the right thing (Benkler, 2011). First, leaders and followers must agree on future-valued outcomes. Once a follower understands and accepts a goal, “it remains in the periphery of consciousness as a reference point for guiding and giving meaning to subsequent mental and physical actions” (Locke & Latham, 2006, p. 267). There is a close link between goals and motivation. According to Locke and Latham, “Goals direct attention, effort, and action toward goal-relevant actions at the expense of non-relevant actions” (p. 265).

A motivated follower has the power to enhance organizational potential. Benkler (2011) states that “to motivate people, we need systems that rely on engagement, communication, and a sense of common purpose and identity” (p. 14). If teachers and students are not motivated, goals will be but statements without function. Instead, goals need to give purpose to each faculty member. Throughout the improvement process, teachers and administrators should review goals and communicate plans and outcomes openly. Goal setting plays a significant role in developing a healthy school climate (MacNeil et al., 2009). Goals launch and nurture the collective capacity of people in an organization.

Collective Efficacy

Self-efficacy theory has been applied in many education settings and at different grade levels (Schunk, 1995). According to Bandura, “Self-efficacy is the belief that one can execute needed steps to achieve a goal (as cited in Kardong-Edgren, 2013, p. 327). At its core, efficacy is about attitudes, beliefs, and confidence. Research has found that a strong sense of self-efficacy can enhance teachers’ motivation, openness to new ideas, and instructional effectiveness (DeWitt, 2019; Protheroe, 2008).

The indication that teachers' sense of self-efficacy impacts student learning has led to substantial research on collective efficacy. Collective teacher efficacy (CTE) refers to the perceptions and judgments of a group of educators regarding their ability to positively influence student outcomes" (Donohoo, 2017, p. 102). DeWitt (2019) explains, "Whereas self-efficacy is the confidence we have in ourselves, collective efficacy is the confidence we have in our group to make a difference" (para. 2). Studies by Bandura found that "a collective sense of efficacy among a school community contributes significantly to academic achievement" (as cited in Bloomberg & Pitchford, 2016, p. 10). Therefore, building a culture of efficacy is often a priority of school leaders. Bloomberg and Pitchford (2016) list four sources of efficacy that teachers can experience while participating in professional learning communities. Table 16 demonstrates how this study's revised intervention addresses sources of efficacy.

Table 16

Sources of Efficacy in This Study's PLC

Source of Efficacy	Dissertation's Curriculum-Based PLC
1. **Mastery Moments**: Teacher teams need direct experience that they interpret as successful (p. 18).	Participants experienced inquiry-based science instruction first-hand. Participants interacted with materials from the school's science curriculum, *STEMscopes*. Time was reserved for participants to share their thoughts on curriculum materials and how they may be used or modified in classroom instruction.
2. **Models of Success**: Teams observe successful teams and then see themselves as capable of performing similarly (p. 18).	The PLC applied protocols known to boost collaboration and prompt reflection. For instance, participants used the NGSS-designed screeners for instruction and performance tasks. The intervention applied Constructive-Developmental Theory to help

Table 16 (continued)

3. **Feedback**: A key ingredient to effective teams is diving deeply into productive feedback practices (p. 19).	participants realize their preferences for giving and receiving feedback. Understanding the different ways of knowing (Drago-Severson & Blum-DeStefano, 2017) increased discourse and risk-taking.
4. **Safety**: Relational trust in teams translates into team members who genuinely listen to one another, who respect others' opinions even if they differ from their own, who willingly share knowledge, and who feel accepted (p. 19).	Members of the intervention identified and studied their Enneagram types during PLC meetings. Not only did the Enneagram promote self-discovery, but it also nurtured a collective culture of interconnected personalities who valued one another.

Note. This study's intervention presented opportunities for participants to experience four sources of efficacy. Adapted from *Leading impact teams: Building a culture of efficacy,* by P. Bloomberg, and B. Pitchford, 2016. Copyright 2016 by Corwin Press.

Adherence to the four sources of efficacy relies on collaboration, which is essential to building a culture of efficacy (Bloomberg & Pitchford, 2016). Professional development (PD) is designed to enhance any teaching profession aspect, including collective teacher efficacy (CTE) (Donohoo, 2017). Donohoo examined 11 peer-review articles on CTE that were published between 2007 and 2014. "In each of the studies, professional learning took place in a collaborative rather than isolated environment" (Donohoo, 2017, p. 113). Professional learning holds great promise in building collective capacity among team members. In this study's iterated intervention, teachers observed colleagues' instruction, tested initiatives, exchanged feedback, and revised teaching practices based on group inquiry.

Professional learning communities possess motivational sources for collective teacher efficacy. Loughland and Nguyen (2020) conducted a science PLC case study at a primary school in Australia. The study found that teachers' sense of efficacy increased when they spent collaborative planning sessions developing detailed lessons. This dissertation's revised intervention enacted instructional coaching sessions with teachers. Instructional coaching centered on curriculum design and resource allocation to address the Next Generation Science Standards.

Heidi Hayes Jacobs, a pioneer in K–12 curriculum development, believes curriculum mapping sharpens standards-alignment, identifies gaps in learning skills, and creates a coherent core instructional program for all learners (as cited in Archambault & Masunaga, 2015, p. 506). Increased collaboration improves curriculum development. The curriculum mapping process "puts decisions about curriculum alignment in the hands of the teachers who deliver the instruction" (Koppang, 2004, 157). PLCs have an unprecedented opportunity to develop a sound standards-based curriculum in service of student learning (Hirsh, 2018). During the present study, the process of mapping curriculum helped familiarize PLC members with learning objectives and content that instilled a greater sense of confidence.

Reflective dialogue is integral in the development of collective efficacy. Loughland and Nguyen (2020) found the PLC model an effective avenue for teachers to share their unique teaching experiences. When given the opportunity, teachers will openly express their thoughts and concerns on school objectives and instructional practices. Thematic and theoretical coding of qualitative data suggested that vicarious learning is a motivational source of teacher collective efficacy (Loughland & Nguyen, 2020).

Not everyone appreciates collaborative inquiry. Sometimes a person's affective state is counterintuitive to the work of a professional learning team. In the study by Loughland & Nguyen (2020), one teacher felt discomfort when asked to participate in collaborative planning. Differentiated instruction is a best classroom practice because it addresses individual student needs and interests. The same is valid for adult learners. This dissertation's research project differentiated professional learning activities based on participants' classroom contexts, personality types, and processing (feedback) preferences.

"Although teaching is of a highly inter-personal nature, teachers are isolated from their colleagues for most of the working day, and professional interaction among teachers is often limited" (Davis, 1986, p. 72). Decades later, Schmoker (2006) and other contemporary researchers agree. Isolation occurs at many different points in a teacher's career. PLCs offer teachers a set of motivational sources known to create a culture of collective efficacy. According to Yeol (2020), "Overall, the school organizational culture and professional learning community explain approximately 27% of the variance of teacher efficacy" (p. 215). The development of teacher efficacy at both the individual and collective level requires assistance from the entire organization.

Systems Approach

School reform is about system change, and according to Owens and Valesky (2014), change must involve the whole school. Systems theory investigates the dynamic interactions of elements in an organization to challenge assumptions and create change. According to Falk et al. (2015):

> Systems theory was developed to understand how relationships and connections between the various sub-elements within the system combine to constitute the whole and how external factors influence the system. (p. 148)

The transformation of schools into professional learning communities depends on the efforts of many users. Stakeholders and personnel from different ranks and backgrounds should be involved in reform efforts. For example, the design of the present study's intervention involved administrators, curriculum specialists, technology integrationists, and central office staff. Leadership, personnel, and stakeholders influenced the collective capacity of PLC members.

"Improvement science is a systematic approach to continuous improvement in complex organizations" (Hinnant-Crawford, 2020, Chapter 1, para, 1). Schools' complexity can be lost on detached bureaucrats who pass education policy but have no hand in its implementation. The federal secretary of education, state politicians, education agencies, and other influencers place conditions on district operations and practices to encourage reforms (Goldstein, 2015). "Policy to practice" priorities are often misinterpreted at the local level. School districts do not always have proper guidance for training staff on new systems or adequate time to roll out reform drivers. Goldstein (2015) states:

> In the absence of these 'bridging instruments' between policy and practice, I fear American politics will continue to reflect profound disappointment in teachers,

and teachers themselves will continue to feel embattled. (Epilogue, Section 11, para. 4)

Fortunately, there are opportunities for school improvement to occur from the ground up. No matter where reform starts, its success depends on system-wide efforts.

Change endures when efforts address the whole organization. Nevertheless, "it is important to remember that essential to systems theory is the concept that systems are composed of subsystems that are highly interactive and mutually interdependent" (Owens & Valesky, 2014, p. 109). According to Zelichenko et al. (2016), “a system has to be considered as a sum total of the elements that are somehow ordered and connected by certain relations” (p. 1365). Schools are social systems defined by their community’s shared notions, values, and activities (Capra, 1997, as cited in Zelichenko et al., 2016, p. 1367). Education is also an open system where information is exchanged among employees and stakeholders (Zelichenko et al., 2016).

In addition to intrinsic motivators, external factors also affect the dynamics of complex human systems (Falk et al., 2015). Factors such as time, space, and resource allocation contribute to an intervention’s initiation and sustainability. Because of heightened interest in sustainability, systems science has begun to focus more on the concept of resilience (Falk et al., 2015). Schools face many unexpected contingencies that affect the progress of reform. Adaptive leadership can support systems theory, especially during the Do and Study phases of the improvement cycle.

Robust and healthy systems are dependent on social interaction and collective action based on networks of relationships, reciprocity, trust, and social norms” (Falk et al., 2015, p. 152). Falk et al. conducted a case study to describe science education as a holistic system. The researchers administered a questionnaire to different science community sectors such as schools, libraries, publishers, museums, and universities. Results showed that members of the science education community prioritize the promotion of science interest and engagement on school-aged children. Falk et al. (2015) raise a crucial point:

> The current situation suggests that the system as a whole is not optimally functioning since, in general, everyone in the system appears to be trying to accomplish much the same thing for many of the same people while leaving other audiences and goals relatively unattended to. (p. 162)

The goal of this dissertation's intervention was to improve teachers' efficacy toward inquiry-based science instruction. The aim of school improvement may be written as a single statement, but the outcome depends on many factors. School reform efforts such as this intervention's subject-based PLC centers on the establishment of mutual goals. However, the activities and processes to reach shared objectives may differ among participants. "The generation and maintenance of diversity is fundamental to healthy systems because greater diversity leads to greater complexity (Gell-Mann, 1994, as cited in Falk et al., 2015, p. 163). Divergence of ideas may generate just enough conflict, if managed effectively, to improve organizational functioning (Owens & Valesky, 2014).

A systems approach to school improvement is often associated with human resources. Equally important to a systems approach are an organization's inputs, outputs, and processes. According to Salam (2015), "Objectives, contents, methods and assessments are the integral part of system approach and key elements in any educational planning which is inter-related with each other" (p. 2). Members of this study's PLC engaged in activities where they reviewed and analyzed curriculum materials. Participants examined standards and teaching materials from horizontal (within grade levels) and vertical (across grade levels) perspectives. The PLC reflected on assessment practices and criteria for common science performance tasks. Action and reflection on various processes presented participants with a clearer vision of how science instruction can be an integral part of the school's curriculum.

Classroom instruction encapsulates a complex system. Teachers must make decisions from many sources, including professional development, curriculum resources, assessments, school leadership, families, administrators, and from their own experiences (Porter, 2002, as cited in Sears, 2018, p. 172). Participants in the present study's intervention collaborated on the design of a science curriculum that "accounts for what content and skills should be taught and for how they should be instructionally presented over time" (Hlebowitsh, 2020, p. 2). A careful inspection of the science curriculum using a "systems lens" cultivated a more comprehensive and coherent educational experience for all students.

Mary Park Follett, a pioneer in organizational theory and organizational behavior, stated that orders should be given based on the situation rather than a single leader (Owens & Valesky, 2014). Follett's research clashed with customary hierarchal communication because she believed that all members of an organization (even those at the lowest levels) should heed situations and be involved in the planning process. Organizations have the potential to sustain change and make improvements when individuals believe in common goals and objectives. There are many systems in and surrounding a school district. Each system is vital to the collective whole, but nothing compares to an organization's human element.

Theory of Action

This study's intervention was framed around multiple theories, which comprised a theory of action. School leaders use theories of action to make improvements in teaching and learning. A theory of action directs behavior in any situation. Most research operates under dual theories of action: an espoused theory and a theory-in-use. In the 1974 landmark book on professional effectiveness, *Theory in Practice,* Argyris and Schön, define espoused theory as what we *believe* works in a given situation, whereas theory-in-use is what actually guides our day-to-day *actions* (as cited Moss & Brookhard, 2012, Chapter 1, para. 5). This dissertation's theory of action directed the implementation of improvement drivers to support iterations made to the intervention's curriculum-based PLC. The theory of action guided the design of PLC activities and coaching approaches to increase participants' knowledge, alter their attitudes, and change behaviors. This study utilized the following theories to increase teachers' efficacy toward inquiry-based science instruction.

Constructive-Developmental Theory (Drago-Severson's Ways of Knowing)

Feedback is a commonly used strategy by teachers and school leaders. The benefits of feedback are vast, from conflict management to performance improvement. "Ideally, feedback is a continuing two-way communication that encourages progress" (Dowden et al., 2013, p. 349). Despite its ubiquity in education, many people do not realize that they have preferences for giving and receiving feedback. Drago-Severson and Blum-DeStefano (2017) argue that "through a better understanding of basic human nature, feedback can be flipped to become a force for positive change" (as cited in Giegerich, 2017, para. 3). In *Tell Me So I Can Hear You*, Drago-Severson and Blum-DeStefano (2017) explain how leaders can learn to deliver feedback in a way that strengthens relationships, improves performance, and builds followers' capacity for growth.

Drago-Severson (2009) identifies four "ways of knowing" adults use to make sense of their work, lives, and relationships. These sense-making systems were first presented by Robert Kegan, known as the forefather of "constructive-developmental theory." Kegan's theory attends to the structure and the process of an individual's meaning-making system (Drago-Severson, 2009). According to Drago-Severson, "Principles of the theory help leaders across school systems differentiate the kinds of leadership needed to encourage the growth of adults at different levels of development" (p. 32). Dragon-Severson applies practical applications to Kegan's "constructive-developmental theory" to focus on adults' different ways of knowing to support their professional growth.

The most common ways of knowing are instrumental, socializing, self-authoring, and self-transforming. Each way of knowing, or lens, influences how people make sense of experiences, feedback, and relationships (Drago-Severson & Blum-DeStefano, 2014). Table 17 outlines the four ways of knowing.

Table 17

Ways of Knowing

Way of Knowing	Brief Description
Instrumental	Instrumental knowers believe that there are right and wrong answers to problems, and right and wrong ways to do things, think, and behave.
Socializing	Socializing knowers feel responsible for others' feelings and, in turn, hold other people responsible for their own.
Self-Authoring	Self-authoring knowers value opportunities to voice their own opinions, offer suggestions and critiques and formulate their own goals.
Self-Transforming	Self-transforming knowers see interconnection as a strength and opportunity and can examine issues from multiple points of view.

Note. Four essential ways of knowing. Adapted from "Tell me so I can hear," by E. Drago-Severson, and J. Blum-DeStefano, 2014. Copyright 2014 by Learning Forward.

Central to the cognitive-developmental theory is the intersection of interpersonal and internal experiences. Research shows that teachers' intrapersonal and interpersonal skills are directly related to self-efficacy levels (Angeles, 2012). Attention to Kegan's subject-object balance principle helps adult learners improve both their inter and intra relationships. Subject-object balance "centers on the relationship between what we can have a perspective on and control (object) and what we cannot see about ourselves or others (subject)" (Drago-Severson, 2016, p. 40). Seeking different perspectives is an important step in developing oneself (Kegan, 1980, as cited in Kenofer, 2013, p. 67).

Self-awareness and self-efficacy can be influential to decision-making and capacity building (Özek & Ferraris, 2018).

The environment—context—also dictates how a person grows. Kegan expands on the idea of "holding environments," which was first described by D. W. Winnicott in 1965. Holding environments are instrumental in the professional learning process. The context of adult learning situations should offer a healthy balance of both support and challenge, which Kegan affirms is necessary for growth (Drago-Severson, 2004). The design of this dissertation's PLC provided support through its integration of the transformational coaching model. Transformational coaching is professional development focused on reflection, growth, and practice refinement (Aguilar, 2020). The present study challenged participants by posing questions and implementing PLC activities that stimulated new ways of thinking.

A healthy holding environment provides continuity, and it remains accessible to people as they grow. A robust learning environment realizes all people do not learn the same. Professional development should honor people's preferences by matching expectations and learners' ways of knowing (Drago-Severson, 2004). PLCs need to vary pedagogical practices according to participants' preferences and significant contextual factors. Therefore, learners and facilitators should take the time to recognize and understand their ways of knowing. Sharing sense-making preferences with teammates lead to collaborative and inquiry-based learning environments.

The present study created a questionnaire to help determine participants' ways of knowing (see Appendix L). Respondents selected the choice that best described their preference for giving and receiving feedback. Fields derived from *Tell Me So I Can Hear*

You: A Developmental Approach to Feedback for Educators by Drago-Severson and Blum-DeStefano (2017). I tallied each participant's scores, which tiered their ways of knowing (instrumental, socializing, self-authoring, and self-transforming). Participants were notified of their scores. After reviewing results and reflecting on the different sense-making types, respondents completed a reflection form to confirm or counter initial results (see Appendix M). Table 18 displays data from the questionnaire and the follow-up reflection form.

Table 18

Participants' Ways of Knowing

Participant	Highest Ranking Way of Knowing According to Questionnaire	Preferred Way of Knowing
1st Grade Teacher #1	Socializing	Self-Transforming
1st Grade Teacher #2	Self-Transforming	Self-Transforming
2nd Grade Teacher #1	Instrumental	Instrumental
2nd Grade Teacher #2	Socializing	Instrumental
2nd Grade Teacher #3	Self-Transforming	Self-Transforming
2nd Grade Teacher #4	Instrumental	Instrumental
3rd Grade Teacher #1	Self-Authoring	Self-Transforming
3rd Grade Teacher #2	Self-Transforming	Self-Transforming
3rd Grade Teacher #3	Instrumental	Instrumental
3rd Grade Teacher #4	Self-Transforming	Self-Transforming
3rd Grade Teacher #5	Self-Transforming	Self-Transforming
Curriculum Coordinator	Self-Authoring	Self-Authoring

Table 18 (continued)

Principal	Self-Transforming	Self-Authoring
Researcher	Self-Authoring	Self-Authoring

Note. Respondents used results from the questionnaire and information from Drago-Severson and Blum-DeStefano (2017) to identify their preferred way of knowing.

There are many practical applications for using constructive-developmental theory in teacher professional development. Comments left by participants on the reflection form revealed connections between constructive-developmental theory and collaboration. One respondent noted, “I think understanding everyone’s way of knowing would enhance collaboration and the roles that we play in it. We should be able to see a complete picture.” A theme also emerged on relationship building. Participants agreed that a better understanding of teammates’ attitudes and beliefs would help them grow closer. A teacher noted that exploring the PLC’s different ways of knowing would “help me understand the person better and how they think so that I can acclimate to their way of knowing.”

Information collected about participants’ preferred ways of knowing enhanced the giving and receiving of feedback for growth. According to Drago-Severson and Blum-DeStefano (2017), “Giving feedback that takes a person’s developmental orientation into account is one powerful way to honor and recognize the intrinsic promise of colleagues, and to demonstrate faith in this kind of important growth” (Chapter 3, Section 4, para. 4). Understanding the different feedback preferences upfront enabled people to construct a sound awareness of how people give and receive feedback. Participants needed opportunities to make sense of their expertise as well as their growth areas. One's potential to make sense of new ideas is maximized through collaboration and feedback.

One of the open-response items on the constructive-developmental theory reflection form asked, "How will an understanding of your and others' "ways of knowing" enhance the way you grow as a teacher, leader, and learner?" Communication, collaboration, and camaraderie were common ideas mentioned. According to the school's curriculum specialist:

> It [ways of knowing] can give each of us on the team a role and play to our strengths. It can help us better communicate with each other and work toward a common goal if we can understand all the different ways each individual thinks. It can unite us.

Awareness of the team's ways of knowing increased participants' engagement in the feedback process. It also helped each member in differentiating their feedback to support ongoing learning and improvement. Drago-Severson and Blum-DeStefano (2017) write, "Through our feedback and communications, we can help each other bring new consciousness, awareness, perspective, and intentionality to our thinking and acting" (Chapter 3, Section 4, para. 7).

"Constructive-developmental theory offers a hopeful and new foundation for considering practices supportive of teachers' transformational learning and development" (Drago-Severson, 2004, p. 35). Teachers orient to their craft in different ways. Professional learning needs to accommodate a variety of teacher perspectives by differentiating the way feedback is provided. Two chief principles of cognitive-developmental theory guided the implementation of this study's intervention: subject-object balance and holding environment. Each learner's "filter" for making sense of experiences, or ways of knowing, is central to these principles. One participant in this study articulated the purpose and power of constructive-developmental theory by proclaiming, "It [ways of knowing] teaches me about myself, shows that I have characteristics of all types [ways of knowing] and that I like to stay true to myself but also grow with others."

Enneagram Theory of Personality

Humans possess associative learning powers to better understand their motivations and behavioral patterns (Baron, 2018). To truly learn about ourselves, we must possess knowledge of our inner self, which is no easy task. Fortunately, there is a model of the human psyche that has been described as a sort of roadmap to help clear the road of our consciousness (Baron, 2018). According to Loh-Hagan (2004), "The Enneagram personality system attempts to explain why people act in certain ways" (p. 4).

The Enneagram is a model of the human psyche. The Enneagram is principally understood and taught as a typology of nine interconnected personality types (Matise, 2007). The primary personality types are the starting point for understanding the Enneagram and seeing its applications in professional learning. Figure 46 provides a brief description of each Enneagram type. Accompanying each description is the leadership paradigm for that personality type. According to Lapid-Bogda (2006), a leadership paradigm is a set of assumptions and beliefs about how leadership influences behavior (Lapid-Bogda, 2006).

Figure 46

The Enneagram Types

Type 1

- Seek a pefect world and work diligently to improve both themselves and everyone and everything around them
- **Leadership Paradigm**: The leader's job is to set clear goals and inspire others to achieve the highest quality.

Type 2

- Want to be liked, try to meet the needs of others, and attempt to orchestrate the people and events in their lives.
- **Leadership Paradigm**: The leader's job is to assess the strengths and weaknesses of team members and to motivate and facilitate people toward the achievement of organizational objectives.

Type 3

- Organize their lives to achieve specific goals and appear succesful in order to gain the respect and admiration of others.
- **Leadership Paradigm**: The leader's job is to create an environment that achieves results because people understand the organization's goals and structure.

Type 4

- Desire deep connections both with their own interior worlds and with other people, and they feel most alive when they authentically express their feelings.
- **Leadership Paradigm**: The leader's job is create organizations that give people meaning and purpose so they are inspired to do excellent work.

Type 5

- Thirst for information and knowledge and use emotional detachment as a way of keeping involvement with others to a minium.
- **Leadership Paradigm**: The leader's job is to develop an effective organization through research, deliberation, and planning, so that all systems fit together and people are working on a common mission.

Type 6

- Have insightful minds, and prone to worry, and plan for worst-case scenarios in order to feel prepared in case something goes wrong.
- **Leadership Paradigm**: The leader's job is to solve organizational problems by creating a creative problem-solving environment where each person feels that he or she is part of the solution.

Type 7

- Crave the stimulation of new ideas, people,and experiences; avoid pain and discomfort; and create elaborate future plans that will allow them to keep all of their options open.
- **Leadership Paradigm**: The leader's job is to get people excited and create innovative ventures so the organization can take advantage of new and important business opportunities.

Type 8

- Pursue the truth, like to keep situations under control, want to make important things happen, and try to hide their innocence and vulnerability.
- **Leadership Paradigm**: The leader's job is to move the organization forward by leading decisively, getting capable and reliable people into the right jobs, and empowering competent people to take action.

Type 9

- Seek peace, harmony, and positive mutual regard and dislike conflict, tension, and ill will.
- **Leadership Paradigm**: The leader's job is to help achieve the collective mission by creating a clearly structured and harmonious work environment.

Note. The Enneagram is a study of the nine basic types of people. From “Developing communities of leaders through the Enneagram,” by G. Lapid-Bogda, 2006, *OD Practitioner*, *38*(4), p. 58–59. Copyright 2006 by Organization Development Network.

The Enneagram has many purposes and applications across many settings. Research shows that personality types influence workplace attitudes and cognitions. Kale and Shrivastava (2001) declare, “Enneagram theory implies that a personality type is predisposed to enjoying certain types of jobs/tasks” (Section 5, para. 3). Attention to employees’ personality types supports differentiation in professional learning activities, including instructional coaching.

Sutton et al. (2013) administered an extensive survey to 416 individuals who had participated in a week-long intensive Enneagram course. The researchers tested for systematic differences between personality types on established models, personal values, implicit motives, job attitudes, and career-related factors (Sutton et al., 2013). ANOVAs showed that the Enneagram type had a significant effect on job involvement and self-efficacy (Sutton et al., 2013). Sutton et al. conclude that the Enneagram can develop the self-knowledge that is key to personal development and increased managerial effectiveness.

Enneagram theory can play a pivotal role in motivating teachers. Motivation in the workplace is often studied using expectancy theory (i.e., motivation contingent mainly upon external factors; Kale & Shrivastava, 2001). Enneagram theory, on the other hand, identifies internal motivations and assigns them to specific personality types. According to Kale and Shrivastava (2001), “Enneagram theory suggests that individuals cannot help getting motivated, provided their energies are engaged in a manner that answers their calling” (Section 6, para. 5). Therefore, a better understanding of “self” can help one adapt to new situations and approach tasks from perspectives that best suit their personality and possibly that of others.

Participants in the second round of intervention for this study attended an Enneagram workshop led by Gary Houchens, Ph.D., an Enneagram trainer certified by Awareness to Action International. Before the workshop commenced, participants completed an Enneagram personality test from Eclectic Energies. Dr. Houchens decreed, “No assessment has ever been developed that, by itself, will definitively determine someone’s Enneagram type. But I’ve found this quiz to be among the most accurate, at least as a starting point for further self-inquiry” (G. Houchens, personal communication, July 29, 2020). Results in Table 19 indicate each participant’s personality type and instinctual bias. Instinctual biases are “the fundamental biological needs that matter most to us” (Sikora, 2019, p. 8).

Table 19

Participants’ Personality Types and Biases

Participant	Enneagram Type	Instinctual Bias
1st Grade Teacher #1	Type 3	Preserving
1st Grade Teacher #2	Type 9	Navigating
2nd Grade Teacher #1	Type 3	Preserving
2nd Grade Teacher #2	Type 3	Navigating
2nd Grade Teacher #3	Type 2	Transmitting
2nd Grade Teacher #4	Type 1	Transmitting
3rd Grade Teacher #1	Type 1	Navigating
3rd Grade Teacher #2	Type 2	Preserving
3rd Grade Teacher #3	Type 1	Navigating
3rd Grade Teacher #4	Type 2	Preserving

Table 19 (continued)

3rd Grade Teacher #5	Type 3	Transmitting
Curriculum Coordinator	Type 1	Navigating
Principal	Type 3	Preserving
Researcher	Type 1	Preserving

Note. Results provided by an Enneagram test from Eclectic Energies indicated respondents' instinctual variant (bias).

Throughout two, one-hour sessions, Dr. Houchens provided a very high-level introduction to the Instinctual Biases and 9 Strategies (personality types) of the Enneagram based mainly on the Awareness to Action approach. The key focus of the workshop was to:

1) Identify each person's Instinctual Bias and Enneagram strategy (type number).

2) Reflect on how we can use this information to nurture our self-efficacy, especially in our teaching.

Participants' knowledge of colleagues' personality types built a positive learning and work environment. The Enneagram results led to reflective discourse about why we care, how we learn, and what we want to accomplish. These topics were influential to the design of each phase of the intervention's curriculum-based PLC. The purpose of the PLC was to improve teachers' self-efficacy toward science instruction and the inquiry process. The point of the Enneagram is "self-understanding and growing beyond the self-defeating dimensions of our personality" (Cron & Stabile, 2016, p. 14). This study's integration of Enneagram theory enhanced participants' professional growth in teaching science while also improving relationships.

Social Cognitive Theory

This dissertation's intervention was a professional learning community (PLC) whereby participants gained experience and confidence in teaching using the constructivist approach of learning. Gains in efficacy are contingent upon many factors, motivation in particular. "Motivation deals with explanations of why people do the things they do" (Owens & Valesky, 2014, p. 121). Presumably, the absence or lack of motivation hinders potential gains in one's sense of self-efficacy. Motivation theory played a pivotal role in the second round of this PLC intervention. This chapter's theory of action incorporates Bandura's social cognitive theory as a means to increase participant motivation and, ultimately, self-efficacy.

"Bandura's social cognitive theory (1997) provides the theoretical framework underlying both teacher and collective efficacy" (as cited in Goddard & Goddard, 2001, p. 809). Bandura's social cognitive theory's premise is that observation and modeling play a primary role in the learning process. "The hallmark of this theory is that individuals can proactively control their development and make things happen by taking action" (Owens & Valesky, 2014, p. 139). A concern with most teacher professional development (PD) is that participants rarely get sufficient experience using a strategy to feel competent to put it to practice. Professional development on a given topic is usually facilitated in a single session for three hours or less. There is little to no observation and modeling in traditional PD. Thus, most teacher development eludes what Owens and Valesky decree is the social cognitive theory's hallmark—interaction.

According to Bandura’s (1997) social cognitive theory, efficacy positively affects one’s sense of agency. People are more likely to pursue goals in which they believe they can succeed (as cited in Goddard & Goddard, 2001, p. 809). Sources of efficacy operate at both the individual and the collective levels (Goddard et al., 2000). Goddard and Goddard (2001) conducted a multilevel analysis that examined the relationship between teacher and collective efficacy. A survey containing personal teacher efficacy and collective efficacy scales was administered to 452 teachers in 47 urban elementary schools. The data collection instrument produced 21 mean scores, which were averaged to yield an overall collective efficacy score for each school. Collective efficacy scores and school-level contextual variables (mean social-economic status, mean prior math achievement, minority concentration, and school size) were tested separately as predictors of between-school variation in teacher efficacy. When collective efficacy and context factors were considered together, “only collective efficacy was a significant predictor of differences between schools in teacher efficacy” (Goddard & Goddard, 2001, p. 814). According to the study’s findings, “Teachers’ perceptions of self-capability may be either enhanced or attenuated by perceptions of collective capability and related group member expectations for performance” (Gooddard & Goddard, 2001, p. 810).

Perceptions of collective capability and competencies are expanded through social cognitive theorists called mastery modeling (Wood & Bandura, 1989). When opportunities for direct experience are too tedious or costly, professional learning needs to practice mastery modeling. Social cognitive theory suggests that individuals learn from one another via observation, imitation, and modeling. Teacher self-efficacy can be strengthened through mastery experiences and mastery modeling (Wood & Bandura, 1989). The present study's intervention modeled best practices of inquiry-based science teaching and provided opportunities for participants to experience sufficient success.

The present study promoted collective teacher efficacy in teaching science by engaging participants in scientific inquiry first-hand. As members of the intervention's PLC, participants used STEM resources, analyzed student data, made instructional decisions, and developed common science assessments. A curriculum-based professional learning community promotes the creation of new knowledge through collaboration and reflection (Sigurðardóttir, 2010). Social cognitive theory and its attention to valence, or value, of performing tasks aided this study's design (Owens & Valesky, 2014). The curriculum-based PLC encouraged teachers to experience the joys and impacts of inquiry-based learning before planning the curriculum. Because of this process, participants' perception of the value of the PLC's work improved.

In addition to mastery experiences and modeling, social persuasion is a third way of increasing people's self-efficacy beliefs. According to Wood and Bandura (1989), "If people receive realistic encouragements, they will be more likely to exert greater effort and to become successful than if they are troubled by self-doubts" (p. 365). However, successful motivators require more than expressions of positive praise. Wood and Bandura suggest assigning employees tasks that will instill feelings of success. Social persuasion is not to be confused with competition. "To ensure progress in personal development, success should be measured in terms of self-improvement, rather than through triumphs over others" (Wood & Bandura, 1989, p. 365). A constructivist position to collaborative professional learning manifests and supports self-regulatory behaviors (J. Martin, 2004).

Social cognitive theory has been studied extensively since its conception in 1986 by Albert Bandura. The theory holds many implications for professional learning at XYZ Elementary School. Efficacy, motivation, self-regulation, and agency are pillars of social cognitive theory and this dissertation. This study's intervention aimed to increase teachers' efficacy of inquiry-based science instruction through reformed professional development. Participants' professional learning occurred in a social context with a reciprocal interaction of the environment, behavior, and personal and cognitive factors (Bandura, 1986, as cited in Wood & Bandura, 1989, pp. 361–362).

Three unique theories comprised the revised intervention's theory of action: constructive-developmental theory, Enneagram theory of personality, and social cognitive theory. These theories operate harmoniously with the theory of action detailed in Chapter 3. The original theory of action consisted of the constructivist theory of learning, sociocultural learning theory, and transformational coaching. Assumptions and applications of each theory guided the design and implementation of the iterated intervention. Figure 47 presents the connections among the theories and potential implications for the iterated PLC.

Figure 47

Theory of Action

Note. The theoretical framework incorporates established and highly researched philosophies known to advance professional learning.

Revised Design

The pre- and post-survey data in Chapter 3 indicated that the first phase of intervention increased teachers' self-efficacy toward science concepts and teaching practices. While teachers' efficacy improved, teaching practices remained static in large part due to challenges associated with COVID-19. Quantitative data showed that teachers needed additional support in implementing instruction, as results were low for the following scales:

- Student Technology Use
- Elementary STEM Instruction
- 21st Century Learning Attitudes

Iterations to the intervention included hybrid meeting sessions (i.e., online and in-person). In-person meetings adhered to guidelines from the Centers for Disease Control and Prevention for social distancing, mask-wearing, disinfecting, and additional ongoing mitigation guidance. Participants engaged in scientific inquiry using STEM resources and digital learning tools. As the PLC facilitator and instructional coach, I supported the design of instructional procedures, analysis of student data, and development of common science assessments.

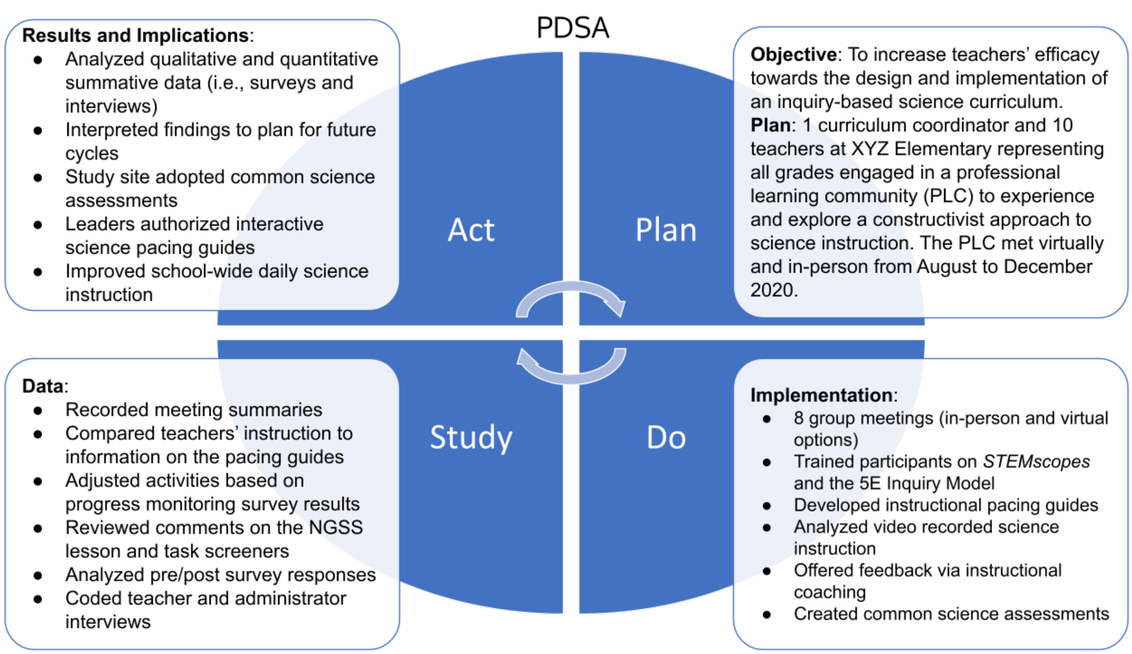
Plan-Do-Study-Act

Data from the first round of intervention guided the planning and preparation of the revised curriculum-based professional learning community (PLC). Structural changes to the science-focused PLC intervention included team teaching, peer observations, collaborative assessment design, and curriculum mapping. Cultural changes to the intervention included creating SMART goals, exploring members' Enneagram types, and investigating participants' sensemaking perspectives. The intervention's iterations focused on relationship and task behaviors to improve teacher confidence and aptitudes toward inquiry-based science instruction.

The updated literature review, revised theory of practice, and inspection of contextual factors influenced the 'do' stage in the Plan-Do-Study-Act (PDSA) cycle. The aim of the PDSA cycle is incremental achievement improvement (Crowfoot & Prasad, 2017). According to Speroff and O'Connor (2004), "The core objective in PDSA quality improvement research is to assess whether a study intervention imposed to change a process produces an improvement in outcome" (p. 17). Figure 48 shows the PDSA Inquiry Cycle for the revised intervention.

Figure 48

Second Round of Intervention Plan-Do-Study-Act Cycle



Note. The Plan-Do-Study-Act is a model for improvement used to plan and monitor the progress of this study's intervention.

The PDSA improvement model is a deliberate nonlinear process. Qualitative and quantitative data were collected and analyzed throughout the intervention to make improvements as needed. While the design of the intervention remained the same, activities and protocols changed according to findings. Data from progress monitoring surveys, field notes, and observations were measured and analyzed during the' study' stage. Modifications to the curriculum-based PLC's format and activities were contingent on qualitative and quantitative data. The goal of PDSA is to pursue effective process changes that favorably affect outcomes (Speroff & O'Connor, 2004). The PDSA cycle assisted in designing and implementing the study. Frequent testing and reflection informed the research of its impact and the need for revision.

Setting/Context

The study site, XYZ Elementary School, consists of first, second, and third grades. School enrollment for the 2019–2020 school year included 699 students. According to the Kentucky Department of Education's School Report, the demographic makeup of students at XYZ Elementary included: 76.5% White, 8.3% African American, 8% Two or More Races, 7.2% Other. One hundred forty-four students received special education services, and 23 students were English Language Learners, which was a 16-point increase from the year prior. XYZ Elementary is Title I eligible, with 73% of students categorized as "economically disadvantaged."

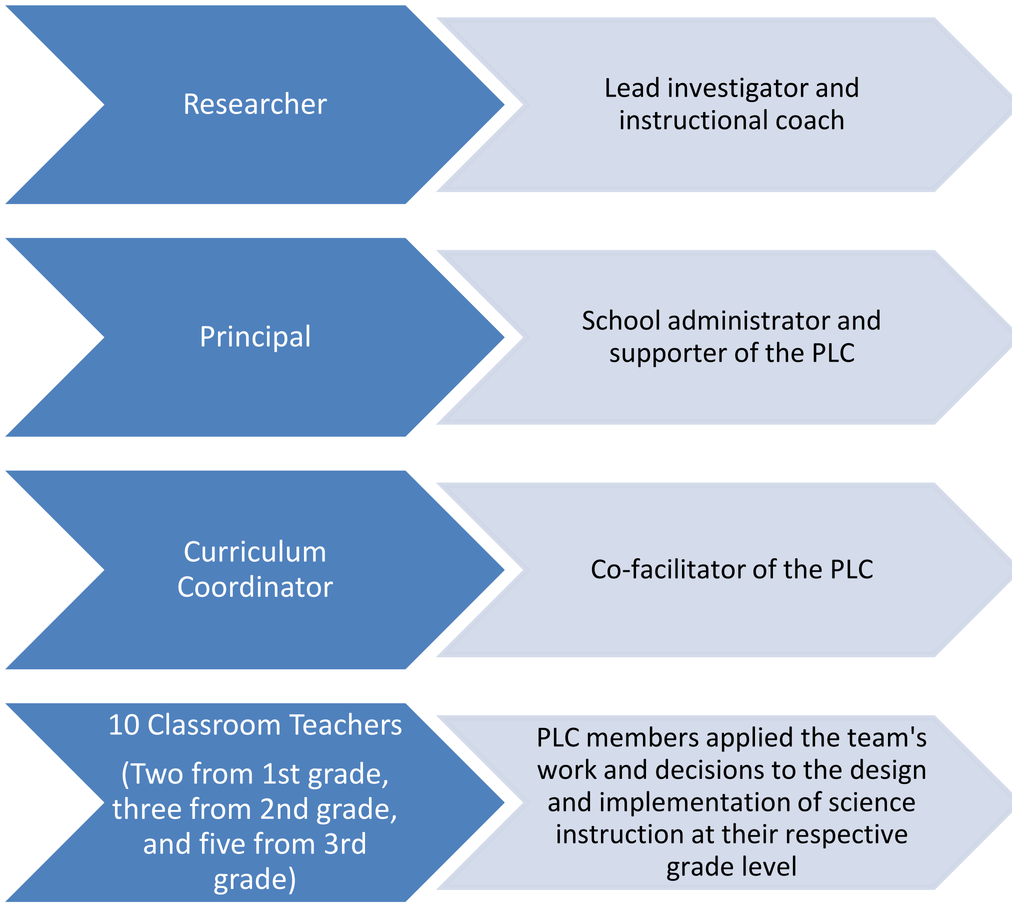
The 2020–2021 school term began in a virtual format at the study site due to the COVID-19 Pandemic. Online learning occurred from August 26 to October 2, 2020. On October 12, students had the option to continue virtual learning or opt for a hybrid schedule. A hybrid model combines in-person teaching with online learning. Hybrid students attended school in person two days a week and learning the other days virtually. Students did not attend school in person on Fridays. I scheduled many of our PLC meetings and instructional coaching sessions on Fridays. Kentucky Governor, Andy Beshear, ordered public and private schools to close classrooms starting November 23, 2020. XYZ Elementary School returned to an all-virtual format before re-commencing the hybrid system on January 11, 2021. The revised intervention spanned four months, from August to December 2020.

Participants

Eleven participants comprised the iterated curriculum-based PLC, including the seven participants from the first round of intervention. The sample size increased to accommodate all teachers interested in improving XYZ Elementary School’s science curriculum. All participants were Caucasian and female. Nine of the 11 teachers possessed a master’s degree. The minimum number of years taught was 1, the maximum number of years teaching was 22, and the median years teaching was 11.5. Figure 49 contains additional information about participants. The principal and curriculum coordinator participated in qualitative research but not quantitative data collection methods. The surveys targeted elementary teacher efficacy and attitudes toward STEM standards, strategies, and assessment.

Figure 49

Second Round of Intervention Participants



Note. The intervention's curriculum-based PLC engaged participants in scientific inquiry to increase teacher efficacy toward science instruction.

Participants did not receive professional development credit by engaging in this intervention. Most teachers were motivated to learn professionally because of dissatisfaction with current science teaching practices (Appova & Arbaugh, 2018). The study's curriculum-based PLC transformed teacher professional development by promoting participant ownership in the learning process through ongoing collaboration and coaching.

Procedures

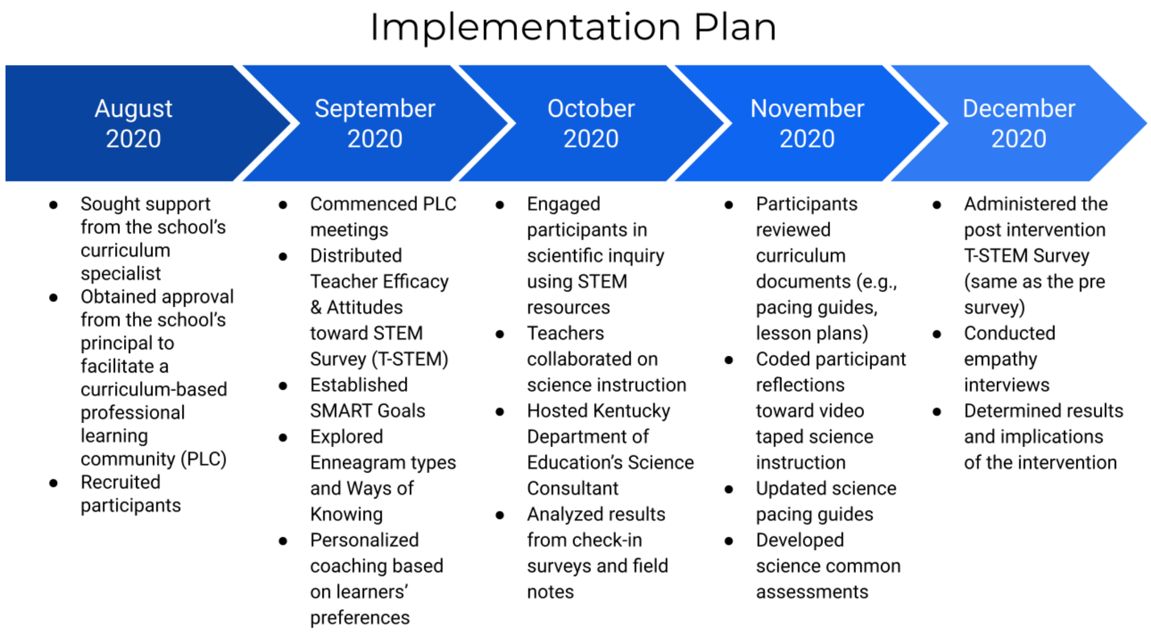
XYZ County Schools' central office staff authorized and supported this study and its interventions. Due to progress made in enhancing science instruction during the first round of intervention, the principal was eager to begin phase two. For the first time at XYZ Elementary School in the 2020 fall semester, professional learning communities were formed by content area (i.e., science, social studies). The intervention's science PLC was named "Science Squad." The curriculum-based science PLC consisted of 10 classroom teachers, one school principal, and a curriculum coordinator. I acted as the PLC's facilitator and instructional STEM coach.

Participants had previously engaged in training on science standards and the inquiry process. I administered the Elementary Teacher Efficacy and Attitudes toward STEM Survey to participants at the start of the PLC in September 2020 and at its conclusion in December 2020. Empathy interviews were conducted with a teacher from each grade level, the principal, and the curriculum coordinator.

The first official meeting with members of the second round of intervention commenced on September 9, 2020. The opening session focused on group norms and expectations. The conversation led to precise and trackable SMART goals. PLC meetings were held in person with a virtual option using Zoom video-conferencing software. The PLC met eight times as a team. Figure 50 displays an overview of the intervention's implementation plan.

Figure 50

Second Round of Intervention Implementation Plan



Note. Implementation of the iterated intervention occurred during the 2020–2021 fall semester.

The following tasks supported this study's goal to increase teacher efficacy toward science education and the inquiry process:

- training on using *STEMscopes* curriculum
- engaging in the 5E Inquiry-Based Instructional Model
- developing interactive grade-level pacing guides
- co-teaching
- instructional coaching
- designing common science assessments
- evaluating of video-recording science instruction

- integrating science into other subject areas.

In addition to PLC meetings, participants collaborated during scheduled and impromptu coaching sessions. The study adopted a transformational coaching model. Instructional coaches focus on many issues such as classroom management, curriculum mapping, pedagogical practices, and assessment (Knight, 2009). I engaged participants in supportive, dialogical conversations about teaching philosophy, instructional practices, and outcomes. Participants updated science curriculum guides, de-constructed the Next Generation Science Standards (NGSS), and used *STEMscopes* to plan instructional procedures. They also reflected on instructional resources, teaching practices, assessment, and outcomes using the NGSS screener tools.

Professional development (PD) reform plays an essential role in *what* teachers learn and *how* they learn. This study's curriculum-based PLC aimed to overcome the "current weaknesses of teacher training, classroom isolation, and traditional PD" (David & Cuban, 2010, p. 148). The intervention promoted collaborative professional learning to increase collegial trust and informed classroom instruction.

Metrics

Metrics are a critical component of improvement methodologies and the PDSA cycle (Hinnant-Crawford, 2020). This study used a multitude of practical measures to evaluate the outcomes of the second round of intervention. Metrics included surveys, interviews, field notes, and artifacts such as curriculum documents and common assessments. Systematic observations of different research methods, or disciplined inquiry, led to reliable conclusions (Jensen, 1989). My analysis and interpretation of data from mixed methods revealed the intervention’s change drivers’ impact, and findings informed the next steps.

Surveys

Pre- and post-intervention quantitative data were collected using the Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) for elementary grades. The T-STEM survey was used with permission from the Friday Institute for Educational Innovation (2012a) of North Carolina State University. The instrument measured teacher efficacy and frequency of some instructional practices. This study’s version of the T-STEM surveyed contained five scales:

- STEM Teaching Efficacy and Beliefs – Science
- STEM Instruction
- Student Technology Use
- 21st Century Learning Attitudes (Inquiry-Based Learning)
- STEM Career Awareness

Pre- and post-data were compared to measure the iterated intervention’s impact (Mintrop, 2019). Summary statistics calculated the mean, minimum, and maximum of each field. Cronbach’s alpha data indicated the instrument’s reliability estimate and internal consistency (Sijtsma, 2009). The T-STEM Survey was a reliable instrument because scales had Cronbach alpha coefficients that pushed 1 (Sijtsma, 2009).

Two progress monitoring (check-in) surveys were administered during the intervention. Each survey contained nine selected-response items and three open-response prompts. Fields were unique to each check-in survey. Items aligned with questions on the pre- and post-T-STEM surveys. The progress monitoring instruments measured participants' attitudes toward science teaching and their use of inquiry-based practices. Pre, post, and progress monitoring surveys were administered online via Qualtrics, and respondents' identities remained anonymous.

Data from surveys established the amount of growth participants experienced because of the intervention. Quantitative data allowed me to assess whether participants' efficacy changed between two points in time (Estrada et al., 2019). Data also informed my decision-making process regarding PLC design and modifications.

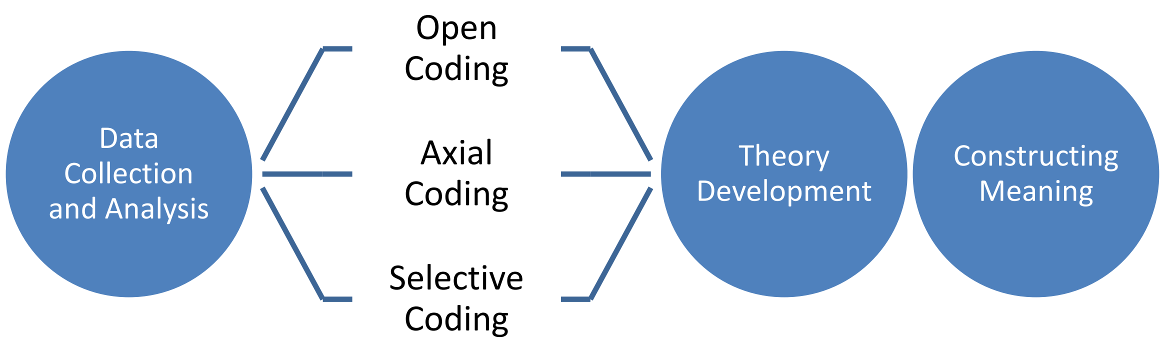
Interviews

Qualitative data provided pivotal information regarding the objectives and outcomes of the intervention. Empathy interviews were conducted at the onset of the revised intervention in September 2020 and at its conclusion in December 2020. "Empathy interviews are a data collection strategy that seeks to understand some concept or experience from the perspective of the interviewee" (Hinnant-Crawford, 2020, Section 7, para. 1). I conducted interviews with classroom teachers and school administrators. Interview questions focused on professional learning, collaboration, science instruction, and student mastery.

Interview data were analyzed using a multi-tiered coding process. Open coding is the first level of coding. "In open coding, the researcher is identifying distinct concepts and themes for categorization" (M. Williams & Moser, 2019, p. 48). I established themes by labeling concepts and defining categories based on their properties and dimensions (Holton, 2007; Khandkar, 2009). The second level of coding is axial coding. Axial coding "focuses on identifying emergent themes, axial coding further refines, aligns, and categorizes the themes" (M. Williams & Moser, 2019, p. 50). Selective coding is the final stage in the process. Selective coding "enables the researcher to select and integrate categories of organized data from axial coding in cohesive and meaning-filled expressions" (M. Williams & Moser, 2019, p. 52). Figure 51 provides an overview of the coding process for qualitative research.

Figure 51

Qualitative Coding Data Process



Note. The process of qualitative coding data is non-linear. Adapted from "The art of coding and thematic exploration in qualitative research," by M. Williams & T. Moser, 2019. Copyright 2019 by International Management Review.

"It is through coding that the conceptual abstraction of data and its reintegration as theory takes place" (Holton, 2007, p. 265). "Coding in qualitative research enables researchers to identify, organize, and build theory" (M. Williams & Moser, 2019, p. 54). The constant comparison of coded interview data among participants and across interventions helps construct new knowledge (Holton, 2007; M. Williams & Moser, 2019) and develop theory grounded in mixed methods research.

Documents and Artifacts

Documents are a major source of qualitative research data (Merriam, 2002). One reason documents are reliable sources of data is that "they do not intrude upon or alter the setting in ways that the presence of the investigator might" (Merriam, 2002, p. 13). Secondly, documents depend on participants' cooperation, as is the case when collecting data through interviews (Merriam, 2002). In fact, there are incidences when entire studies are built around documents.

As was done in the first intervention, I kept summaries of each professional learning community meeting and activity. Each PLC meeting worked off an interactive agenda in Google Docs. Meeting agendas contained headings, links, goals, and other pertinent information about the meeting's topic (See Appendix N for a sample meeting agenda). The revised PLC included more instructional coaching sessions and co-teaching opportunities than in the study's first round of intervention. A description of each activity, along with recommendations, was recorded for each intervention activity. According to Phillippi and Lauderdale (2018), "Field notes are widely recommended in qualitative research as a means of documenting needed contextual information" (p. 381). This study used field notes to customize the intervention's details based on participants' needs and the researcher's needs (Phillippi & Lauderdale, 2018). See Appendix O for a dashboard of intervention activities and field notes. Field notes and agendas show how PLC activities were developed and adapted to increase teacher efficacy toward inquiry-based science instruction.

Curriculum documents and teacher reflections were other artifacts that comprised this study's qualitative data analysis. Learning standards on participants' science lesson plans were compared with information on grade level pacing guides. Three participants agreed to video record a classroom science lesson. These participants analyzed their instructional design, strategies, and student engagement by reflecting on the criteria in the NGSS Lesson Screening Tool. Additionally, three participants engaged students in a summative performance task. The NGSS-aligned task acted as an alternative but common science assessment. Participants reflected on the assessment by responding to questions listed in the NGSS Assessment Task Screening Tool.

I analyzed data from documents, interviews, and surveys as they were collected. "To wait until all data are collected is to lose the opportunity to gather more reliable and valid data" (Merriam, 2002, p. 14). Data analysis is an inductive process that looks for common patterns and themes in different data sources. The combination of documentary evidence with interviews and surveys minimizes bias and establishes credibility (Bowen, 2009).

Validity of Second Round of Intervention

The design of this intervention addressed criteria that made it *research based.* The reasoning for this intervention's design and its use of metrics is grounded in theory and evidence. Mintrop (2020) describes three qualities that make design development research-based. Table 20 conveys how the iterated intervention design is, in fact, researchable.

Table 20

Research-Based Design Development

Qualities of research-based interventions	Characteristic of this study's intervention
1. Interventions consist of carefully planned tools, activities, or organizational formats hypothesized to elicit or foster the kind of adult learning needed to achieve intended outcomes.	This study formed two iterations of a curriculum-based PLC to improve teacher efficacy toward science instruction. Agendas were prepared for each meeting. The PLC had a website and learning management system for engaging participants and archiving resources. Participants' Enneagram types and preferred ways of knowing fostered personalized instructional coaching.
2. Trial and error in accomplishing outcomes are deliberate; they are undergirded by a theory of action drawn from the professional knowledge base. The theory's validity can be assessed by evidence that intervention activities generate.	Documents such as meeting summaries and field notes were kept to track the progress of the intervention. PLC and coaching activities were grounded in the study's theory of action. Curriculum pacing guides, recorded classroom instruction, and academic screening tools show the study's impact on science at XYZ Elementary.
3. Data are collected according to reliable procedures that document and evaluate the design implementation process and impact.	This study used mixed methods research. The T-STEM survey is a validated instrument for measuring participants' attitudes toward inquiry-based science instruction. Interviews were conducted at the beginning and end of the iterated intervention. Transcripts were coded using a three-tied process (open, axial, and selective). Other metrics included progress monitoring surveys, curriculum documents, and teacher reflections.

Note: Present study's interventions addressed qualities of research-based design development. Adapted from *Design-Based School Improvement: A Practice Guide for Education Leaders*, by R. Mintrop, 2020. Copyright 2020 by Harvard Education Press.

I took steps to increase the validity of this study's design and methodology. Impact data from the needs assessment provided a baseline to which results were compared (Mintrop, 2020). Impact data corroborated the impact of the study. Process data (e.g., interviews, observations, reflections) captured a holistic impression of the study, which was useful for data analysis (Mintrop, 2020). Impact data and process data helped justify my claims about causal relationships between the intervention's treatment and outcomes (Mintrop, 2020).

The construct validity of this study established "agreement between a theoretical concept and specific measure or metric" (Mintrop, 2020, p. 188). Metrics were designed to address research questions and establish that outcomes were a direct result of the intervention. Contingencies arose during the implementation of this study that questions its construct validity. For instance, the COVID-19 Pandemic may have distorted adequate expression of the beliefs and attitudes targeted by the intervention. Therefore, external validity played an important role in determining the degree of change caused by the curriculum-based PLC.

> The external validity of a study is high when the results (assuming high internal validity) can be assumed to occur in real life and the findings extend beyond the study's participants and their situation. (Mintrop, 2020, p. 188)

I carefully planned this study's initial conceptualization and constantly revised its problem definition and framing (Mintrop, 2020). Ongoing evaluation of both impact data and process data and observer-expectancy biases safeguarded this mixed methods research study's validity and trustworthiness.

Ethical Considerations

Researchers of all kinds and from every field must be aware of potential ethical issues that might arise during a study. The Institutional Review Board at Western Kentucky University ensured participation was voluntary and subjects had all the information they needed to make informed decisions (Connelly, 2014). Participants were invited to join the intervention's PLC. There were no consequences for declining the invitation. This mixed methods research study received written permission from the school and district to perform research at XYZ Elementary.

It was imperative that participants fully understood what they were being asked to do in this study. I obtained informed consent from each participant before administering surveys and interviews. Participants who had classroom instruction videotaped also signed a consent form. Data was kept confidential and held anonymously to protect the participants' privacy. Participants were able to withdraw from intervention activities or the study altogether if they so desired. This study reported data and findings clearly via statistics, tables, graphs, and written descriptions.

Limitations

The COVID-19 Pandemic posed several limitations to this study. For example, social distancing guidelines made collaboration and instructional coaching challenging. There were fewer opportunities to meet with participants one-on-one to offer support and provide feedback. I used asynchronous communication to remedy this issue. The intervention utilized digital communication tools (e.g., e-mail, Google Sites) to contact and update participants.

Pandemic learning conditions during this study limited teachers' interaction with students. The school schedule transitioned from virtual to hybrid on multiple occasions.

Hands-on STEM kits were rarely used during in-person instruction because of a policy prohibiting material sharing. Virtual learning posed many challenges beyond the scope of this study. Challenges seen and unseen associated with COVID-19 may have affected implementation fidelity. Participants faced pressing issues related to government mandates, health, and wellness.

Summary of Second Round of Intervention

The sequence of activities for this study's intervention design aimed to change teachers' beliefs toward inquiry-based science instruction. A change in attitudes is the first step in changing practices. The activities in this study "revolved around new inquires, materials, tools, rules, procedures, or resources that fostered opportunities for new practices to take hold" (Mintrop, 2020, p. 133). Interventions for school improvement are designed according to the researcher's needs, contextual factors, and outcomes. Research design and iterations should be in accordance with a theory of action. A theory of action is more than a principle; it is a "practice that underlies the improvement science process" (Hinnant-Crawford, 2020, Chapter 6, para. 2).

The design of this study is centered on the Plan-Do-Study-Act cycle. The intervention's goals, procedures, metrics, and results targeted the setting's problem of practice, which was limited science education in the early grades. "Iterative cycles are essential to learning" (Hinnant-Crawford, 2020, Chapter 8, Section 5, para. 4). The iterated intervention was grounded in a theoretical framework and results from this study's first round of intervention.

Both rounds of the intervention took form as a curriculum-based PLC. The PLC design applied theory on cognitive development, self-efficacy, adult learning, and instructional coaching. The intervention's main objective was to increase teacher self and collective efficacy toward teaching science using an inquiry model. Implementation of the intervention was as important as the results. Refinement of the *process* yielded improvement in other areas. This study used practical measures to monitor variation and observe how change occurs in the larger system (Hinnant-Crawford, 2020). Throughout it all, the focus remained on the user and each participant's efficacy toward inquiry-based science instruction.

Results

Surveys

Pre- and post-intervention surveys were administered to 10 classroom teachers: first grade (n = 2), second grade (n = 3), and third grade (n = 5). The survey consisted of 56 items from the Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) for elementary grades. The T-STEM survey asked participants about their perception of teaching and learning in terms of teaching efficacy, science teaching outcome expectancy beliefs, student technology use, STEM instruction, inquiry-based learning, and STEM career awareness. Fields were the same for pre- and post-T-STEM surveys.

Surveys were delivered using a digital form generated in Qualtrics, an online survey tool. The study used summary statistics to quantitatively examine the mean, minimum, maximum, and standard deviation for each field. Data analysis also calculated each scale's Cronbach alpha reliability coefficient to show how closely related a set of items are as a group (Statistical Coding, n.d.). Tables 21 and 22 display the scale reliability coefficient for the five scales in the pre- and post-intervention surveys. The scale reliability coefficient of scales in both surveys indicated acceptable reliability ($\alpha >$ 0.81).

Table 21

Pre-Survey Cronbach's Alpha

Scale	*Number of Items*	*Average Interitem Covariance*	*Scale Reliability Coefficient*
Science Teaching	15	.1137566	0.8239
Elementary STEM Instruction	15	.2503053	0.8982
Student Technology Use	7	.515873	0.9685
21st Century Learning Attitudes	15	.502963	0.9571
STEM Career Awareness	4	.35	0.8984

Note. Cronbach's alpha for each scale of the T-STEM survey before implementation.

Table 22

Post-Survey Cronbach's Alpha

Scale	*Number of Items*	*Average Interitem Covariance*	*Scale Reliability Coefficient*
Science Teaching	15	.2077249	0.8979
Elementary STEM Instruction	15	.2974603	0.9098
Student Technology Use	7	.2544974	0.8252
21st Century Learning Attitudes	15	.226455	0.8887
STEM Career Awareness	4	.1888889	0.8803

Note. Cronbach's alpha for each T-STEM survey scale at the intervention's conclusion.

Pre-Intervention Survey Results

The T-STEM survey is intended "to measure (a) changes in science educators' confidence and efficacy toward STEM, (b) their attitudes toward 21st-century learning and teacher leadership, (c) the frequency with which they use some instructional practices related to STEM, and (d) the frequency of student technology use" (T-STEM Survey, n.d., para. 3). Appendix P is a table of each field's minimum score, maximum, mean, standard deviation, variance, and count. Table 23 displays the descriptive statistics for each of the survey's five scales.

Table 23

Summary Statistics for Pre-Iterated Intervention Survey

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	10	52	5.21	46	60
Elementary STEM Instruction	10	38.8	7.41	28	51
Student Technology Use	10	17.1	5.11	10	28
21st Century Learning Attitudes	10	40.7	10.87	28	56
STEM Career Awareness	10	12.7	2.50	8	17

Note. Summary statistics for each scale of the pre-iterated intervention T-STEM survey.

Results from the pre-T-STEM survey for the revised intervention confirmed findings from the first round of intervention. Participants' self-efficacy toward STEM education improved, as indicated by the stacked bar chart in Figure 52. There were only a few disagreements with fields in the STEM Teaching Efficacy and Beliefs scale. Data from the next scales (see Figures 52–56) suggested low-frequency levels in terms of STEM instruction, student technology use, and inquiry-based teaching strategies.

Figure 52

Pre-Iterated Intervention Data for STEM Teaching Efficacy and Beliefs Scale

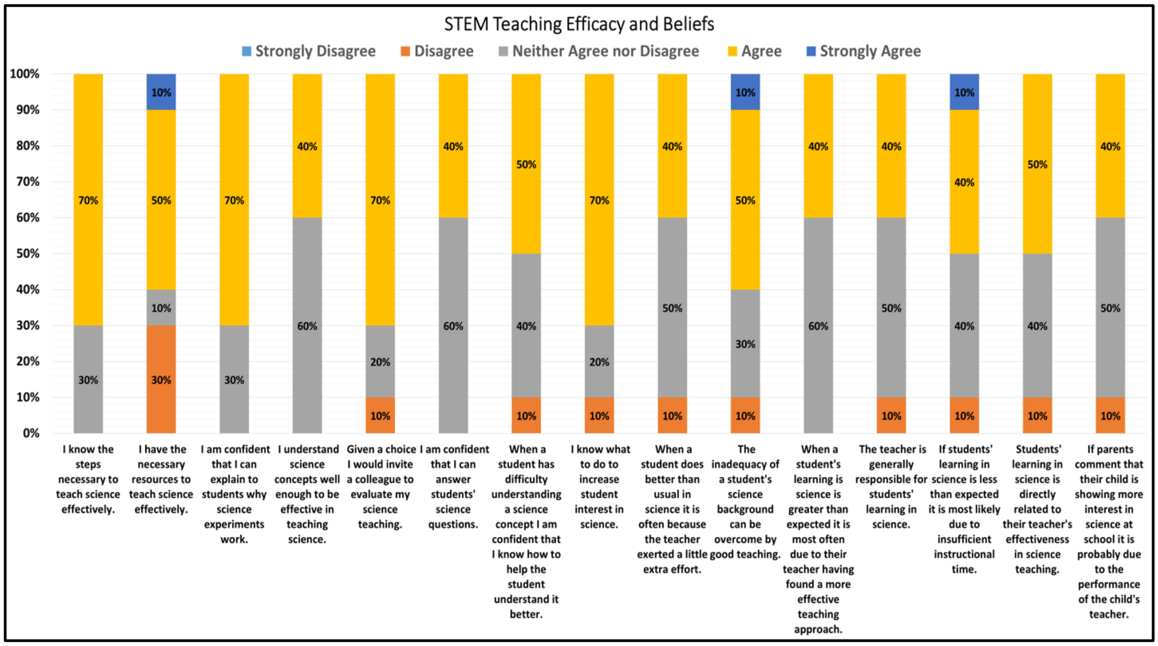


Figure 53

Pre-Iterated Intervention Data for STEM Instruction Scale

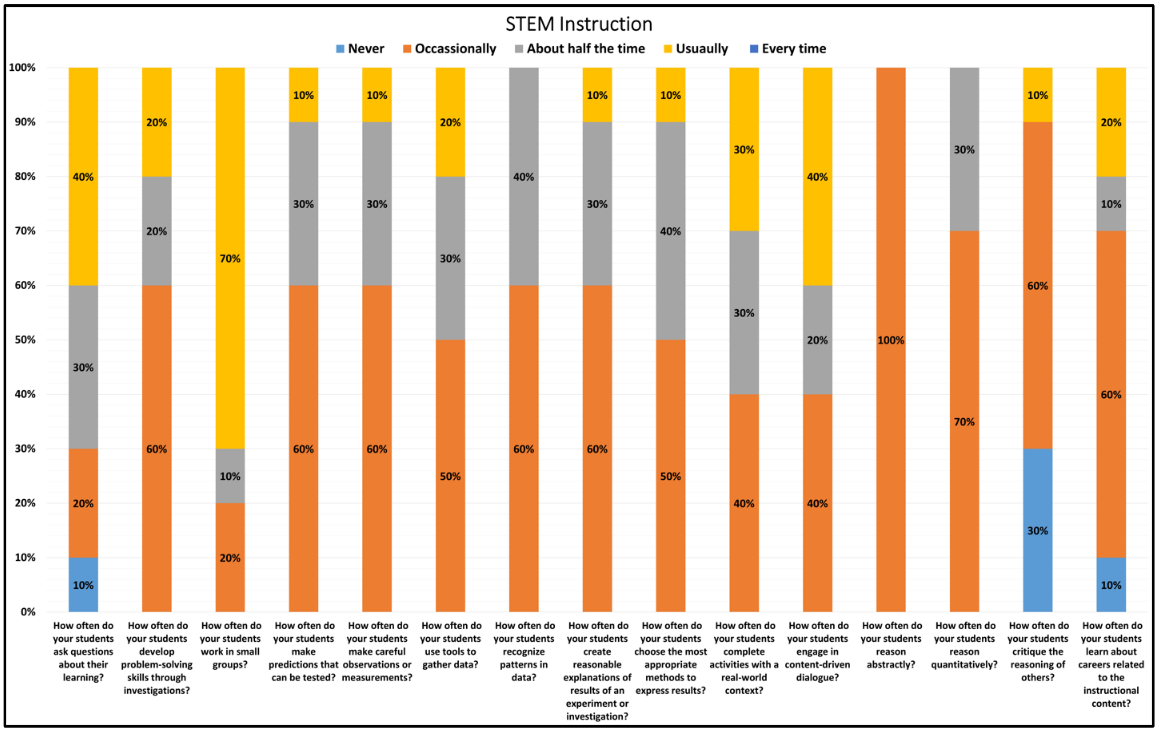


Figure 54

Pre-Iterated Intervention Data for Student Technology Use Scale

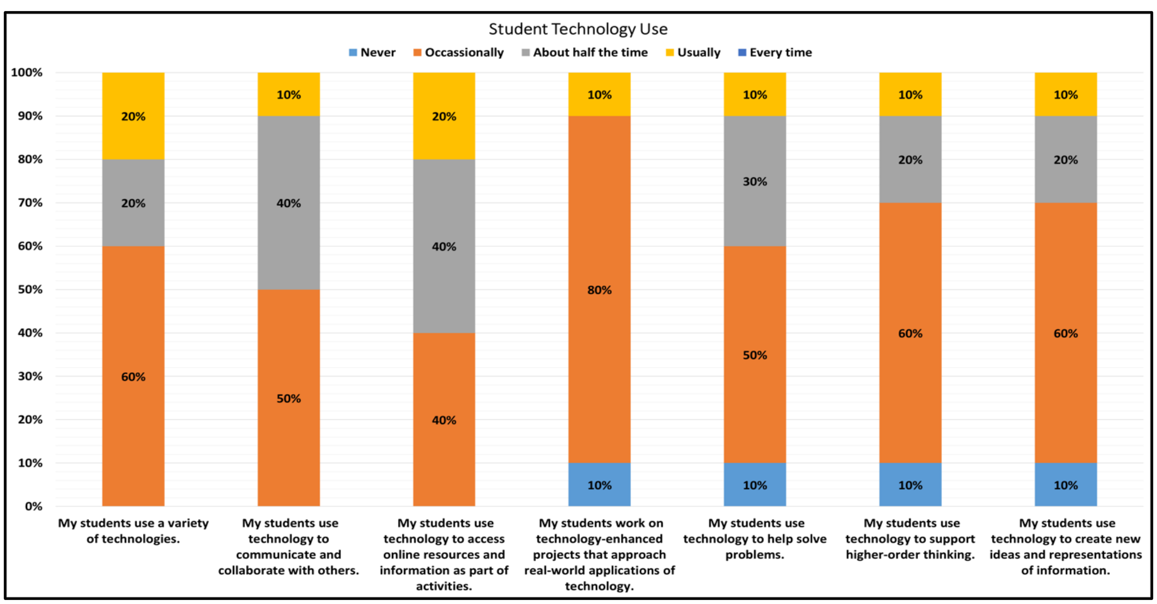


Figure 55

Pre-Iterated Intervention Data for 21st Century Learning Attitudes Scale

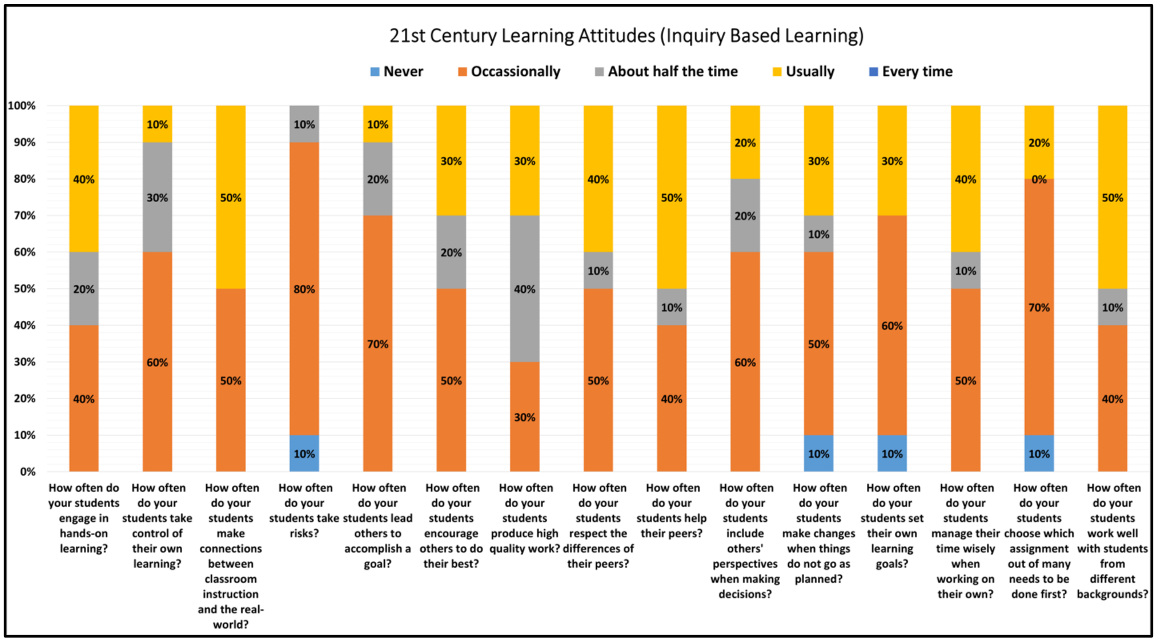
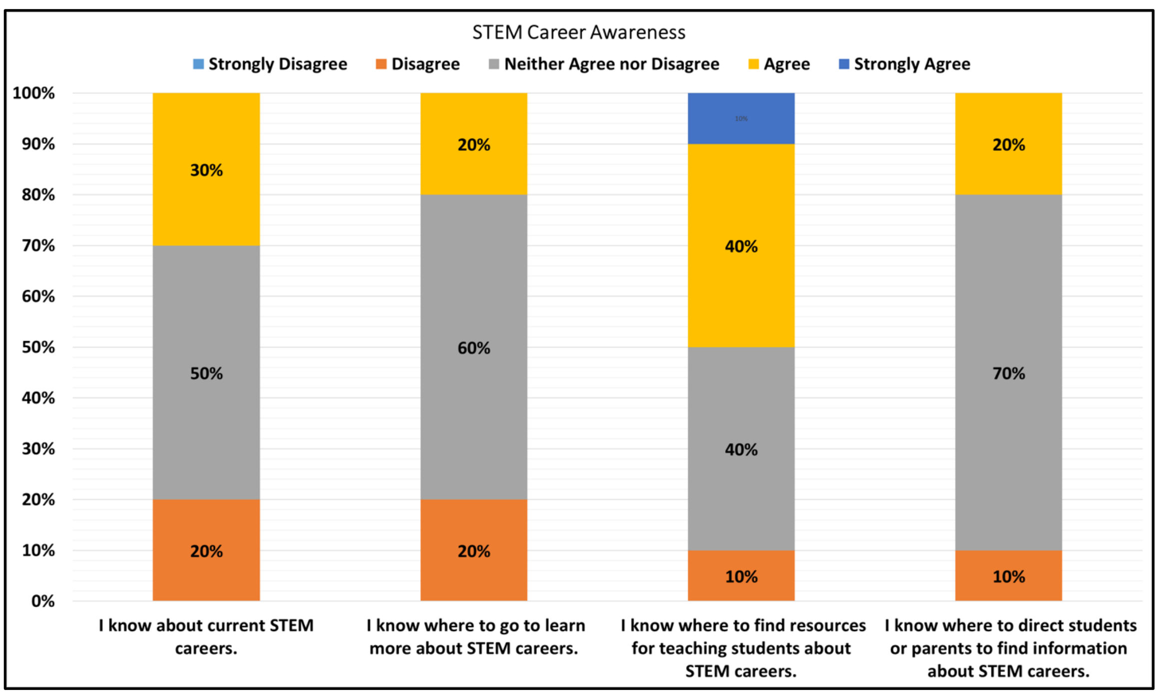


Figure 56

Pre-Iterated Intervention Data for STEM Career Awareness Scale

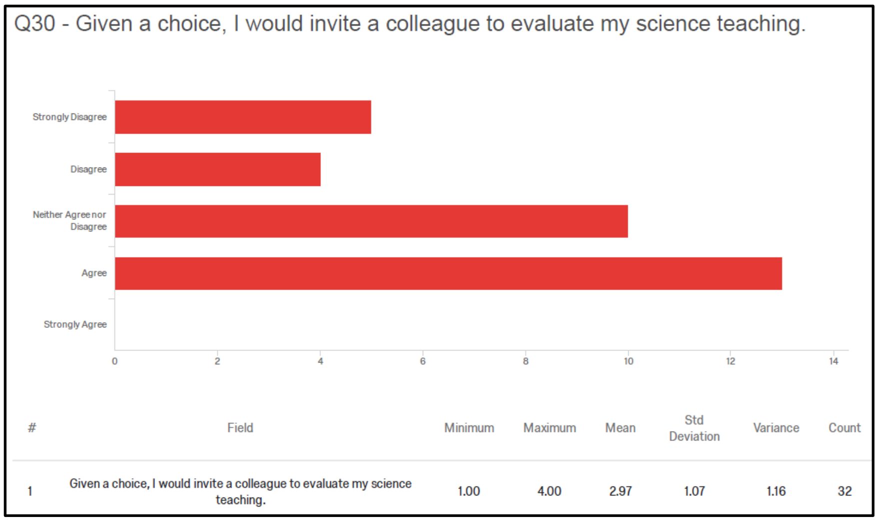


Few fields in the survey scales were marked “never” or “strongly disagree” by respondents. Only one respondent marked “disagree” for eight fields in the scale labeled STEM Teaching Efficacy and Beliefs – Science. Two respondents “disagreed” with the survey item claiming that the teacher is generally responsible for students’ learning in science. Overall, participants’ attitudes toward STEM instruction improved since the needs assessment a year earlier in December 2019. The following two figures illustrate the change in teachers’ attitudes toward science teaching. Panel A in Figure 57 displays a survey item from the needs assessment (*M* = 2.97, *SD* = 1.07). Panel B is the same field for the pre-intervention survey of the revised curriculum. It has a higher average score (*M* = 3.6, *SD* = .66).

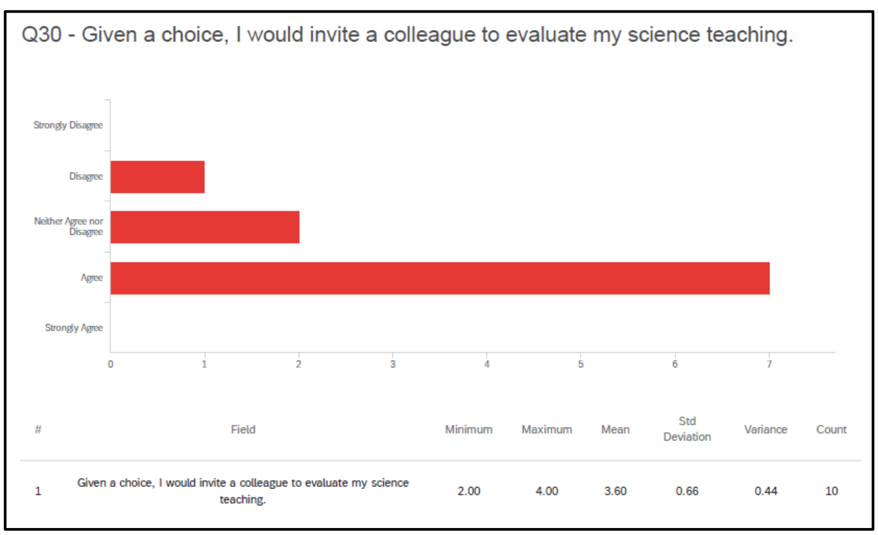
Figure 57

Pre- and Post-Survey Results for Item Q30

A



B



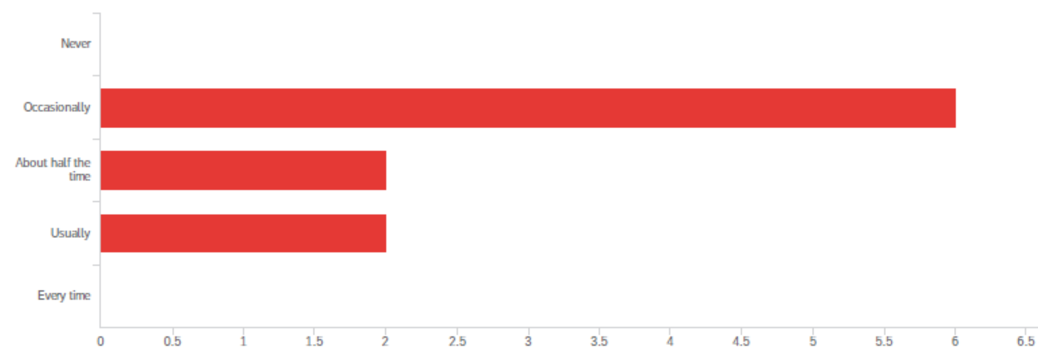
Note. Results indicated gains in participants' efficacy toward science teaching after the first round of intervention.

T-STEM survey scales pertaining to technology and pedagogy had lower average scores than the scales on efficacy and career awareness. Survey results indicated that participants had some experience with STEM teaching practices. Data also suggest that participants "occasionally" utilized STEM instructional practices. For instance, most participants (60%) indicated that their students "occasionally" developed problem-solving skills through the investigation (see Figure 58).

Figure 58

Pre-Iterated Intervention Results for Survey Item Q118

Q118 - How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	2.00	4.00	2.60	0.80	0.64	10

Note. Results for field Q118 from the STEM Instruction survey scale.

Survey data indicated that participants frequently engaged students in small group learning. Small group instruction is often a component of inquiry-based learning. Dolmans and Schmidt (2006) analyzed research students on the cognitive and motivational contributions of small-group sessions to problem-based learning activities. Findings indicated that small group instruction activates prior knowledge, supports causal reasoning, and builds a conceptual understanding of topics (Dolmans & Schmidt, 2006).

Results from the pre-intervention T-STEM survey suggested a disconnect between small group instruction and principles of inquiry-based learning. Data indicated that students rarely make careful observations (M = 2.5, SD = .67) or recognize patterns in data (M = 2.4, SD = .49). This study's professional learning community (PLC) designed activities that encouraged teachers to connect science instruction to enduring themes and multiple disciplines. Group learning presents students opportunities to cultivate science practices. An extensive meta-analysis of 164 studies investigating eight cooperative learning methods found a significant positive impact on student achievement (D. W. Johnson et al., 2000). The revised intervention demonstrated the impact of cooperative learning through a constructivist approach to professional development.

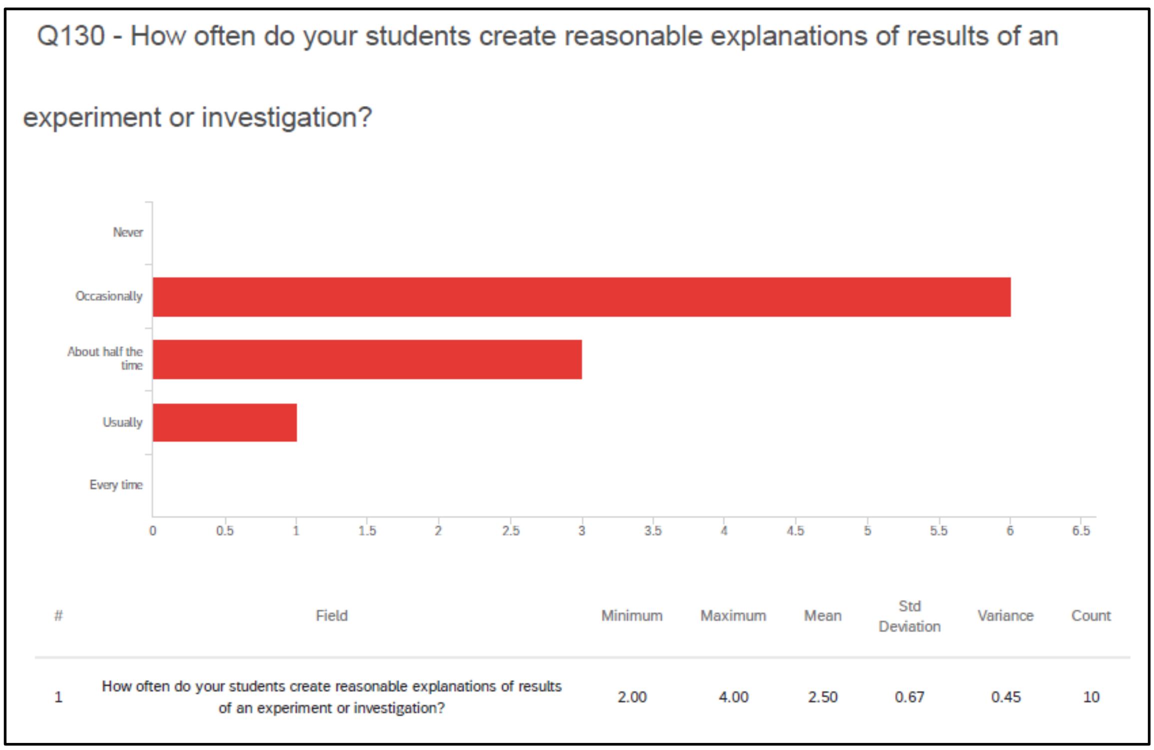
Another change driver of the present study was the adoption of common science standards for each grade level. The science consultant at the Kentucky Department of Education clarified the purpose of summative assessments in science:

> Common assessments are generally designed to provide information in regards to the school curriculum. So the question would be: What information do the teachers want that would tell them what kinds of curricular changes may need to occur? The answer to this question would provide guidance as to the format, remembering that the teachers should act upon that information. (R. McEntyre, personal communication, October 5, 2020)

To act based on assessment results, students' claims and reasoning should be visible and well-articulated. Survey data revealed that participants' students infrequently constructed explanations in science. Ninety percent of respondents indicated that their students created reasonable explanations of investigation results about half of the time or less (see Figure 59). Furthermore, students rarely (if ever) reasoned quantitatively in science class (see Figure 60).

Figure 59

Pre-Iterated Intervention Results for Survey Item Q130



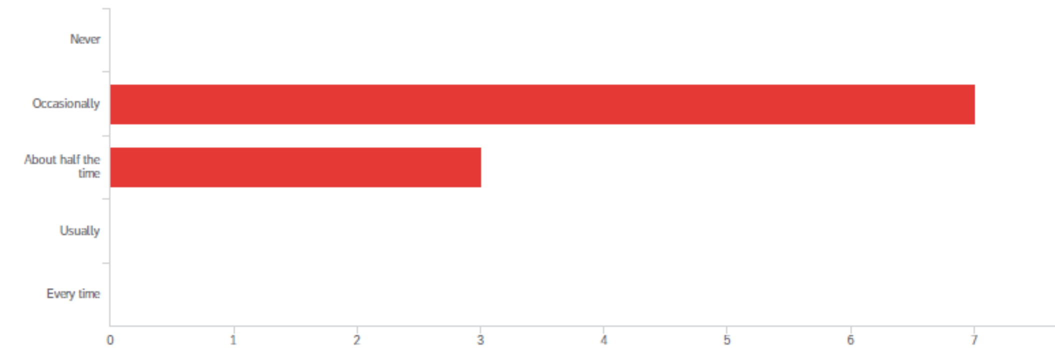
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students create reasonable explanations of results of an experiment or investigation?	2.00	4.00	2.50	0.67	0.45	10

Note. This survey item indicates that participants' students seldom created explanations in science.

Figure 60

Pre-Iterated Intervention Results for Survey Item Q140

Q140 - How often do your students reason quantitatively (i.e., use computations and numerical data to explain answers)?



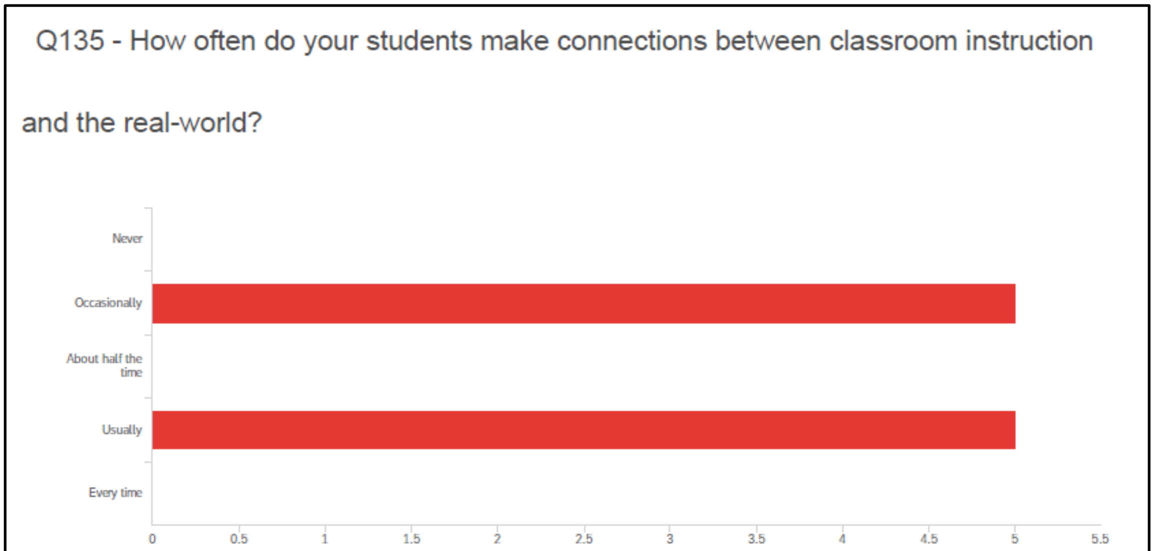
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students reason quantitatively (i.e., use computations and numerical data to explain answers)?	2.00	3.00	2.30	0.46	0.21	10

Note. The maximum for this field was 3.00, indicating students rarely used numerical data in their explanations.

One survey field asked participants how often students make connections between classroom instruction and the real world. This item received mixed results (see Figure 61). Half of the respondents indicated “occasionally,” and the other half marked “usually” for how often students engage in real-world learning. The disparity of results for this field warranted further inquiry. Inauthentic learning in science may account for why students irregularly used various class technologies (M = 2.6, SD = .8) (see Figure 61). Authentic learning helps students develop mental models for thinking creatively and solving problems (Lombardi, 2007). Information technology supports authentic learning by providing students with access to phenomena and bringing abstractions to life (Lombardi, 2007).

Figure 61

Pre-Iterated Intervention Results for Survey Item Q135



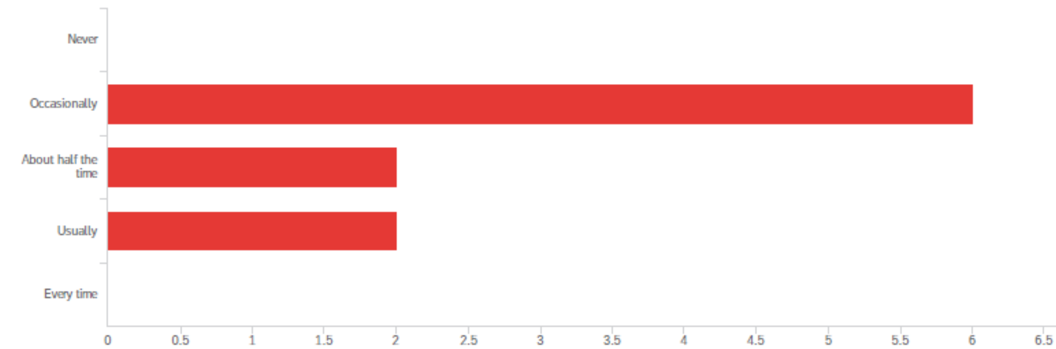
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students make connections between classroom instruction and the real-world?	2.00	4.00	3.00	1.00	1.00	10

Note. A disparity in results of how often students made real-world connections in science class.

Figure 62

Pre-Iterated Intervention Results for Survey Item Q45

Q45 - My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.



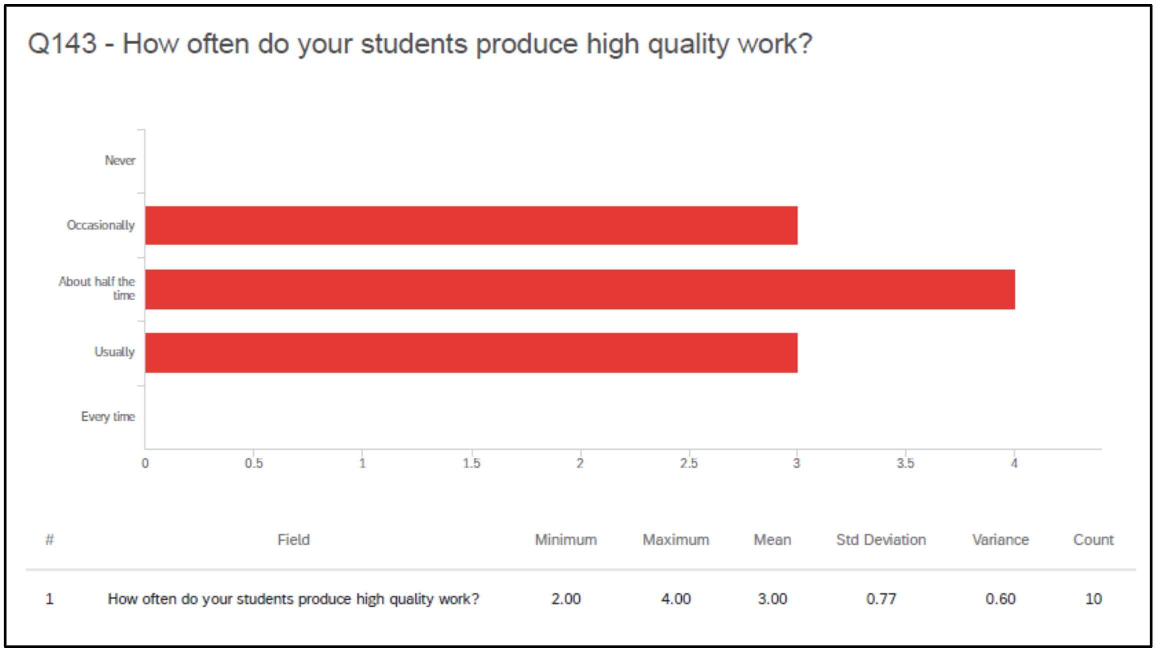
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	2.00	4.00	2.60	0.80	0.64	10

Note. Sixty percent of respondents confirmed that students “occasionally” used various technologies in the classroom.

The application of technologies to investigate real-world topics may improve the quality of student work. “Authentic learning activities culminate in the creation of a whole product, valuable in its own right” (Lombardi, 2007, p. 4). Figure 63 displays an array of responses to the question, “How often do your students produce high-quality work?” (M = 3, SD = .77). This dissertation’s intervention supported participants’ design of relevant, experiential, and standards-based science instruction. Students’ investigation of complex tasks over a sustained period requires a significant investment of time and intellectual resources, leading to improvements in student performance (Lombardi, 2007).

Figure 63

Pre-Iterated Intervention Results for Survey Item Q143



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students produce high quality work?	2.00	4.00	3.00	0.77	0.60	10

Note. Results were mixed for how often students produced high-quality work.

Results of the pre-intervention T-STEM survey were pivotal to the iterated curriculum-based PLC's goals. Quantitative methods allowed for objectivity and accuracy of results. However, informed decisions require a careful examination of quantitative and qualitative data. The next section describes this study's use of empathy interviews as a method to collect qualitative data. Qualitative research methods provide additional details on the local context, which enriches data collection (Johnson & Christensen, 2017).

Pre-Intervention Interview Results

Before the iterated improvement cycle commenced, I interviewed the school's principal, curriculum specialist, and three teachers (one from each grade level).

Interviewees responded to questions regarding their views on collaboration, teacher development, instructional goals, and student mastery. See Appendix Q for semi-structured interview questions. I coded interview transcripts for recurring themes. The themes that were uncovered influenced the intervention's goals and activities. Table 24 lists seven overarching themes determined as a result of general qualitative coding.

Table 24

Main Themes from Qualitative Analysis

Theme #	Theme
1	Shared responsibility
2	Vertical alignment
3	Common curriculum sequence
4	Standards-based resources
5	Student engagement
6	Essential skills and understandings
7	Performance-based assessments

Note. This table lists themes derived from coded interview data.

Many of the emerging themes from qualitative interview data were on topics associated with science pedagogy. Interviewees expressed an interest in common curriculum maps, standards-based resources, instructional strategies, and assessment practices. Participants appreciated quality instruction and were aware that students infrequently experienced inquiry-based science instruction, as indicated by responses to items on the STEM Instruction and 21st Century Learning Attitudes survey scales. The study site’s curriculum specialist asserted a list of skills students should gain from science education:

- critical thinking
- conducting research
- asking questions
- making claims
- providing evidence
- reasoning how information supports claims

Interviewees implied that the inquiry process, hands-on activities, and peer collaboration were key drivers to students’ understanding of science standards.

Another common reference made by participants was students’ interest and curiosity in science content. The school’s principal compared curiosity to phenomena. He explained how curiosity drives student inquiry, similar to how phenomena anchor concepts associated with a science standard. One teacher remarked that students’ love for science makes teaching the subject less challenging. Despite students’ innate curiosity for how things work, teaching science in the primary grades has its challenges.

There are obstacles to implementing a rigorous science curriculum in the early grades. The principal discussed some of the challenges associated with implementing inquiry-based science instruction at XZY Elementary School. He referenced science as an “afterthought” for many teachers because of limited time, isolated lesson planning, and low efficacy toward integrating science standards in reading and math classes. COVID-19 Pandemic learning conditions added to the challenge of teaching science in elementary school. Nevertheless, participants were optimistic that the intervention would uphold students' scientific engagement and scientific curiosity. A third grade teacher commented, "We're finding ways to still get them [students] excited and involved in the learning process."

Interviewees emphasized the benefits of collaboration on the design of science instruction. When I asked a second grade teacher what would support faculty best in developing science instruction, she said, "definitely continuing to work collaboratively with other grade levels." Remarks made by the school administrator posit the impact of this study's curriculum-based PLC. The principal at XYZ Elementary confirmed the benefits of vertically-aligned professional development. He applauded this study's effort to collaborate with science teachers from the district's intermediate school. According to the principal:

> Only ten school districts across the state of Kentucky are set up like us. We've got first, second, and third grade in one building, fourth and fifth in another, and then middle and high school. And so vertical collaboration can be difficult when teachers are not all in the same building.

Iterations to the intervention aimed to support vertical collaboration at the school and district levels. Revisions to the PLC included the integration of Schoology, a learning management system, where participants posted resources and engaged in discussion posts. The addition of a learning management system to the hybrid PLC provided opportunities for participants to collaborate despite the absence of common planning periods.

A major focus of classroom assessment is to increase learning. Classroom assessments should do more than merely measure student achievement. Assessment should resemble an instructional tool that promotes learning (Chappuis & Stiggins, 2002). A theme on assessment emerged as a result of coding qualitative interview data. Participants referenced student performance and communication as ways learners demonstrate mastery of science content. A third grade teacher described student mastery as when “they explain the process of what we’re learning to a friend.” A second grade teacher asserted that student evaluations should consist of performance-based tasks.

Traditionally, summative assessment displays student learning at the end of an instructional unit. On the other hand, performance-based assessment is a process that demonstrates student learning throughout an instructional sequence (Stanley, 2014). The effects of performance-based instruction and assessment cannot be measured by student engagement alone. The assessment of student learning in science should center on a conceptual understanding of essential standards (R. McEntyre, personal communication, September 29, 2020). A viable and coherent curriculum prioritizes the learning standards that are enduring and transferrable (Bloomberg & Pitchford, 2016).

Prioritized standards are often called focus or power standards. According to Ainsworth (2003), power standards are “derived from a systematic and balanced approach to distinguishing which standards are absolutely essential for student success from those that are ‘nice to know.’” (p. 1–2). When a participant was asked what skills students should gain in science class, she replied, “I want them just to gain an understanding of the standards and how they can be followed over into their real life.” During the second round of intervention, participants prioritized a subset of science standards per grade level. The power standards were communicated on curricula maps, and the standards guided the development of formative assessments (Bloomberg & Pitchford, 2016).

The themes that emerged from pre-iterated intervention interview data informed the PLC's primary and secondary drivers. The second round of intervention utilized numerous metrics to monitor the progress of the improvement cycle. I analyzed data from the intervention's metrics in conjunction with the pre-intervention survey and interview data. A comparison of mixed methods data elucidated the degree to which the intervention's change ideas affected teacher efficacy toward STEM instruction.

Progress Monitoring Surveys

Participants completed two progress monitoring (check-in) surveys at different periods of the revised intervention. Progress monitoring tools are short but sound instruments that provide scholar-practitioners with valuable data regarding changes in users' efficacy and outcome expectancies. Progress monitoring, or benchmarking, is an integral part of comprehensive and continuous quality improvement (Ettorchi-Tardy et al., 2012; Overington & Ionita, 2012). School improvement relies heavily on the actions of its users. Progress monitoring surveys emphasized users' pursuit of goals, which is often more desirable than completing the goal (Koo & Fishbach, 2012).

Each check-in survey from the second round of intervention consisted of nine selected-response items. Survey items used a 5-point Likert scale (*strongly disagree* = 1, *agree* = 2, *neither agree nor disagree* = 3, *agree* = 4, *strongly agree* = 5). Findings from a series of studies by Chang et al. (2017) show that "the more that participants thought about their goal progress in quantifiable terms, the more that they monitored their progress, and the easier that they felt monitoring to be" (p. 7).

The revised intervention's progress monitoring surveys contained three open-ended items. These fields remained the same for both check-in surveys. Responses to these questions revealed participants' perceptions of the effects of the intervention. Qualitative and quantitative data collected from the check-in surveys supported the design of subsequent PLC activities. Tables 25 and 26 show how each selected-response item from the progress monitoring surveys aligned to fields on the T-STEM survey.

Table 25

Progress Monitoring Survey #1

Progress Monitoring Field	T-STEM Survey Field(s)
The Science Squad PLC has helped my students use technology to access online resources and information.	My students use technology to access online resources and information as part of activities.
The Science Squad PLC has helped me develop activities where students investigate phenomena.	How often do your students develop problem-solving skills through investigations (e.g., scientific, design, or theoretical investigations)?
The Science Squad PLC has helped my students use technology to think at high levels (e.g., problem-solving).	My students use technology to help solve problems. My students use technology to support higher-order thinking, e.g., analysis, synthesis, and evaluation of ideas and information.
The Science Squad PLC has helped my science instruction engage students in hands-on learning.	How often do your students engage in hands-on learning?
The Science Squad PLC has helped my students use evidence to support claims.	How often do your students create reasonable explanations of the results of an experiment or investigation?
The Science Squad PLC has helped my students see patterns in their learning.	How often do your students recognize patterns in data? How often do your students make predictions that can be tested? How often do your students make careful observations or measurements?

Table 25 (continued)

The Science Squad PLC has helped me find resources for teaching students about STEM careers.	I know where to find resources for teaching students about STEM careers.
The Science Squad PLC has helped me set instructional goals.	How often do your students set their own learning goals?
The Science Squad PLC has helped me monitor student learning in science.	How often do your students produce high-quality work?
Open-Ended Items on the Progress Monitoring Survey	
How has the Science Squad PLC helped you as a science teacher?	
What should the Science Squad PLC do differently to help you design, implement, and/or evaluate science instruction?	
What other comments do you have about the Science Squad PLC?	

Note. Progress monitoring survey items align with fields on the intervention's pre-T-STEM survey.

Tables 26

Progress Monitoring Survey #2

Progress Monitoring Field	T-STEM Field
The Science Squad PLC has helped my students make real-world connections.	How often do your students complete activities with a real-world context? How often do your students make connections between classroom instruction and the real-world?
The Science Squad PLC has helped me create activities where students collect data.	How often do your students use tools to gather data?
The Science Squad PLC has helped my students make claims about phenomena.	How often do your students critique the reasoning of others?
The Science Squad PLC has helped me integrate different types of technology during science instruction.	My students use a variety of technologies.

Table 26 (continued)

The Science Squad PLC has helped my students make decisions based on class discussions.	How often do your students include others' perspectives when making decisions?
The Science Squad PLC has supported my implementation of small group work in science.	How often do your students work in small groups? How often do your students work well with students from different backgrounds?
The Science Squad PLC has helped me increase student interest in science.	I know what to do to increase student interest in science.
The Science Squad PLC has helped me implement experiments with students.	I am confident that I can explain to students why science experiments work.
The Science Squad PLC has helped me reflect on my science instruction.	When a student's learning in science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.

Open-Ended Items on the Progress Monitoring Survey
How has the Science Squad PLC helped you as a science teacher?
What should the Science Squad PLC do differently to help you design, implement, and/or evaluate science instruction?
What other comments do you have about the Science Squad PLC?

Note. Progress monitoring survey items align with fields on the intervention's pre-T-STEM survey.

Data from the progress monitoring surveys revealed the intervention's effect on participants' attitudes and practices toward teaching science. The mean score for each field rounds to the number four, which signified high levels of agreement on statements about the PLC's impact.

First Progress Monitoring Survey Results

The average of the mean scores for the first check-in (progress monitoring) survey was 3.9, which suggested a general level of agreement for all fields. However, survey results also indicated that participants needed extra support in specific areas. Table 27 presents the summary statistics for the quantitative items on the revised intervention's first check-in survey.

Table 27

Summary Statistics for Check-In Survey #1

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
The Science Squad PLC has helped my students use technology to access online resources and information.	10	4	.77	3	5
The Science Squad PLC has helped me develop activities where students investigate phenomena.	10	4.2	.6	3	3
The Science Squad PLC has helped my students use technology to think at high levels (e.g., problem-solving).	10	3.9	.7	3	5
The Science Squad PLC has helped my science instruction engage students in hands-on learning.	10	4	.89	3	5
The Science Squad PLC has helped my students use evidence to support claims.	10	3.5	.5	3	4
The Science Squad PLC had helped my students see patterns in their learning.	10	3.5	.5	3	4
The Science Squad PLC has helped me find resources for	10	3.9	.54	3	5

Table 27 (continued)

teaching students about STEM careers.					
The Science Squad PLC has helped me set instructional goals.	10	4.1	.7	3	5
The Science Squad PLC has helped me monitor student learning in science.	10	3.9	.83	3	5

Note. Summary statistics for each item on the first progress monitoring survey.

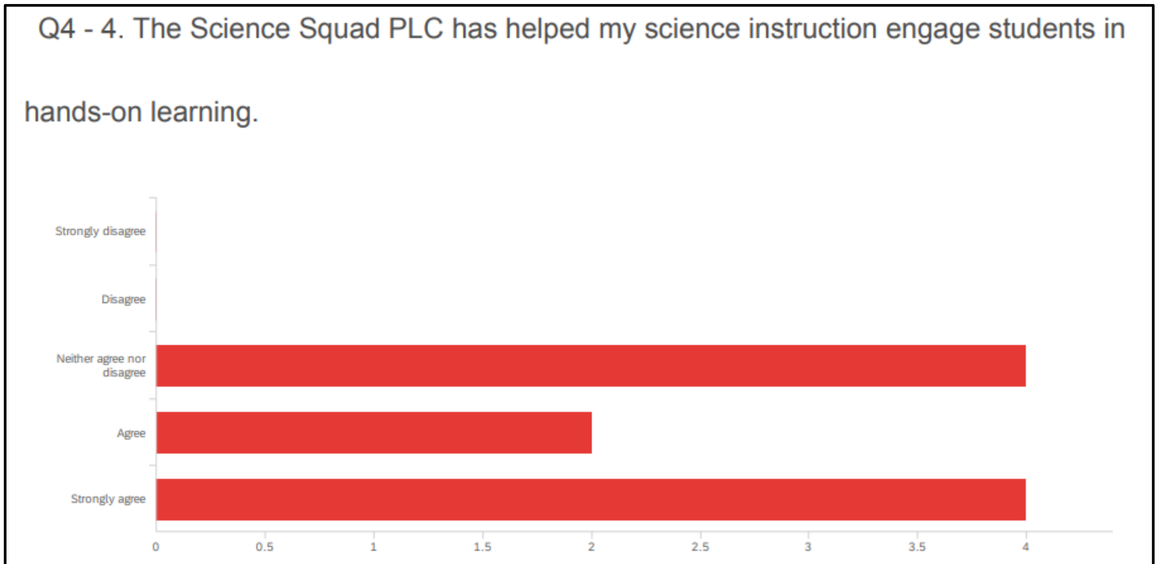
The first check-in survey of the revised intervention received high mean scores for all items. One item with an exceptionally high average (*M* = 4.2, *SD* = .6) asked participants how the PLC helped them develop activities where students investigate phenomena. Many PLC activities leading up to this benchmarking instrument focused on using phenomena to anchor students' conceptual understanding of the Next Generation Science Standards (NGSS). The Kentucky Department of Education science consultant demonstrated to PLC members how to connect phenomena with the NGSS performance expectations. Anchor phenomena provoke student inquiries and allow students to use a broad sequence of science and engineering practices to learn science through first-hand or second-hand investigations (Next Generation Science, n.d.-c).

Participants indicated high levels of agreement with survey fields on student use of technology. This intervention was conducted during the COVID-19 Pandemic learning conditions. Science was taught in a hybrid format, which combined in-person teaching with online learning. On average, participants "agreed" with the field, suggesting that the PLC improved students' use of technology to access resources (*M* = 4, *SD* = .77). When presented with the field, “The Science Squad PLC has helped my students use technology to think at high levels (e.g., problem-solving),” 70% either “agreed” or “strongly agreed.” Curricular factors strongly influenced technology integration in science teaching (ChanLin et al., 2006). The goals of the PLC focused on students’ understanding of science standards because of experiential learning. The key issue surrounding the use of technology in science teaching was to improve student learning (ChanLin et al. 2006).

The majority of participants (60%) responded favorably (*M* = 4, *SD* = .89) to the field, “The Science Squad PLC has helped my science instruction engage students in hands-on learning” (see Figure 64). Despite the high percentage of participants who “strongly agreed” for this field, four people “neither agreed nor disagreed.” Hands-on learning is a pillar of the constructivist approach to teaching (Bada & Olusegun, 2015; Bevevino et al.; Seimears et al., 2012; 1999). Every science classroom should engage learners in investigative processes. The intervention employed transformational coaching to clarify participants’ perceptions of inquiry-based teaching. The transformational coaching model helped the organization better understand some of the challenges associated with hands-on science pedagogy. As a result, subsequent PLC activities demonstrated how to use questioning techniques, data collection tools, and small group strategies to make instruction interactive.

Figure 64

Results for Progress Monitoring Survey Item Q4



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	4. The Science Squad PLC has helped my science instruction engage students in hands-on learning.	3.00	5.00	4.00	0.89	0.80	10

Note. The intervention supported teachers' use of hands-on learning activities.

The lowest mean scores on the progress monitoring survey were for fields about students' use of evidence to support claims (*M* = 3.5, *SD* = .5) and students' ability to see patterns in their learning (*M* = 3.5, *SD* = .5). The results were not surprising, as the intervention had not yet targeted these areas. I used quantitative data to plan PLC activities and instructional coaching on important topics. I co-taught science lessons with participants. Co-teaching was intended to support students' ability to make claims and see patterns. Insights made on claim-evidence-reasoning and how to embed patterns throughout the curriculum were shared at PLC meetings. Instead of telling PLC members how to support student learning in these areas, participants constructed their own understanding through modeling, experimentation, and reflection.

Responses to the open-ended items were as equally enlightening. There were several positive comments on digital resources, the use of phenomena, and the inquiry process. For instance, one respondent remarked, “It was very nice to be able to review the 5E Model of teaching.” Another person stated, “The Science Squad PLC has helped me as a science teacher to plan engaging, in-depth lessons for students that they can connect to in order to understand the curriculum.” One way to connect topics to standards is through the integration of phenomena. One participant said that the meeting with the science consultant from the Kentucky Department of Education caused her to “think in terms of engaging phenomenon that will spark interest in my students as we enter a new unit/lesson.”

Some comments expressed concerns and challenges of the PLC. At XYZ Elementary School, designated teachers from each grade level are responsible for planning science. One participant remarked, “With how things are being planned right now, it is not benefiting me since I am not planning the science lessons.” Perhaps, the school leadership team needs to clarify teachers’ roles and responsibilities when it comes to teaching different subjects. Participants also expressed an interest in more time planning lessons with grade-level team members. Teachers desired more time to plan standards-based lessons that are part of a cohesive unit rather than stand-alone and disconnected instructional activities. Hence, I concentrated PLC work on lesson planning, delivery techniques, and formative assessment practices.

Second Progress Monitoring Survey Results

The second check-in survey had a high overall response rate (M = 4.1), suggesting a general level of agreement for all fields. Each survey item had a maximum of 5, which on the Likert-scale denotes "strongly agree." Table 28 presents the summary statistics for the quantitative items on the intervention's second check-in survey.

Table 28

Summary Statistics for Check-In Survey #2

Variable	*Obs*	*M*	*SD*	*Min*	*Max*
The Science Squad PLC has helped my students make real-world connections.	9	4.22	.42	4	5
The Science Squad PLC has helped me create activities where students collect data.	8	3.75	.66	3	5
The Science Squad PLC has helped my students make claims about phenomena.	9	4.22	.42	4	5
The Science Squad PLC has helped me integrate different types of technology during science instruction.	8	4.25	.43	4	5
The Science Squad PLC has helped my students make decisions based on class discussions.	8	3.88	.6	3	5
The Science Squad PLC has supported my implementation of small group work in science.	9	3.78	.79	3	5
The Science Squad PLC has helped me increase student interest in science.	9	4.22	.42	4	5
The Science Squad PLC has helped me implement experiments with students.	9	3.78	.92	2	5

Table 28 (continued)

The Science Squad PLC has helped me reflect on my science instruction.	9	4.22	.42	4	5

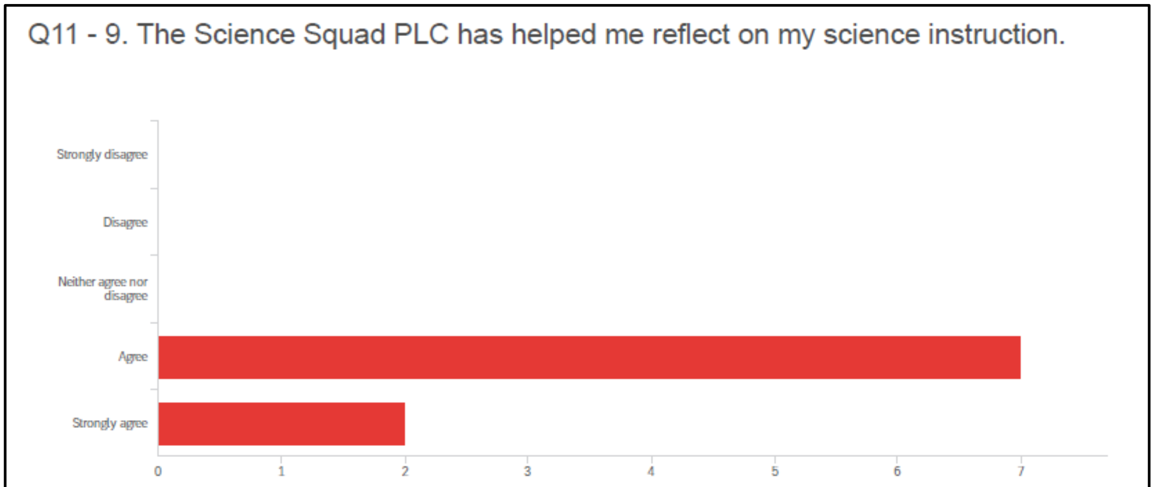
Note. This data set provides the summary statistics for each item on the second progress monitoring survey.

The second progress monitoring survey was used to measure the intervention's impact and adjust PLC activities accordingly. The high means suggested that the intervention's implementation was effective. Overall, participants agreed with statements about the PLC's impact on inquiry-based science teaching.

Every participant either "agreed" or "strongly agreed" with survey items that addressed real-world learning (item #1), student claims (item #3), technology integration (item #4), student interest in science (item # 7), and reflective practice (item # 9). Survey item 9 asked for participants' level of agreement for the following statement, "The Science Squad PLC has helped me reflect on my science instruction." See Figure 65 for the field's results. This question addressed a significant concept of social cognitive theory—self-regulation. The intervention emphasized self-reflection and self-regulation in numerous ways. For example, participants used the Next Generation Science Standards (NGSS) lesson screening tool to evaluate their instructional plans. The NGSS assessment task screener guided participants' analysis of their video-recorded science instruction.

Figure 65

Results for Progress Monitoring Survey Item Q11



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	9. The Science Squad PLC has helped me reflect on my science instruction.	4.00	5.00	4.22	0.42	0.17	9

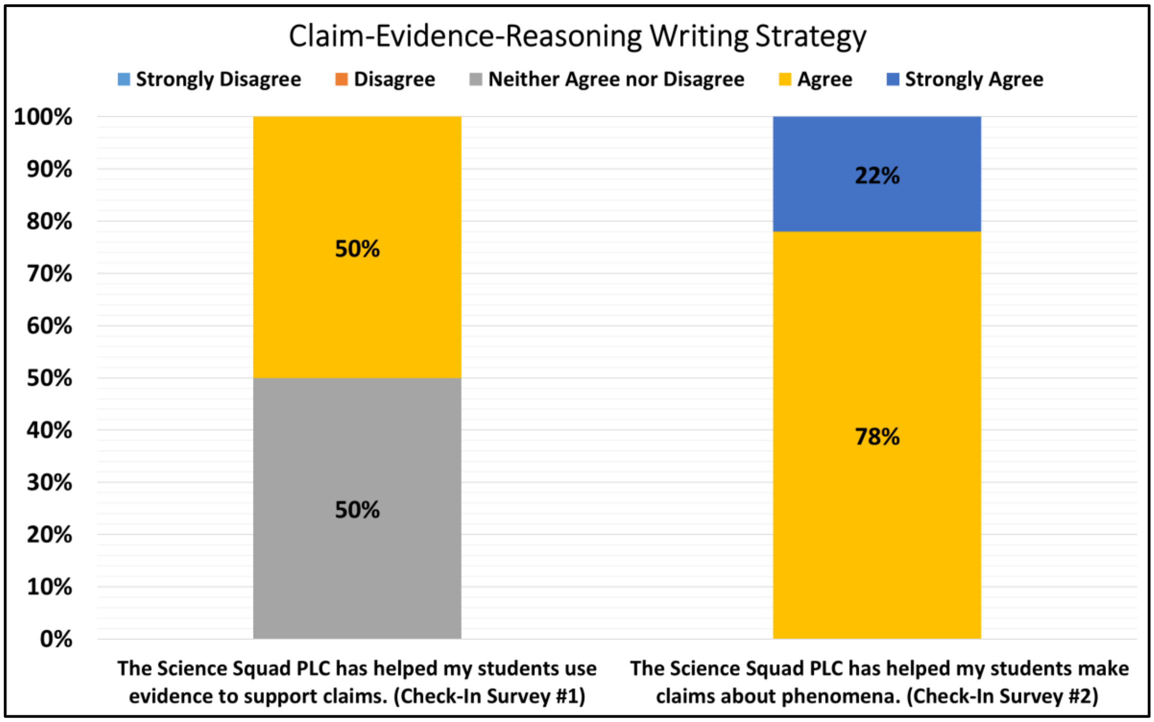
Note. Results for Q11 on the second check-in survey suggest the intervention promoted reflective practices.

The first progress-monitoring survey indicated the intervention's need to address students' ability to support scientific claims. Item five on the first check-in survey stated, "The Science Squad PLC has helped my students use evidence to support claims" (*M* = 3.5, *SD* = .5). Fifty percent of respondents marked "neither agree nor disagree" for this field. After the first progress monitoring survey, the intervention incorporated activities addressing Claim-Evidence-Reasoning writing strategy. Modifications to PLC activities based on survey results proved beneficial. Item three on the second check-in survey asks for participants' level of agreement regarding the PLC's influence on students' claims (*M* = 4.22, *SD* = .42). Seventy-eight percent "agreed" and 22% "strongly agreed" that the

Science Squad PLC helped students make claims about phenomena. Figure 66 provides a stacked bar graph of the field from each progress monitoring survey addressing the Claim-Evidence-Reasoning writing strategy.

Figure 66

Pre- and Post-Progress Monitoring Survey Data for Claim-Evidence-Reasoning

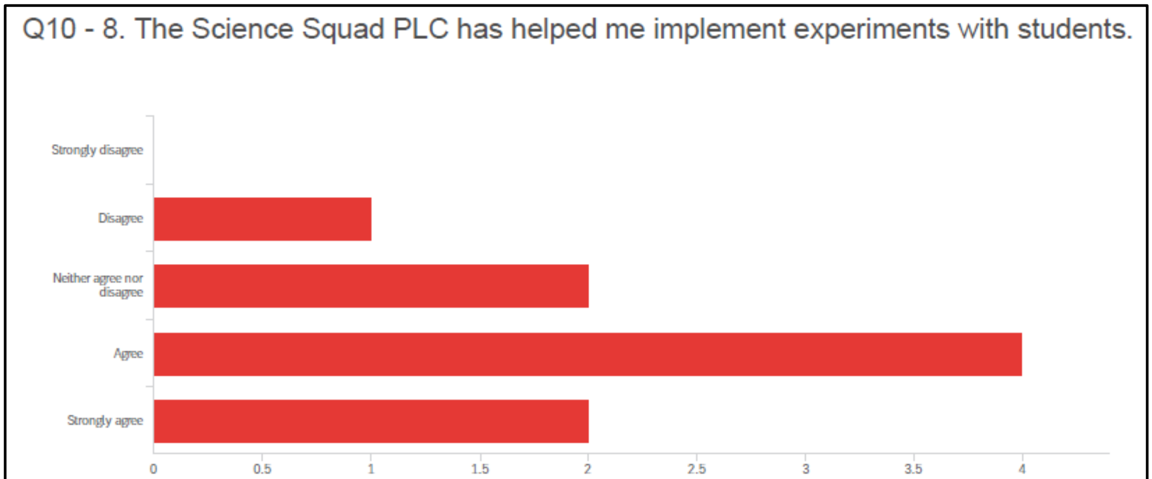


Note. Number of participants who agreed that the PLC helped students craft claims increased from the first progress monitoring survey.

There was one field from the second progress monitoring survey that received a wide array of responses. Sentiments concerning the intervention's influence on science experiments ranged from "disagree" to "strongly agree." See Figure 67 for a graph of the results. The different selected responses indicated that teachers needed more support in designing and implementing scientific investigations. Consequently, subsequent activities of the intervention's PLC focused on the "Explore" phase of the 5E Inquiry-Based Instructional Model.

Figure 67

Results for Progress Monitoring Survey Item Q10



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	8. The Science Squad PLC has helped me implement experiments with students.	2.00	5.00	3.78	0.92	0.84	9

Note. Results for the check-in survey posit the intervention's effect on classroom experiments.

The second progress monitoring survey, like the first version, contained open response questions. To strengthen the trustworthiness of the progress monitoring instrument, participants' identities remained anonymous. There were no apparent identifiers, such as demographics and teaching position. Anonymity protects participants' privacy (Wiles et al., 2006). Research participants' anonymity promotes honesty, but some research suggests that complete anonymity may compromise measurement accuracy rather than improve it (Lelkes et al., 2012). Participants' comments to the first open-response item are exhibited in Table 29.

Table 29

Participants' Comments to Open-Response Item 10 on Check-In Survey #2

How has the Science Squad PLC helped you as a science teacher?
The science squad helped bring focus and importance to our science instruction in the primary grades. We set goals as a PLC, and that helps drive our work. We have analyzed our own work and others' work, as well as explored and organized a wealth of resources. We have curriculum maps and pacing that guide our instruction as a grade level across a common resource [*STEMscopes*]. We also have access to STEM activities and *STEMscopes* science experiment tools.
The PLC has helped me think critically and creatively about my science instruction and how it aligns to the standards as well as peaks student interest.
It has helped me find different resources to engage my students in science content.
It has helped me explore new avenues of teaching to integrate into my science lessons for my virtual students
It has given me lots of resources that I can use in my science instruction.
The Science Squad PLC has helped me to think more critically about science in order to engage students.
The Science Squad PLC has done an amazing job to help me design, implement, and evaluate my science instruction.

Note. Participants' comments highlight the intervention's impact on teacher professional development.

The second open-ended survey item asked participants to share their thoughts on how the PLC could further support their science teaching. Only one of the 10 participants responded. The teacher commented, "Common science assessments by grade level." During this same period, select participants were preparing to implement the NGSS-aligned performance assessments. Results of progress monitoring surveys were satisfactory. Whether data appears favorable or otherwise, improvement plans must continue. This study used data from check-in surveys, observations, coaching sessions, field notes, and other artifacts to focus its attention on areas that would most likely increase teacher efficacy.

Documents and Artifacts

Several documents comprised a large portion of this study's qualitative research. According to Merriam (1988, as cited in Bowen, 2009), "Documents of all types can help the researcher uncover meaning, develop understanding, and discover insights relevant to the research problem" (p. 118). Artifacts from the revised intervention included SMART goals, curriculum maps, pacing guides, lesson plan screeners, performance task screening tools, and meeting summaries.

Analysis of these sources served several functions. For instance, documentary material indicated the conditions that impinged upon teachers' attitudes and efficacy toward science teaching. Additionally, documents and artifacts provided a means of tracking change, advised the design of PLC activities, and corroborated evidence from interviews and surveys (Bowen, 2009).

SMART Goals

> A common trait of teacher teams that demonstrate a sense of urgency is that they are learners themselves, constantly in search of a better way, but unlike their colleagues, they reject a shotgun approach to a laundry list of goals in favor of a laser like focus on a limited number of goals. (Many et al., 2019, p. 85).

A root of the collaborative practice found in this intervention's PLC was goal setting. Members of this study's PLC converted shared priorities into SMART goals (see Table 30). The revised intervention intentionally employed technical approaches to learning to maximize the collective inquiry process. Meaningful conversations, ongoing feedback, peer observations, hands-on activities, and reflective practice helped the team reach goals.

Table 30

The Curriculum-Based PLC's SMART Goals

Priority Issue	SMART Goal	Result
Use phenomena to anchor science lessons, spark student interest, and foster a sense of curiosity and wonder in our students.	The Science Squad will create a HyperDoc of phenomena for each science standard that will anchor students' interest in learning goals and sustain students' motivation to investigate responses to compelling questions.	Science phenomena for the NGSS and phenomenon-based learning resources were curated and stored on the PLC's Google Site.
Integrate ELA standards into the science curriculum and embed science topics during core reading class.	The Science Squad will compile a collection of literacy strategies for students to use when engaging in science sources (i.e., texts, graphs, observations, computations).	Literacy strategies were saved and organized in a digital folder (Wakelet). The Wakelet URL was embedded in the PLC's learning management system page.
Administer alternative forms of assessments to gain insights into students' progress on achieving the NGSS performance expectations.	Science Squad members will develop at least one common assessment for each grade level during the first semester of the school year.	A common assessment was developed and administered for second and third grades. The summative assessment was essentially a performance task, modified from a Through Course Task

Table 30 (continued)

		available on KDE's website.
Model best practices of three-dimensional learning so that students can communicate their understanding of a phenomenon using data, information, and an explanation of the underlying science concept that produced the evidence.	The Science Squad will script one mini-lesson for each grade level that incorporates compelling and supporting questions to prompt the investigation of claims that are supported with evidence and explanations (C-E-R: Claim, Evidence, Reasoning).	The NGSS-aligned instructional plans were developed for each grade level. Each lesson adhered to criteria agreed upon by PLC members. Lesson plans were stored and made accessible in Google Drive Folders.

Note. Agreed upon priorities by participants were crafted into SMART objectives.

SMART goals were closely monitored and pursued, which evoked in participants a "goal-conscious state of mind" (Conzemius & O'Neill, 2009, p. 41). SMART goals were reviewed and monitored at each PLC meeting. Over time, SMART objectives became the norm of the team's culture. "Routines help promote more promote more productive team meetings" (Many et al., 2019, p. 60). Participants' devotion to meeting goals demonstrated a certain degree of commitment and, thus, confidence.

SMART goals prioritized efforts and resources, which influenced participant behavior (Conzemius & O'Neill, 2009). Participants' immersion in purposeful work around inquiry-based STEM increased motivation and improved collective efficacy. Collective efficacy roused collaboration and nurtured participants' intrinsic belief that they can accomplish goals (Many et al., 2019).

Observations made during PLC meetings and coaching sessions validated participants' focus on the *process* of improvement rather than the results themselves (see

Appendix O for a dashboard of PCL task summaries). Adaptive leadership theory helped participants navigate and respond to challenges caused by COVID-19. PLC members practiced behavioral flexibility when unexpected changes occurred to the schedule, learning environment, and other school policies. SMART goals did more for the team than prioritize tasks; they developed participants' leadership capacity. According to Yukl and Mahsud (2010):

> To be effective, a leader must find an appropriate balance for objectives that involve difficult tradeoffs, such as reliability and efficiency versus the need for innovative adaptation to emerging threats and opportunities. (p. 82)

Participants found a balance between goals and contingencies surrounding the COVID-19 Pandemic. Instead of developing unique common assessments, participants modified performance tasks from the Kentucky Department of Education's Science Through Course Task bank. Rather than use valuable meeting time to review instructional resources, participants decided to add materials to the shared collection as they emerged. SMART goals were strategically aligned to school-wide goals (e.g., assessments, instruction, resources). The intervention's focus on specific, measurable, attainable, results-based, and time-bound school improvement trigged other important objectives. One such objective was the revision and reformatting of grade-level science curriculum maps.

Curriculum Maps

Engaging in the curriculum design process influenced participatory decision-making and teacher efficacy (Bauml, 2015). Curriculum is comprised of two overarching concepts: scope and sequence. Hlebowitsh (2010) defines these concepts in the *Encyclopedia of Curriculum Studies*:

> *Scope* specifically refers to the breadth of the curriculum the organizing threads that constitute the skills and content that teachers are expected to include in their instruction. *Sequence* refers to how these skills and subject matter should be ordered. (p. 771)

Participants formulated a vision for science curriculum documents by reviewing maps and pacing guides in place prior to the intervention. The curriculum mapping process focused on science education's scope, while pacing guides targeted the sequence of instructional procedures and assessments.

The first round of intervention attempted to refine grade-level curriculum maps for science. During the first curriculum-based PLC, participants unwrapped and prioritized the *STEMscopes* curriculum. *STEMscopes* designs instruction around the 5E Inquiry-Based Instructional Model to support the Next Generation Science Standards (NGSS). The work of participants from both rounds of intervention improved grade-level curriculum documents. Updated curriculum maps aligned with *STEMscopes'* standards-based bundles (units) and scopes (lessons). Figure 68 displays a portion of the second grade curriculum map for science before this study. The original curriculum map listed standards for each unit but provided little other information.

Figure 68

Sample Science Curriculum Map Before This Study

Timeline	Topic	Standard	Notes/Thoughts for Unit Planning
Weeks 3–10 (8 weeks)	**Structure and Properties of Matter**	2-PS1-1 Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties.	
		2-PS1-2 Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.	
		2-PS1-3 Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object.	LEGOs, tangrams
		2-PS1-4 Construct an argument with evidence that some changes caused by heating or cooling can be reversed and some cannot.	

Note. Sample of the second grade science curriculum map prior to this study.

The newly refined science curriculum map for second grade at XYZ Elementary addressed inquiry-based instruction principles (see Figure 69). For instance, each unit was accompanied by a compelling question. Compelling questions reflect an enduring topic or concept. The scopes (i.e., lessons) in each unit bundle included supporting questions. Supporting questions organize disciplinary content. Questions are critical to the 5E Inquiry Model. “Good questions can be difficult to create, but they can also help teachers and their students focus their inquiries and produce powerful learning outcomes” (Grant, 2013). Citing questions on the curriculum map kept teachers mindful of questioning during the inquiry process.

Figure 69

Sample Science Curriculum Map Generated During the Revised Intervention

Date	STEMscopes Unit	Scopes	Clarification	Common Core Standards	Learning Targets & Compelling Questions	Critical Vocabulary
9/14-10/2	**Bundle 1 Organisms-Needs and Interactions** *(What do plants and animals need to survive, grow, and reproduce?)*	**What Plants Need** *(What do plants need to grow?)*	*Assessment Boundary: Assessment is limited to testing one variable at a time.*	**2-LS2-1** Plan and conduct an investigation to determine if plants need sunlight and water to grow. *What do plants need to grow?*	I can plan and conduct an investigation to determine if plants need sunlight and water to grow.	plan, conduct, investigation, plants, sunlight, water, grow
		Animal and Plant Dependence *(I know some animals depend on plants, but do plants depend on animals?)*	**Performance Task**	**2-LS2-2** Develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants. *I know some animals depend on plants, but do plants depend on animals?*	I can develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants.	simple, model, mimic, function, seeds, disperse, pollinate
				K-2-ETS1-1 Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.	I can ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.	question, observation, information, situation, change, simple, problem, solved, development, improved, object, tool
				K-2-ETS1-2 Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.	I can develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.	develop, sketch, drawing, physical model, illustrate, shape, object, function, solve, problem
				K-2-ETS1-3 Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.	I can analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.	analyze, data, object, designed, solve, compare, strength, weakness, performs

Note. Sample second grade science curriculum map created during revised intervention.

Revisions to the curriculum map included clarifying statements for specific standards, learning targets, and critical vocabulary. A focal area of curriculum mapping is the "measures used to determine whether the student has achieved the expected learning outcomes" (Harden, 2001, p. 123). This study's revised curriculum map provided general information about assessments in a column labeled "Clarification." The new addition emphasized an important area in curriculum mapping: *assessment*. Effective curriculum maps link assessment to learning outcomes. Future updates to the curriculum map focused on making clear connections among objectives, instructional procedures, and assessment practices.

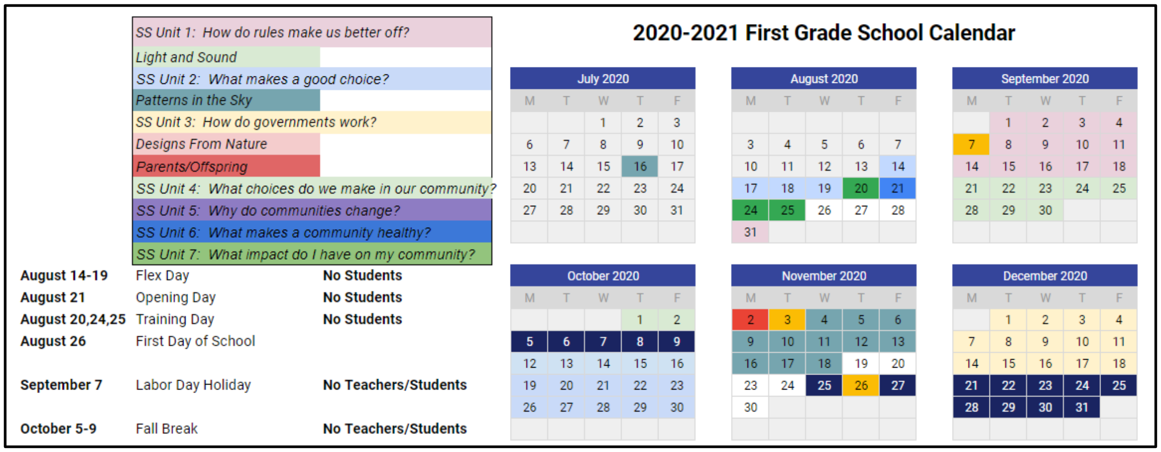
A curriculum map must be a flexible, living tool that evolves with the curriculum (Harden, 2001). The PLC's revised curriculum maps were generated in Google Sheets so participants could make contributions and edits as needed. Persistent monitoring and reflection helped maintain the overall quality of curriculum documents. Not only did participants update science curriculum maps, but they also transformed curriculum pacing guides. Together, curriculum maps and pacing guides renewed science teaching at XYZ Elementary School. Science instruction and assessment are now structured around relationships between teacher reflections and evidence of student learning.

Pacing Guides

One activity that enhanced participants' self-efficacy toward science education was the development of interactive pacing guides. Prior to this study, preliminary pacing guides for each grade level were simply color-coded school calendars. The colors coordinated with a unit topic in either science or social studies since the two subjects are taught on a rotating basis at XYZ Elementary School. Figure 70 presents a snapshot of the 2020–2021 science curriculum pacing guide for first grade.

Figure 70

Sample Science Pacing Guide Generated Before the Revised Intervention



Note. Sample of the first grade science pacing guide prior to this study.

The iterated intervention engaged participants in the development of a new pacing guide. Changes to the document's design made the pacing guide interactive. According to Harden (2001), "An aspect of curriculum development which has been relatively neglected is communication about the curriculum" (p. 123). The revised pacing guide for science enhanced accessibility and interaction with the curriculum. Teachers made comments directly onto the pacing guide. Digitized curriculum documents were reviewed by participants and shared with colleagues and administrators.

Harden (2001) points out that "The ready availability and developments in computing have given the concept of curriculum mapping a new impetus" (p. 132). Updated pacing guides were generated in Google Slides. The pacing guide's new design encouraged participants to give feedback and record reflections concerning the science curriculum. PLC members made comments on the slides and responded to peers' suggestions. Greater accessibility and increased collaboration on science scope and sequence documents fostered a reflective practice for PLC members. See Figure 71 for a sample of first grade's iterated science pacing guide.

Figure 71

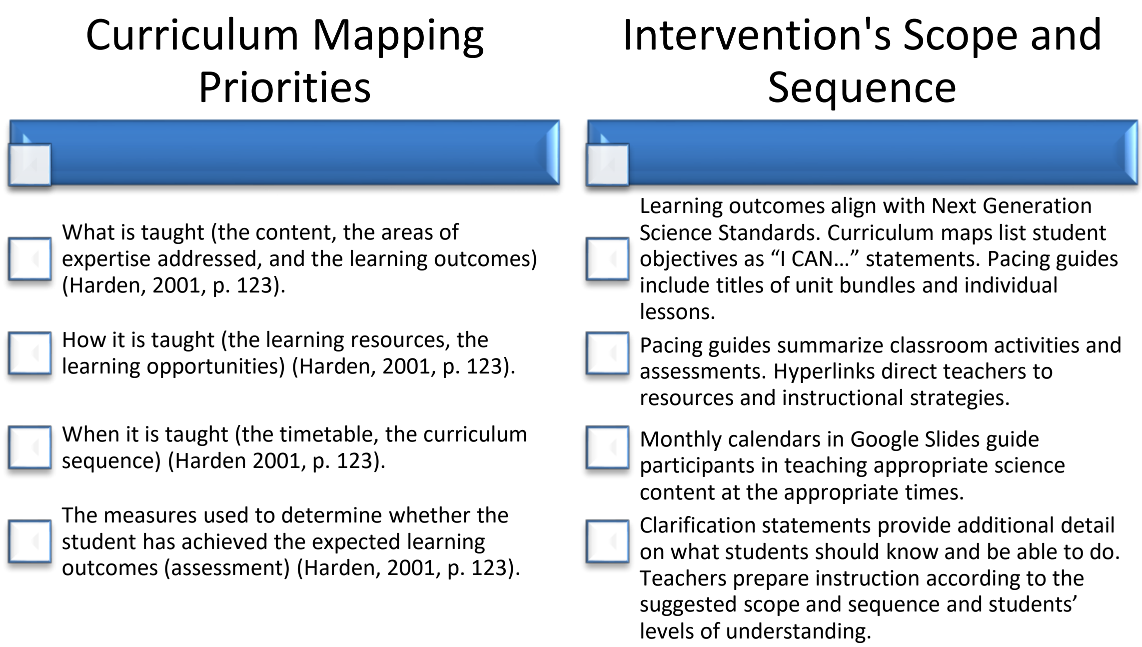
Sample Science Pacing Guide Generated During the Revised Intervention

Note. The new science curriculum pacing guide was generated in Google Slides to enable online collaboration.

Curriculum maps and pacing guides provide a framework for *what* and *when* which content, concepts, and skills are taught and assessed. A scope and sequence is *not* a list of content standards but rather a cohesive outline of goals and outcomes for educators to use to help students move from one conceptual understanding to another (Stambaugh, 2009). Science curriculum documents developed throughout this study's interventions "reduces the overlap of goals and standards within and across grade levels and prevents gaps in instruction" (Stambaugh, 2009, p. 778). The intervention's scope and sequence documents complied with curriculum development's chief principles (see Figure 72).

Figure 72

Intervention's Curriculum Mapping Process



Note. Science curriculum maps were updated to address concerns identified by: Harden, R. M. (2001). Curriculum mapping: a tool for transparent and authentic teaching and learning. *Medical Teacher*.

It is not the curriculum *documents* that transform teaching and learning nor educators' self-efficacy. What matters most is how the curriculum impacts student learning. If instruction focuses on pacing rather than rigor, students will miss out on cognitively demanding tasks (Sears, 2018). Bauml (2015) cites several studies that suggest, “standardizing curricular materials can undermine teachers’ ability to facilitate learning (p. 391). Some teachers value the structure afforded them by curriculum documents. Bauml (2015) conducted a qualitative study of three primary grade teachers’ experiences with curriculum maps and pacing calendars for math and science instruction. Participants in the study appreciated the instructional sequence presented in curriculum guides. A scope and sequence help teachers address priority standards and administer meaningful assessments during a unit of study.

Curriculum maps and pacing calendars face criticism as well. Mandated curricular materials can cause complications in the areas of pedagogy and the pacing of daily lessons. Educators value their sense of agency in planning and implementing instruction. Scope and sequence documents can be met with resistance if they strip teachers of their autonomy.

This intervention’s PLC promoted teacher agency during the process of curriculum development. Participants were encouraged to modify curricular materials as needed with collaborative document editing. The integration of collaborative work with existing structures built trust among participants and deepened their collective understanding of inquiry-based teaching (Robbins, 2015).

Peer Observations

Collaboration and collective inquiry were driving principles of this study’s intervention. Scholars hypothesize that peer interaction builds collegiality, increases one’s level of understanding, prompts action, and evokes reflective analysis (Manouchehri, 2002; Robbins, 2015; Soisangwarn & Wongwanich, 2014). One-time, one-size-fits-all professional development (PD) often restricts active learning and collective participation (Desimone, 2011). The integration of peer observations in this round of intervention constructed an avenue for building participants' competence in using inquiry to teach science (Robbins, 2015).

A second-grade teacher and two third grade teachers (*n* = 3) agreed to share a videotaped science lesson with fellow PLC members. I engaged participants in pre- and post-conferences. Discourse revolved around criteria on the NGSS Lesson Screening Tool. Screening instruments are used widely in education for various purposes, including identifying disorders and selecting instructional strategies. The NGSS Lesson Screener helped teachers design instruction that engaged students in making sense of phenomena and designing solutions to problems through performance tasks (Next Generation Science, n.d.-b). The screening instrument asked participants a series of questions about instructional procedures, resources, and assessments. See Appendix R and Appendix S for lesson screeners completed by participants representing second and third grades, respectively. Table 31 displays the categories that were revealed in participants' reflections for their classroom observations.

Table 31

Main Categories from Peer Observations

Category	Participant Comments
Sustained inquiry	I posted the compelling question: "I know some animals depend on plants, but do plants depend on animals?" It's important to consider methods in which students can record and compile their questions during the activity.
Student-initiated learning	Students studied an interactive diagram of a bee pollinating a flower. Next time, I will challenge students to select the

Table 31 (continued)

	phenomenon by viewing photos of bees and other insects.
Relevant applications	I feel that with real-life connections, students can relate to the content more.
Experiential learning	The class went outside and actually experienced the pollination process. The activity was NOT a simulation that students just watched on the computer. They actually got to do it.
Design thinking	Students drew pictures to represent stages in the pollination process. I will continue to find ways for students to construct their own models of the lesson's content.
Teaching with intentionality	I was very intentional with using phenomena during this lesson. We went back to the phenomenon on a regular basis throughout the lesson. I realized how important it is to be intentional with the vocabulary.
Scientific explanations	Students completed a Claim-Evidence-Reasoning prompt to show what they know about plant traits.

Note. Key ideas from participants' comments on the NGSS Lesson Screener.

Before each video lesson was presented to PLC members, the videotaped participants discussed their planning process. Participants explained the rationale for changes made to the lesson during its implementation. When viewing the recorded lesson, colleagues asked clarifying questions about the context, pedagogy, and resources. Discourse on the lesson was responsive, not evaluative. Carter (2008) states, "Peer review works best when it resembles formative assessment (intended to focus on improvement) more than summative assessment (intended to pass a kind of final judgment)" (p. 87). Trust and collective efficacy emerged from nonjudgmental analyses of classroom observations.

Peer observations were a useful tool for professional learning. Comments and conservations on the NGSS Lesson Screener demonstrated teachers' competence in teaching standards-based science instruction. The learning-focused dialogue produced by this metric established trust among participants and informed collective practices (Robbins, 2015). Peer observations initiated motivation and collaboration on another metric of this intervention—common assessments.

Common Assessments

A culture of over-testing students has permeated throughout America's schools over the past few decades. Educators express concerns about being "data wealthy but information bankrupt" (Erken, 2016, p. 20). One problem is that common assessment systems are usually designed by "experts" instead of all teaching team members (Erken, 2016). Collaboratively designed common assessments *support* rather than *measure* learning. Teachers in the present study developed and implemented common science assessments for the first time at XYZ Elementary School. The team's ownership of the process increased their collective efficacy toward delivering and analyzing common assessments (Erken, 2016).

Four teachers (n = 4) volunteered to design and administer a common science assessment. Two participants developed an assessment to support second grade students' learning. The other two participants developed a third grade science assessment. The process improved participants' skills of assessment literacy and instructional agility. The teachers' conversations focused on solutions to complex challenges that were Next Generation Science Standards (NGSS)-aligned and grade-level appropriate. Participants developed assessments that addressed all three dimensions for a given science standard (Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas). The NGSS call for three-dimensional science proficiency whereby students "make arguments about science, develop and use models, generate and analyze data, and make connections to crosscutting concepts" (Cafarella, n.d., Section 2, para. 1). Participants decided that students would demonstrate their understanding and skills of science concepts by engaging in performance tasks.

Curriculum-embedded performance assessments are becoming a popular alternative to standardized, norm-referenced tests. "Curriculum-embedded performance assessments represent an instructional-driven measurement in which students' actual classroom performance is evaluated in terms of standards-infused criteria" (Baron & Wolf, 1996; Darling-Hammond, 1992, as cited in Meisels, 2003, p. 3). With performance-based assessment, teachers maintain greater control and responsibility for student learning compared to conventional testing methods. Teachers who effectively implement performance assessments hone and develop best teaching practices. Common performance-based assessments developed in this intervention were inspired by scenarios from the Kentucky Department of Education's (KDE) Through Course Tasks. According to the Kentucky Department of Education. (n.d.), "Through Course Tasks are a vital component for a fully functioning and comprehensive science assessment system" (para. 1). Participants used information and processes from KDE's Through Course Tasks to develop robust common science assessments.

The process of collaboratively designing, implementing, and reviewing common performance assessments enhanced participant attitudes toward inquiry-based science teaching. The impact of preparing and performing common assessments was determined by coding participants' reflections on the NGSS Task Screener. The screening instrument was used for in-depth review and modification of assessment tasks. Next Generation Science (n.d.-e) organizes the NGSS Task Screener around four criteria:

A. Tasks are driven by high-quality scenarios that focus on phenomena or problems.
B. Tasks require sense-making using the three dimensions.
C. Tasks are fair and equitable.
D. Tasks support their intended targets and purpose.

For each criterion, participants recorded evidence from their newly designed common assessment to determine how well the task addressed each criterion. Participants also made suggestions for improvement based on observations of the assessment's implementation. Appendix T includes a completed the NGSS Task Screener from participating second grade teachers and Appendix U is a screener completed by third grade teachers. Participants' comments are indicated by red text. Patterns emerged from the process of coding qualitative data. Table 32 presents categories reflected in participants' responses on the science task screening document.

Table 32

Categories Developed from Coded Reflections on the NGSS Task Screeners

Category	2nd Grade Teachers' Comments	3rd Grade Teachers' Comments
Student engagement	I would like the assessments to be hands-on and performance-based and not too heavily text and literacy-based, although you need that in there.	There would be times when I would look up, it will be 3 o'clock, and the students were still researching and reading books because they were so engaged since they picked what they wanted to research.
Scaffolded procedures	Students discuss learning with others when sorting picture cards. Students write notes on a tablet and in the graphic organizers. The sock activity simulates seed dispersal.	Even after the first day of this task, my team talked about how we should have modeled how to fill in the chart, how to get data from a picture, and then sent the students off to do their own work.
Relevant scenarios and data	It matters when you teach things because you can't talk about pollination in December in Kentucky weather because you're not going to see as much as you would when it is warm. We really need to plan science around the seasons.	It was great to allow them to choose and say, oh, I do know things about animals. And then, students can take what they already know to learn about animals they are unfamiliar with.
Multiple modes of student response	An improvement of the task would be to elicit student responses using multiple modalities (i.e., speech, visuals, and skits) rather than solely written answers.	It would be nice for students to do their own version of an animal diagram, maybe somewhere online like a Google Slide. Maybe students could put their animal to scale with chart paper.
Connection and patterns	Students apply information from the task about seed structures to what they learned in a previous unit about animal and plant interdependence.	I liked this task a lot because I could connect it back to students' previous learning, which was all about inheritance traits, so we are able to continue to make connections.

Table 32 (continued)

Visibility	Students make learning visible by sorting picture cards based on seeds' characteristics. Students also post observations to a Padlet (online bulletin board). Students construct an argument using the Claim-Evidence-Reasoning Writing Strategy.	A gallery walk is a good idea because the class can go around and see other work and especially for the lower students that have a hard time making sense of technical concepts.
Evidence-based explanations	To be successful at completing this task, students need to investigate things that move seeds (wind, insects, and animals).	A suggestion for improvement would be to give students more practice crafting claims and supporting their thinking with evidence.

Note. This table lists categories formed from participants' comments on common performance assessments.

Participants' unwavering commitment to developing and implementing common science assessments demonstrated improved self-efficacy toward three-dimensional science education. Extensive research has been conducted on teachers' self-efficacy concerning motivation, commitment, and effectiveness (Canrinus et al., 2012). Participants' reflections on the design of assessments undergirded themes associated with best practices of STEM education. Members of the intervention's PLC incorporated hands-on learning, critical thinking activities, student products, authentic contexts, and cross-curricular connections during science instruction, including assessments. The study site's curriculum specialist expressed the impact of collaboratively designed common assessments:

> We were pretty mediocre to poor in our science focus, rigor, and pedagogy. Now I feel like we have moved to a more balanced curriculum. At least it is in the

> forefront of people's minds in wanting to work on it. We now have a common driving force. We know kids need modeling; we know kids need to be engineering; we know kids need critical thinking. I think we have found what that looks like even though it is very different than how we were taught science. (S. Vaughn, personal communication, December 7, 2020)

The intervention and its development of common science assessments strengthened what teachers "know" about STEM education. The PLC prioritized science as an integral part of the school's curriculum. Erken (2016) writes, "Collaborative common assessments provide the vehicle for implementing new initiative" (p. 43). Because of this study, science is no longer a timeslot on XYZ Elementary School's daily schedule. Science instruction is valued, closely monitored, and tenaciously implemented. The Next Generation Science Standards, the 5E Inquiry-Based Instructional, and performance-based assessments are staples of students' academic experience at XYZ Elementary School. Participants' transformation from "teachers of science" to "agents of change" happened directly and vicariously from the work of this study's curriculum-based PLC.

Post-Intervention Survey Results

The post-survey for the revised intervention was administered at the end of the 12-week improvement cycle. The T-STEM survey contained the same fields and scales as the pre-intervention instrument. The mean of each scale on the post-survey increased from what was reported on the pre-survey, indicating changes in participants' attitudes toward STEM and inquiry-based learning. Summary statistics for each scale on the post-intervention T-STEM instrument are displayed in Table 33. See Appendix V for a complete data table.

Table 33

Summary Statistics for Post-Iterated Intervention Survey

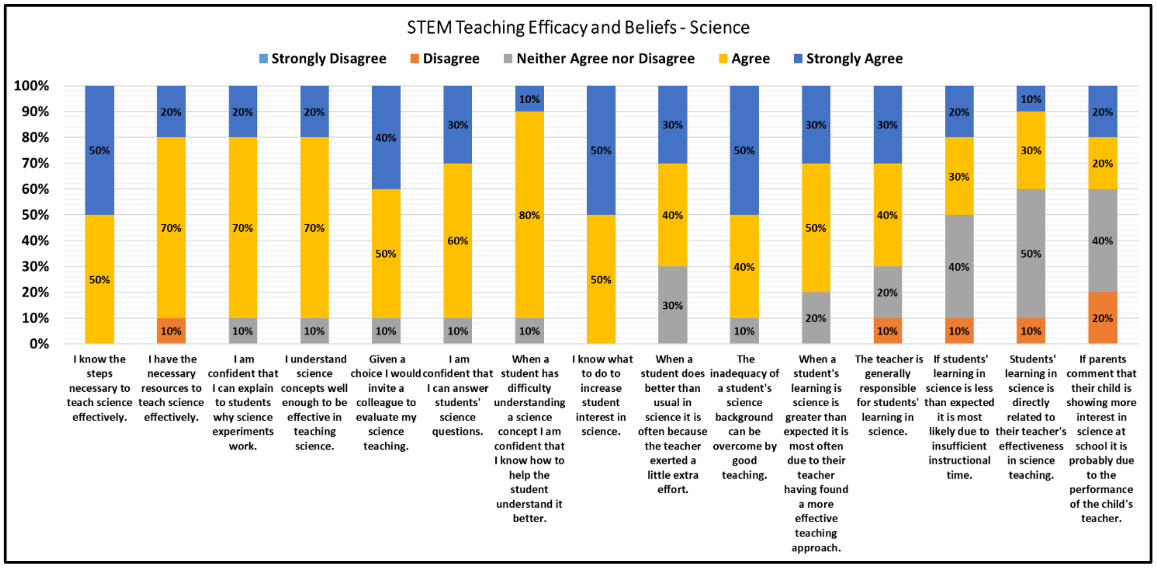
Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	10	60.5	7.21	48	71
Elementary STEM Instruction	10	49.7	8.58	37	59
Student Technology Use	10	27	3.89	21	34
21st Century Learning Attitudes	10	54	7.57	34	61
STEM Career Awareness	10	16.9	1.85	15	20

Note. Summary statistics for each scale of the post-iterated intervention T-STEM survey.

The Science Teaching Scale directly correlates with the study's investigation of professional developments' effect on teacher efficacy toward inquiry-based STEM. Likert-scale questions in this scale asked respondents about their confidence in their teaching skills. Ninety percent of participants "agreed" or "strongly agreed" with nine of the 15 fields about science teaching beliefs. Only one or two participants marked "disagree" for statements, which occurred for only four fields. A stacked column chart shows the percentage of respondents who selected each choice from the Likert-scale on teacher efficacy (see Figure 73).

Figure 73

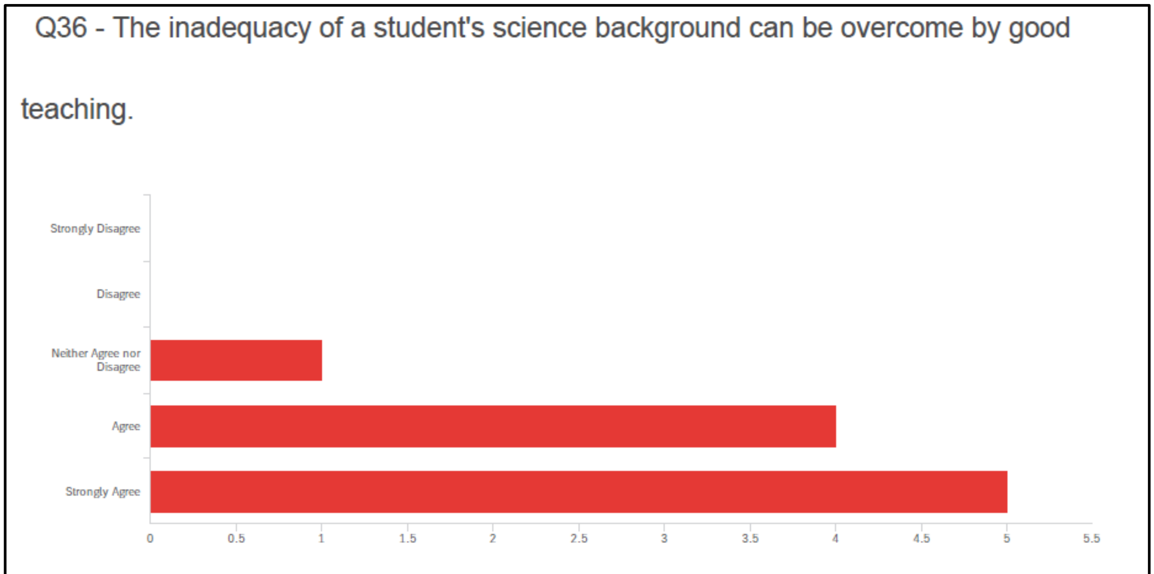
Post-Iterated Intervention Data for STEM Teaching Efficacy and Beliefs Scale



A thorough analysis of each item in all scales informed conclusions about the intervention's impact on teacher confidence in teaching science. Participants associated teaching ability enhanced student learning in science. Ninety percent of respondents agreed that good teaching could overcome the inadequacy of students' science backgrounds (see Figure 74). On the T-STEM survey needs assessment in December of 2019, only 53% agreed with this field.

Figure 74

Results for Post-Iterated Intervention Survey Item Q36



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The inadequacy of a student's science background can be overcome by good teaching.	3.00	5.00	4.40	0.66	0.44	10

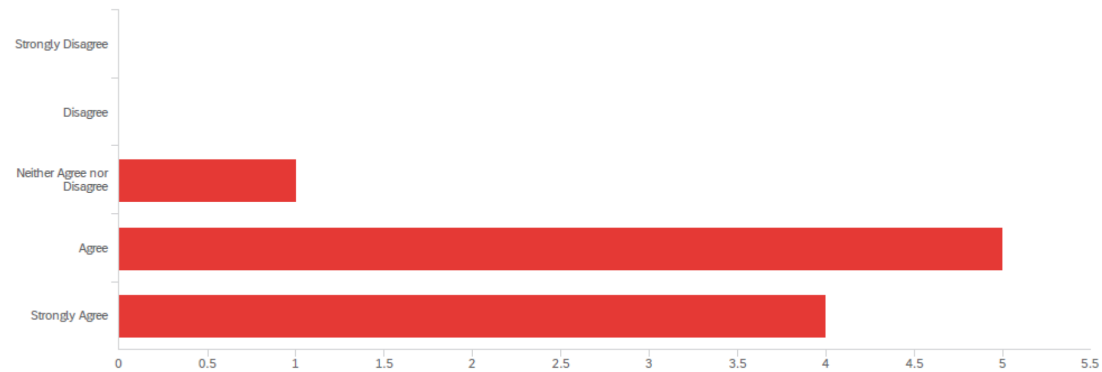
Note. Half of the participants strongly agree that quality teaching can improve students' background knowledge.

One item from the Science Teaching Scale stands as a testament to the impact this study had on teachers' confidence in their teaching skills. If given a choice, 90% of respondents on the revised intervention's post-survey would invite a colleague to evaluate their science teaching (see Figure 75). Results from the needs assessment indicated that 12.51% of teachers either "disagreed" or "strongly disagreed" to asking a colleague to evaluate their instruction (21.88% "neither agreed nor disagreed" and 65.63% "agreed" or "strongly agreed"). Post-survey gains in teacher confidence and self-efficacy in teaching science validated the benefits of a curriculum-based PLC.

Figure 75

Results for Post-Iterated Intervention Survey Item Q30

Q30 - Given a choice, I would invite a colleague to evaluate my science teaching.



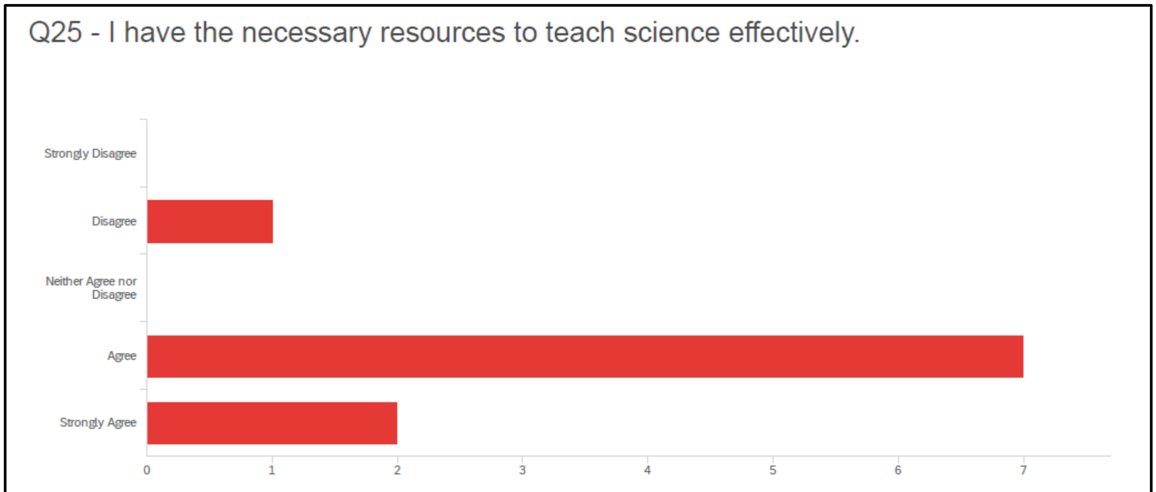
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Given a choice, I would invite a colleague to evaluate my science teaching.	3.00	5.00	4.30	0.64	0.41	10

Note. Majority of participants agreed to have a colleague observe their science instruction.

The curriculum-based PLC intervention supported teachers' use of the *STEMscopes* science curriculum. Participants completed *STEMscopes* scavenger hunts, they curated supplemental resources, and the team re-designed lesson plan templates to reflect the structure of a *STEMscopes* unit. Results from the post-survey showed that many participants agreed to having the necessary resources to teach science (one respondent "disagreed") (see Figure 76). Factors that affected teachers' perception of resources included infrequent use of *STEMscopes* digital platform, the transition to online learning during the pandemic, and lack of planning time to modify resources as needed.

Figure 76

Results for Post-Iterated Intervention Survey Item Q25



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I have the necessary resources to teach science effectively.	2.00	5.00	4.00	0.77	0.60	10

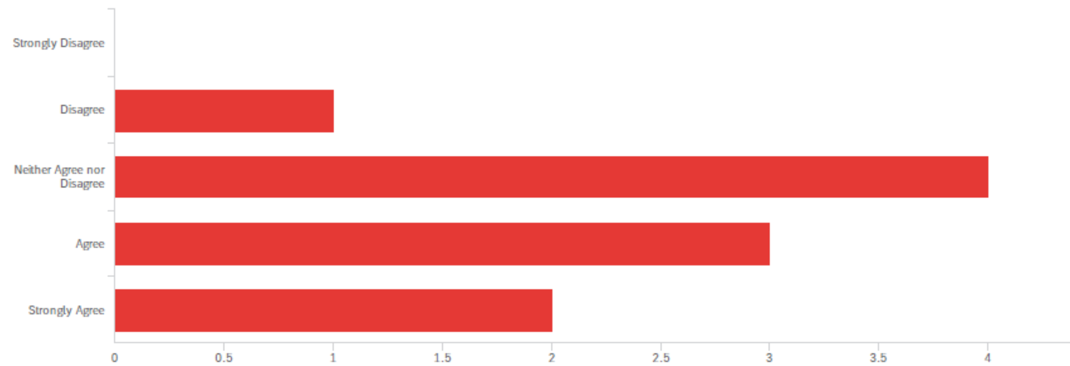
Note. Q25 displays participants' sentiments on the resources available to support science teaching.

Lack of instructional time was at the core of this study's problem of practice. XYZ Elementary School's daily schedule provided 50 minutes to teach science, social studies, *and* writing. Participants had strong feelings toward instructional time. Survey item Q40 asked for respondents' level of agreement for the statement, "If students' learning in science is less than expected, it is most likely due to insufficient instructional time" (*M* = 3.6, *SD* = .92). Responses ranged from "disagree" (*Min* = 1) to "strongly agree" (*Max* = 5). Figure 77 exhibits a bar graph of results for Q40 of the T-STEM post-survey.

Figure 77

Results for Post-Iterated Intervention Survey Item Q40

Q40 - If students' learning in science is less than expected, it is most likely due to insufficient instructional time.



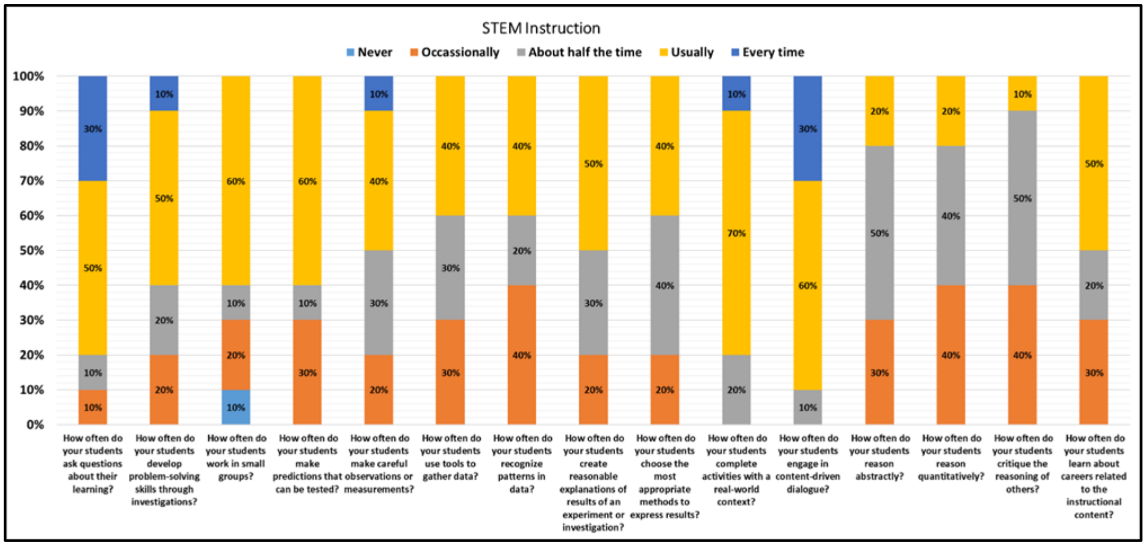
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	2.00	5.00	3.60	0.92	0.84	10

Note. Most participants agreed that insufficient class time negatively impacted student learning in science (M = 3.6, SD = .92).

The second scale in the post-survey is STEM Instruction. It consisted of Likert-scale questions, which asked respondents about the frequency to which their students engage in STEM education practices. The stacked bar graph in Figure 78 signifies the range of responses collected by the T-STEM instrument.

Figure 78

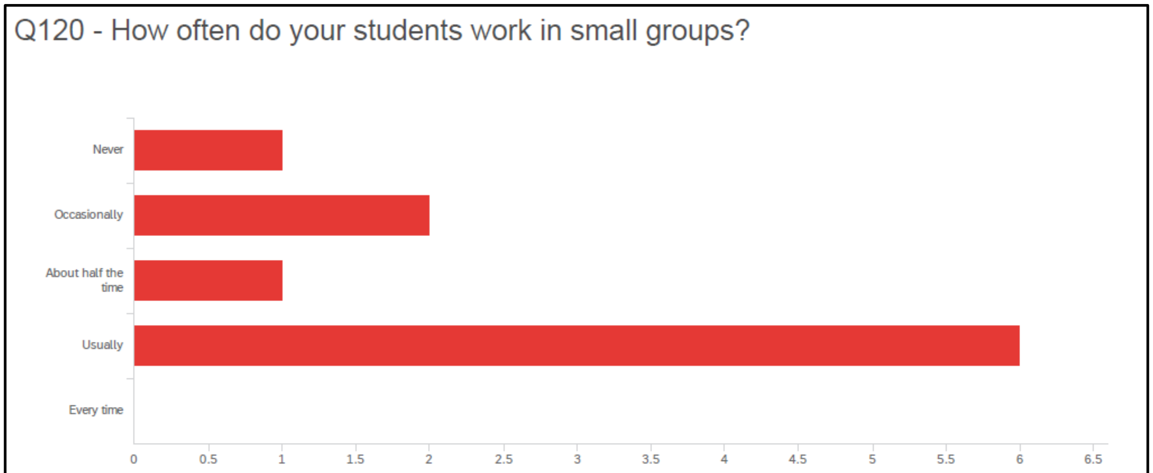
Post-Iterated Intervention Data for STEM Instruction Scale



The COVID-19 Pandemic learning conditions greatly influenced inquiry-based science instruction at XYZ Elementary School. Many students opted to learn strictly virtually. Other students selected a hybrid option to rotate between in-person instruction two days a week and online learning three days. This scale's overall mean score increased due to the intervention (M_{pre} = 38.8; M_{post} = 49.7). Despite the growth made in implementing STEM instruction, some participants rarely used strategies mentioned in survey fields. For example, 60% noted that students "usually" work in small groups, while 40% do so "half the time" or less (see Figure 79). Factors that may have impacted small group instruction were teaching preferences, instructional time, hybrid learning, and online peer collaboration.

Figure 79

Results for Post-Iterated Intervention Survey Item Q120

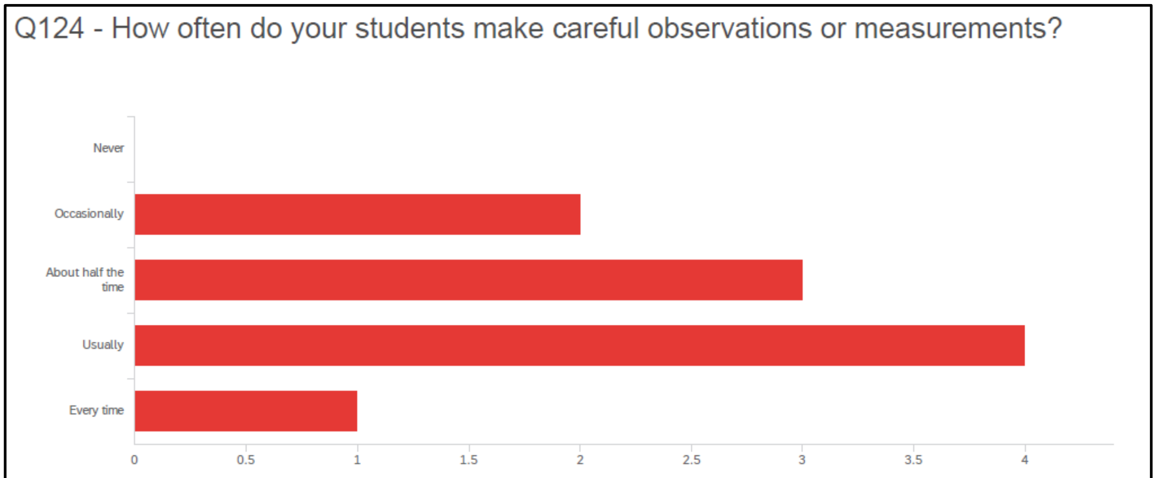


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students work in small groups?	1.00	4.00	3.20	1.08	1.16	10

T-STEM field Q124 asked participants, “How often do your students make careful observations or measurements?” (*M* = 3.4, *SD* = .92). Half of the respondents selected 50% of the time or less. Observational learning is a major component of the NGSS three-dimensional instruction. According to the Next Generation Science Standards (n.d.-e), “scientific inquiry involves the formulation of a question that can be answered through investigation” (para. 3). Results for item Q124 showed that students’ observational learning levels varied depending on the child’s science teacher (see Figure 80).

Figure 80

Results for Post-Iterated Intervention Survey Item Q124



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students make careful observations or measurements?	2.00	5.00	3.40	0.92	0.84	10

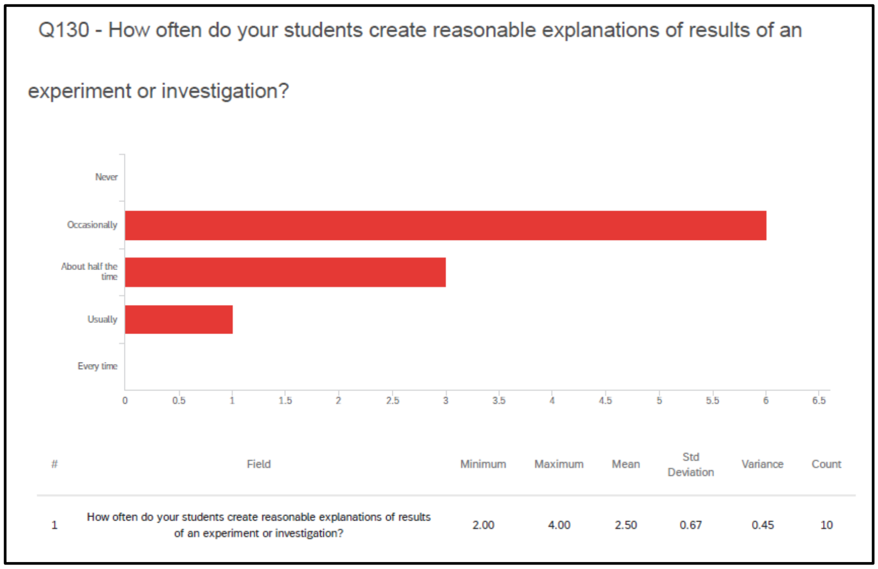
Note. Results for survey item Q124 revealed the frequency rate at which students conduct observations or measurements.

The intervention's instructional coaching activities focused on teaching practices and participants' beliefs on student-centered instruction. Participants transitioned to a dialogic teaching approach, which supported teacher-to-student and peer-to-peer conversations. The curriculum-based PLC engaged participants in hands-on use of classroom strategies for the Claim-Evidence-Reasoning writing method. Results of items in the STEM Instruction field revealed gains in students' opportunity to create explanations based on the results of an experiment (M_{pre-} = 2.5; M_{post} = 3.3). Panels A and B in Figure 81 present pre- and post-intervention data on student-generated scientific explanations.

Figure 81

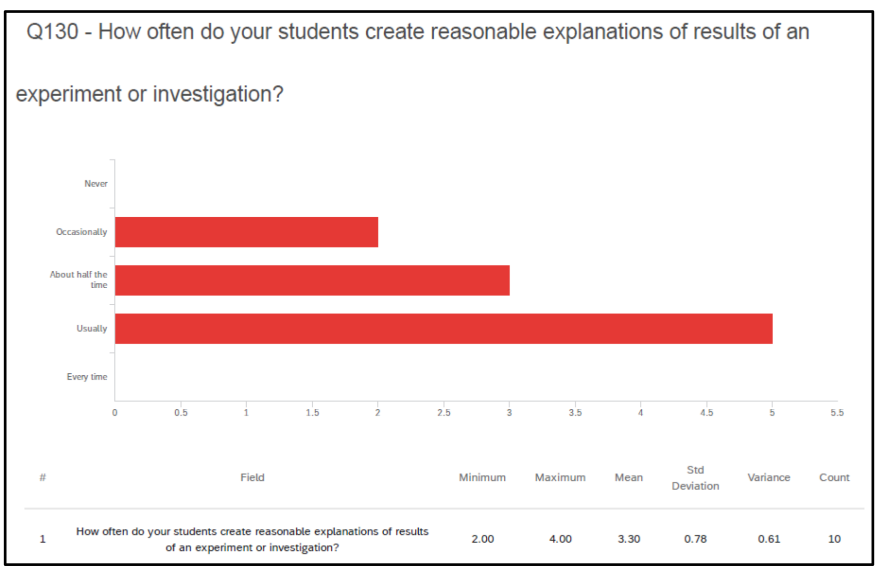
Results for Pre- and Post-Iterated Intervention Survey Item Q130

A



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students create reasonable explanations of results of an experiment or investigation?	2.00	4.00	2.50	0.67	0.45	10

B



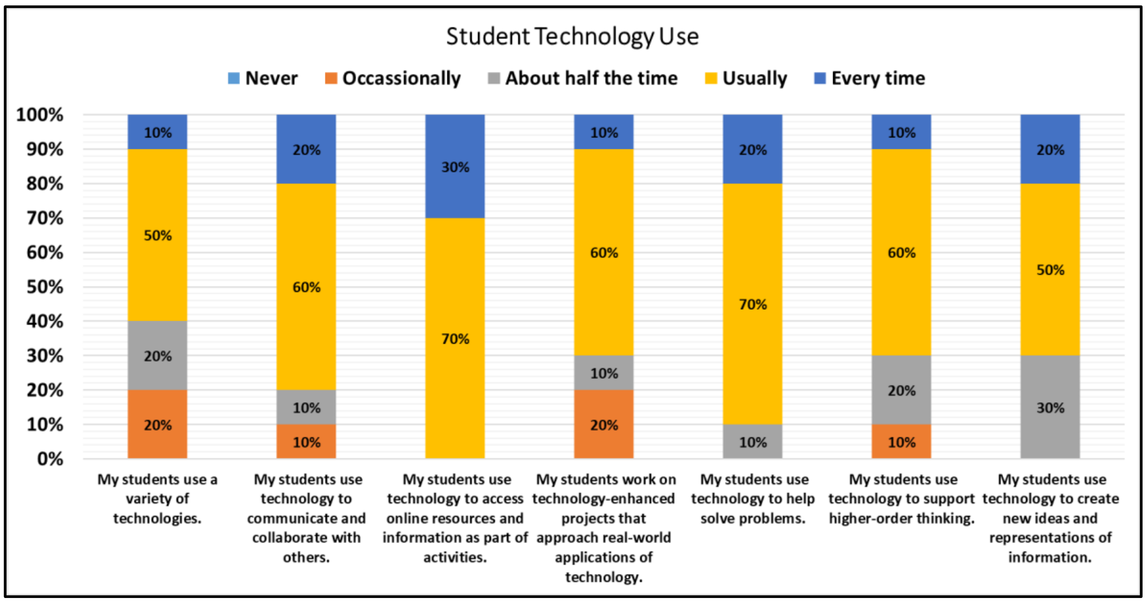
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students create reasonable explanations of results of an experiment or investigation?	2.00	4.00	3.30	0.78	0.61	10

Note. Post-intervention data in Panel B show that 50% of respondents' students "usually" created explanations based on an experiment (10% increase from pre-survey data).

The third scale of the T-STEM survey addressed the frequency of student technology use. A change to online and hybrid instruction focused the intervention's attention on digital learning strategies. The stacked bar graph in Figure 82 displays high percentages for "usually" on the Likert-scale.

Figure 82

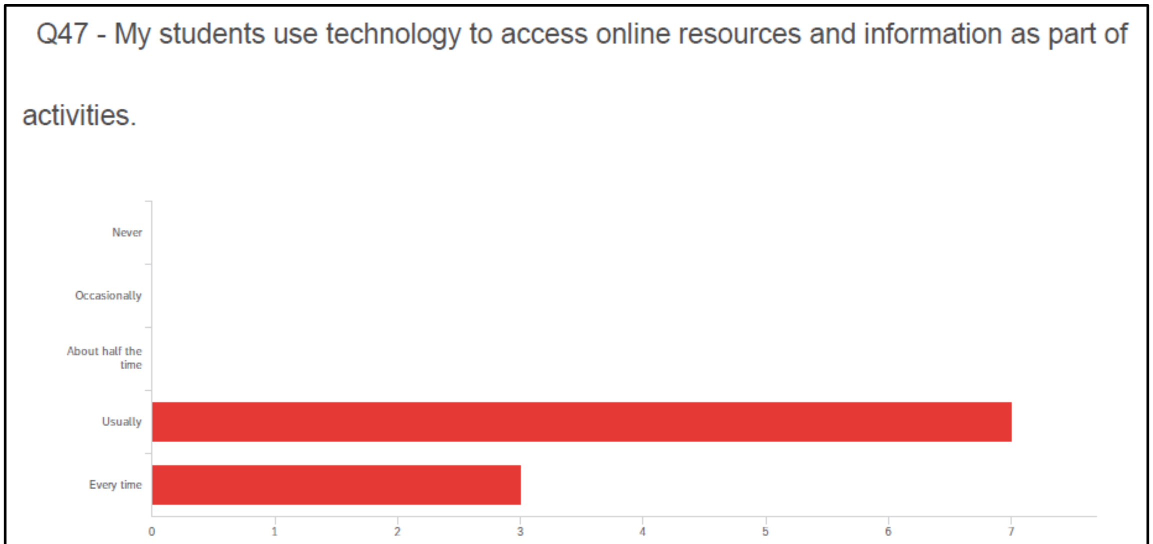
Post-Iterated Intervention Data for Student Technology Use Scale



According to Student Technology Use scale results, 60% or more of participants' students used technology in different capacities more than half the time. Every respondent claimed their students regularly use technology to access online resources and information as part of activities (see Figure 83). This was a significant increase in the rate of students who use digital learning materials. The pre-survey indicated that 80% of respondents' students access online resources either "half the time" or "occasionally."

Figure 83

Results for Post-Iterated Intervention Survey Item Q47

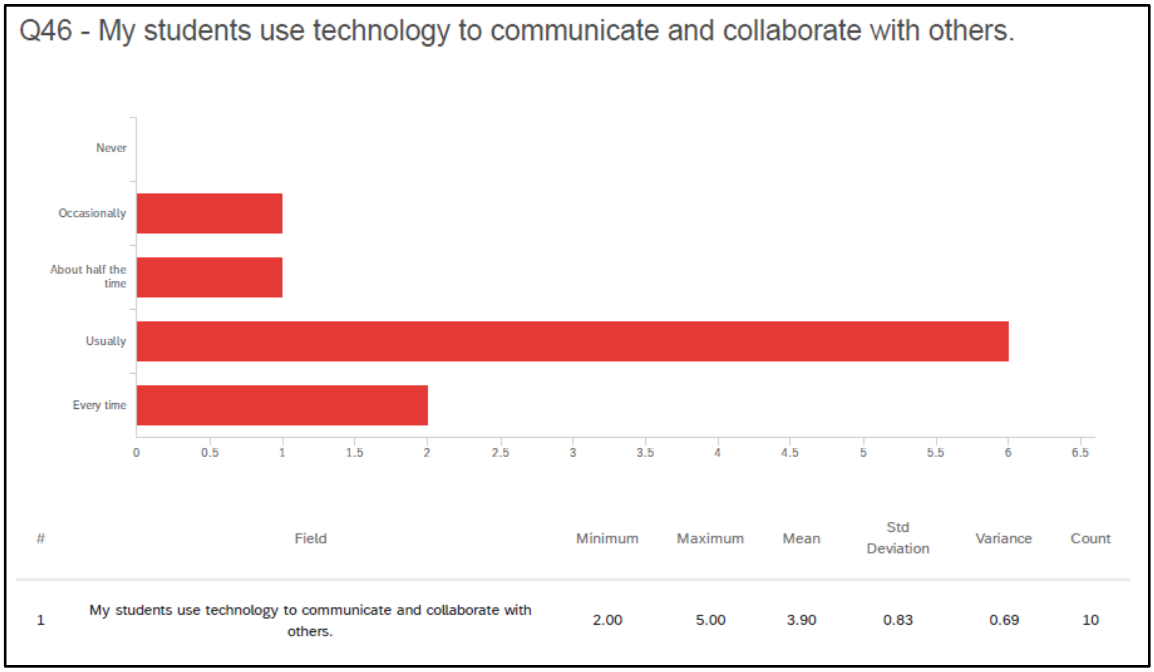


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My students use technology to access online resources and information as part of activities.	4.00	5.00	4.30	0.46	0.21	10

Thirty-three participants completed the needs assessment T-STEM Survey in December 2019. When faculty members were presented with this statement, “My students use technology to communicate and collaborate with others,” 93.76% selected “occasionally” or “never” (*M* = 1.59, *SD* = .61). Participants of the revised intervention were asked the same question. Eighty percent of respondents indicated that their students *routinely* collaborated with others online (*M* = 3.9, *SD* = .83) (see Figure 84).

Figure 84

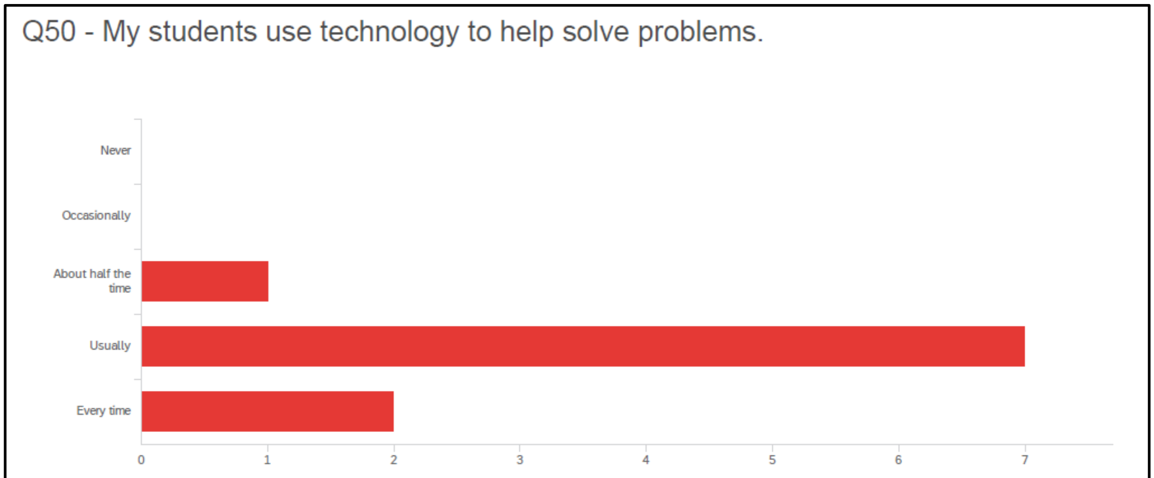
Results for Post-Iterated Intervention Survey Item Q46



Problem-solving and engineering design are essential practices of inquiry-based science instruction. The Next Generation Science Standards engineering strands ask students to define and solve problems. Defining problems involves question asking, data analysis, establishing claims, and proposing designs (National Science Teaching Association, n.d.-a). This study aimed to increase teacher efficacy toward the design and implementation of inquiry-based STEM. Post-survey results suggested teachers feel more comfortable integrating digital learning materials during engineering activities. Figure 85 displays the results for survey item Q50. Ninety percent of respondents indicated that students using technology to help solve problems more than half the time. The post-survey mean (M = 4.1, SD = .54) was a substantial increase from results for the field on the needs assessment a year prior (M = 2.44, SD = .83).

Figure 85

Results for Post-Iterated Intervention Survey Item Q50



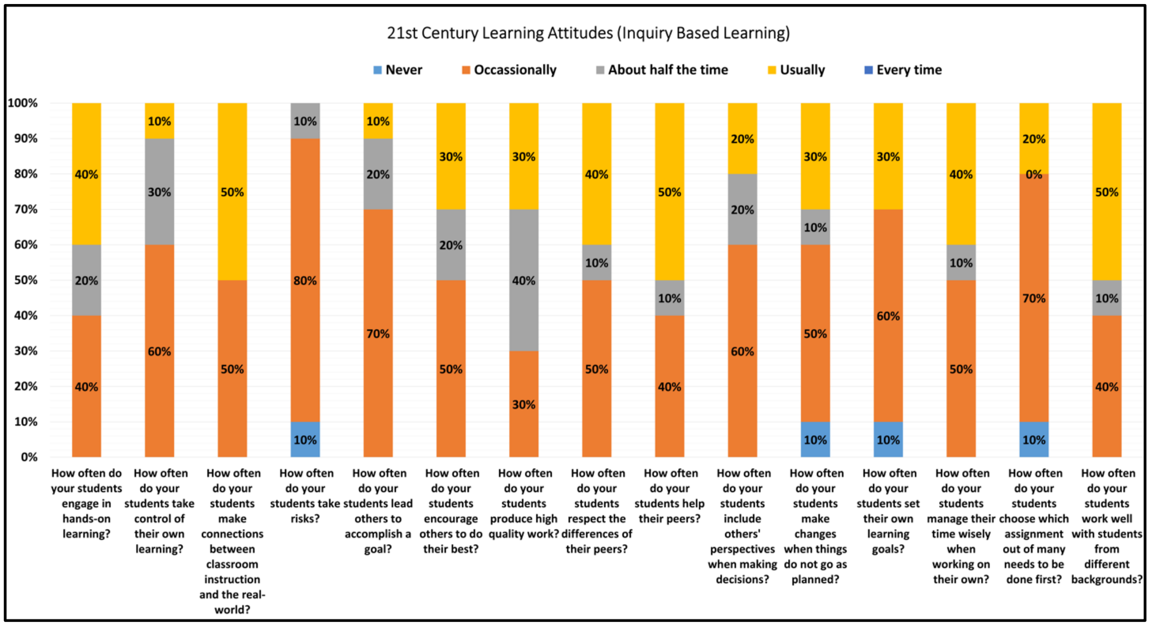
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My students use technology to help solve problems.	3.00	5.00	4.10	0.54	0.29	10

Note. Post-survey results indicated that participants' confidence in incorporating digital learning materials in science improved.

The fourth T-STEM survey scale addressed the frequency of inquiry-based instructional practices. Similar to STEM Instruction, the 21st Century Learning Attitudes scale collected a variety of responses. Figure 86 displays a stacked bar graph for items in the 21st Century Learning Attitudes scale.

Figure 86

Post-Iterated Intervention Data for Student Technology Use Scale



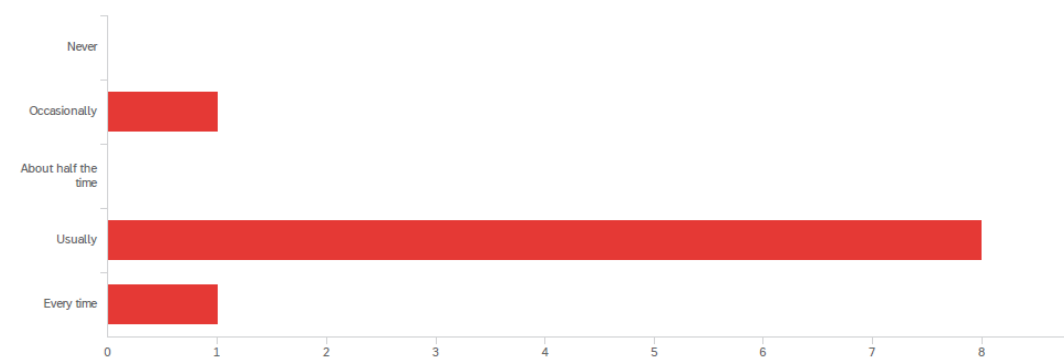
Note. Fields in the 21st Century Learning Attitudes scale received a wide range of responses.

Despite the broad range of results for the inquiry-based learning scale, post-survey results showed improvement compared to pre-survey data. The 21st Century Learning Attitudes scale's post-intervention mean was higher than that on the pre-survey (M_{pre} = 40.7; M_{post} = 54). Additionally, post-intervention survey results indicated that 90% of participants' students regularly engaged in hands-on learning (see Figure 87).

Figure 87

Results for Post-Iterated Intervention Survey Item Q131

Q131 - How often do your students engage in hands-on learning?



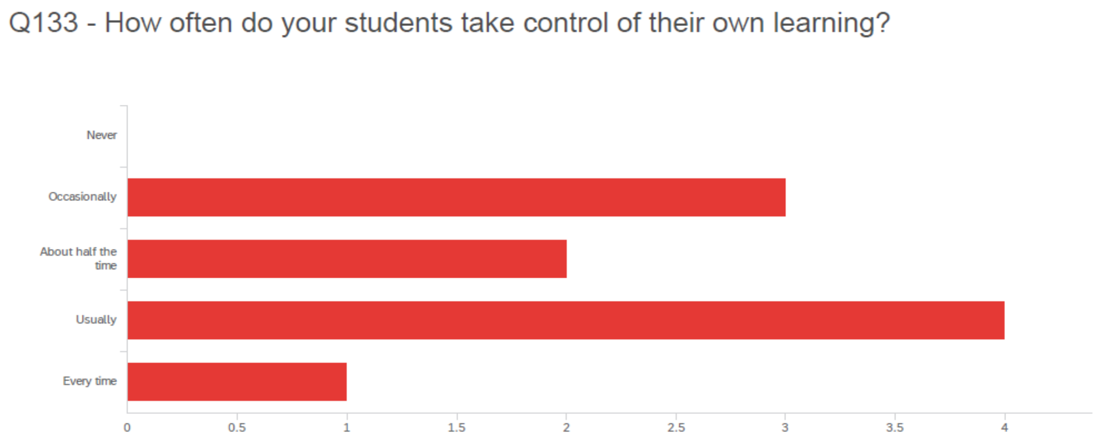
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students engage in hands-on learning?	2.00	5.00	3.90	0.70	0.49	10

Note. Results show the frequency rates at which teachers' students participated in hands-on learning.

Hands-on learning and decision-making go hand-in-hand. Fields asking how often students take control of their learning and make changes to plans received mixed results. One reason for the sundry of responses could be participants' distinctive perceptions of an item's statement. It is probable that participants conjured unique examples for the statements based on their personal science teaching experiences. Figures 88 and 89 depict results for two fields associated with student-led instruction.

Figure 88

Results for Post-Iterated Intervention Survey Item Q133

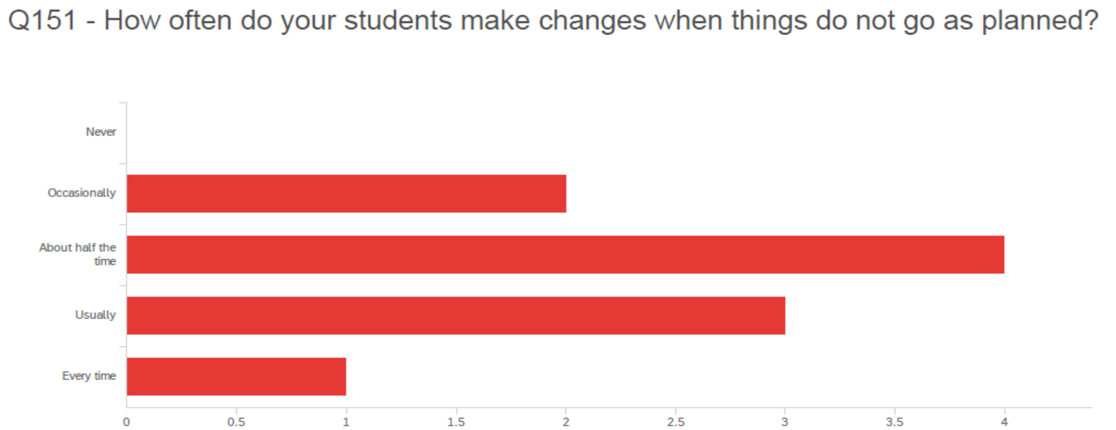


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students take control of their own learning?	2.00	5.00	3.30	1.00	1.01	10

Note. Mean for Q133 increased by 0.8% since this intervention's pre-survey.

Figure 89

Results for Post-Iterated Intervention Survey Item Q151



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students make changes when things do not go as planned?	2.00	5.00	3.30	0.90	0.81	10

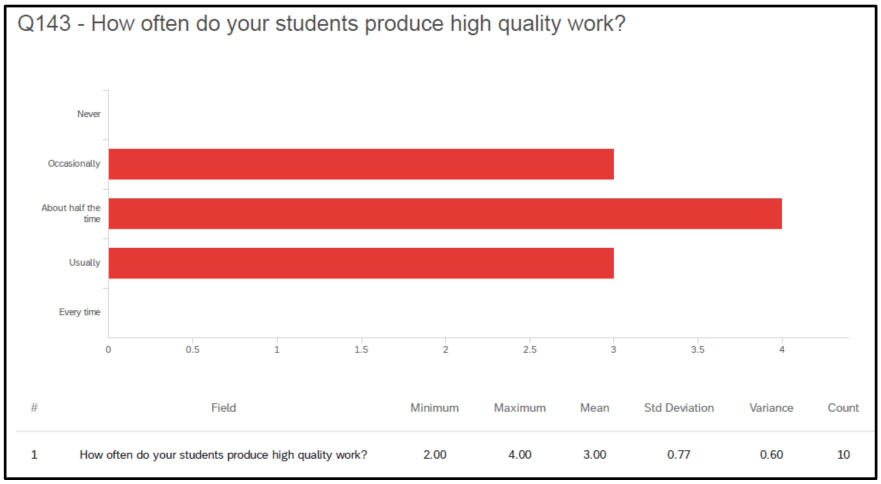
Note. Mean for Q151 increased by 0.7% since the pre-intervention survey instrument.

The intervention's attention to teacher efficacy led to improvements in student learning outcomes. According to pre- and post-T-STEM Survey data, students produced high-quality work more often since the iterated intervention. Panels A and B in Figure 90 present pre- and post-survey data for item Q143, "How often do your students produce high-quality work?"

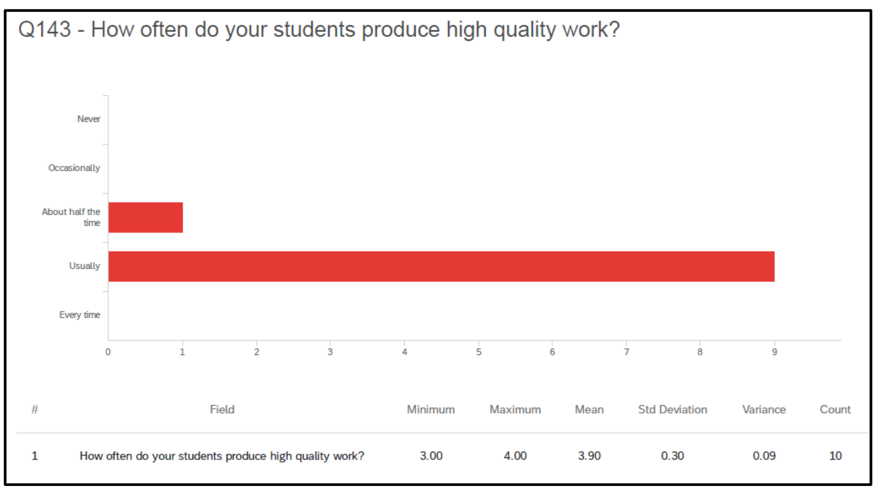
Figure 90

Results for Pre- and Post-Iterated Intervention Survey Item Q143

A



B

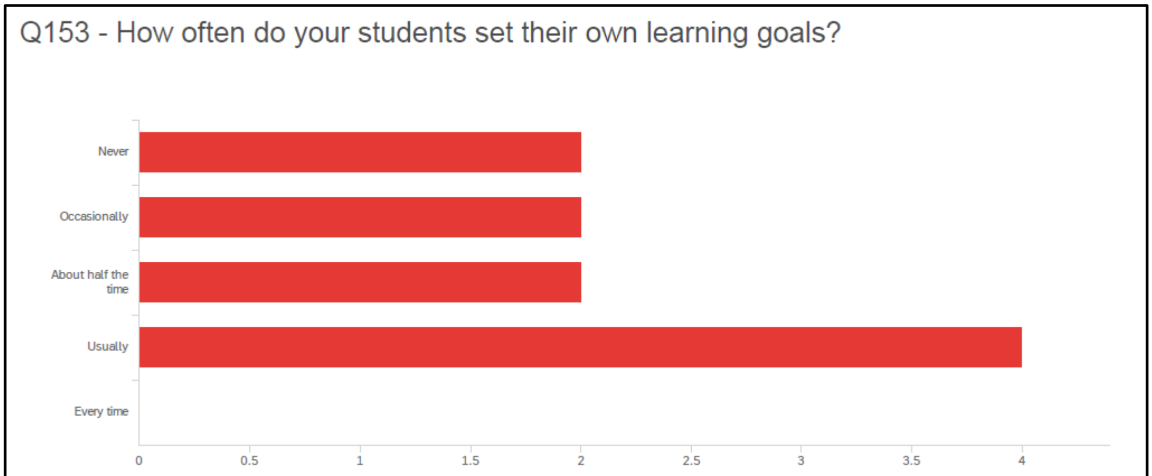


Note. Post-iterated survey data in Panel B show an increase in mean and minimum for the prevalence at which participants' students produced quality work.

Some teachers have reservations about giving students more control of their classroom learning experiences. Teacher-led instruction is efficient, structured, and more comfortable to design. Goal setting may be the first step in helping teachers achieve a constructivist approach to instruction. Goals ensure shared ownership of learning and results among students and staff (Newman, 2012). Student goal setting provides opportunities for personalized and differentiated instruction. Figure 91 displays the results for Q153, which asked respondents how often students set their own goals.

Figure 91

Results for Post-Iterated Intervention Survey Item Q153



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How often do your students set their own learning goals?	1.00	4.00	2.80	1.17	1.36	10

Note. Post-survey results for Q153 indicated that participants needed additional support differentiating instruction.

The process of differentiation can be challenging. Melesse (2015) performed a mixed-methods study with 232 primary school teachers. Data analysis from a questionnaire, semi- interview, and focus group discussion revealed factors that hinder teachers' implementation of differentiated instruction:

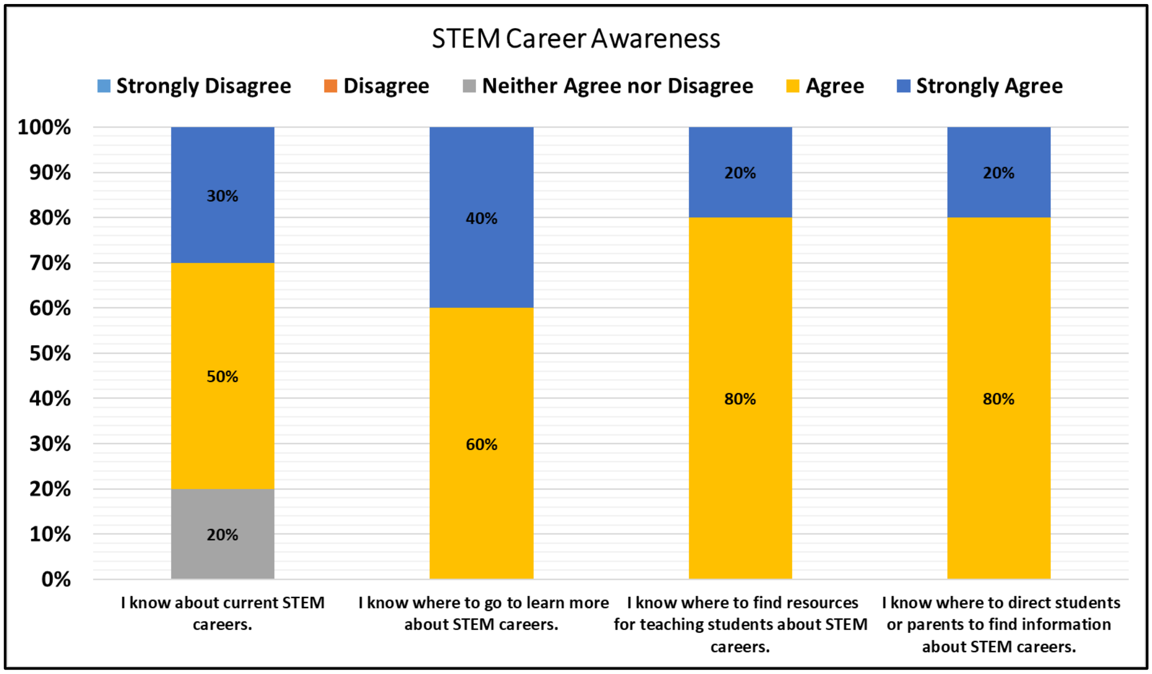
- Lack of knowledge and experience
- Large class size
- Lack of commitment and motivation
- Shortage of materials/ resources
- Shortage of time
- Range of diversity in the classroom
- Lack of parental support
- Lack of school administration support
- Traditional outlook of one size-fits-for all
- Engaging in routine tasks
- Amount of planning time
- Lack of staff collaboration. (Melesse, 2015, p. 262)

Participants in this study's intervention contended with many barriers to differentiating instruction. Collaboration among teachers from across grade levels provided the ongoing support needed to personalize learning based on students' needs.

Final scale items in the post-T-STEM survey asked teachers about their awareness of STEM careers. Percentages displayed in the stacked bar chart in Figure 92 suggest that teachers felt confident connecting students with information on STEM occupations.

Figure 92

Post-Iterated Intervention Data for STEM Career Awareness Scale



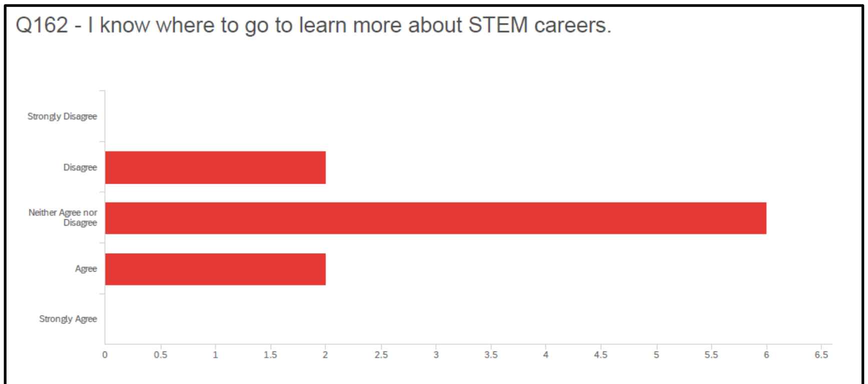
Note. Results of items in the STEM Career Awareness scale indicated high teacher efficacy in this area.

During the revised intervention, participants used resources in the study site's science curriculum, *STEMscopes*, to incorporate career education during science instruction. One goal of the newly designed science pacing guide document was to address a different STEM career in each unit. Results for item Q162 from the pre- and post-surveys are displayed in Figure 93. The intervention improved teachers' awareness of STEM fields and career education resources.

Figure 93

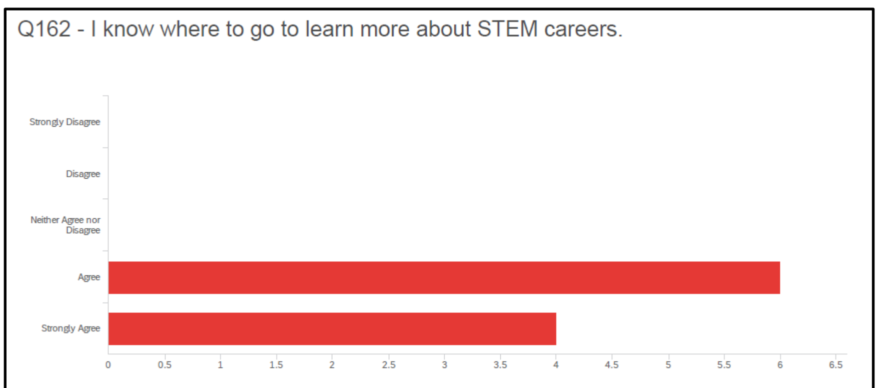
Results for Pre- and Post-Iterated Intervention Survey Item Q162

A



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I know where to go to learn more about STEM careers.	2.00	4.00	3.00	0.63	0.40	10

B



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I know where to go to learn more about STEM careers.	4.00	5.00	4.40	0.49	0.24	10

Note. Data in Panel A suggest that teachers were unsure where to learn about STEM careers before the intervention. Panel B's post-intervention data show an increase in participants' knowledge of STEM careers.

Pre- and Post-Intervention Survey Results

The T-STEM survey is "intended to measure changes in STEM educators' confidence and efficacy toward STEM; their attitudes toward 21st-century learning and teacher leadership; the frequency with which they use some instructional practices related to STEM; and the frequency of student technology use" (T-STEM Survey, n.d., para. 3). The T-STEM survey aligns with this study's goal of improving teacher self-efficacy toward inquiry-based learning by engaging in a curriculum-based PLC and instructional coaching. Mean scores of each scale from pre- and post-T-STEM surveys were compared to signify the intervention's impact. Summary statistics indicated that averages increased for every scale on the T-STEM instrument. Table 34 exhibits summary statistics of the data collected from pre- and post-surveys.

Table 34

Summary Statistics for Pre- and Post-Iterated Intervention T-STEM Survey

Pre-Iterated Intervention Survey					
Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	10	52	5.21	46	60
Elementary STEM Instruction	10	38.8	7.41	28	51
Student Technology Use	10	17.1	5.11	10	28
21st Century Learning Attitudes	10	40.7	10.87	28	56
STEM Career Awareness	10	12.7	2.50	8	17
Post-Iterated Intervention Survey					
Variable	*Obs*	*M*	*SD*	*Min*	*Max*
Science Teaching	10	60.5	7.21	48	71
Elementary STEM Instruction	10	49.7	8.58	37	59
Student Technology Use	10	27	3.89	21	34

Table 34 (continued)

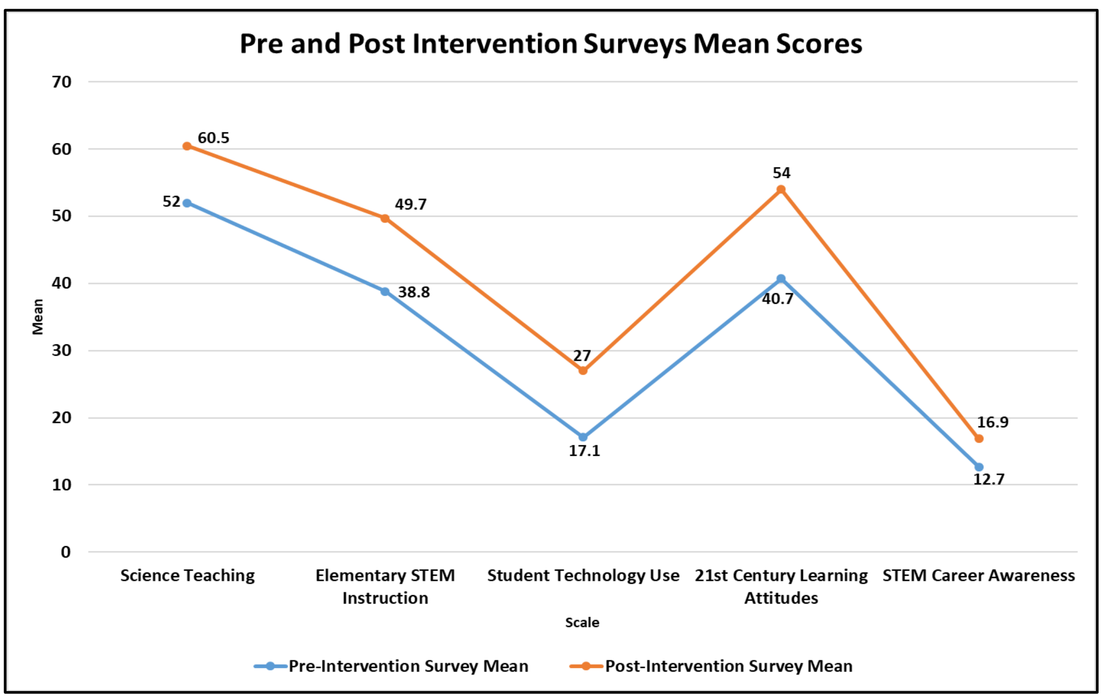
21st Century Learning Attitudes	10	54	7.57	34	61
STEM Career Awareness	10	16.9	1.85	15	20

Note. Means for each scale improved as a result of this study's revised intervention.

Post-survey means increased for all scales. The largest gain occurred for the 21st Century Learning Attitudes scale. A priority of the revised intervention was to support participants' implementation of inquiry-based STEM instruction. Increases in participants' self and collective efficacy toward science influenced the design and implementation of standards-based STEM instruction. Figure 94 presents a double line graph depicting each scale's means from the iterated intervention's T-STEM instruments.

Figure 94

Double Line Graph of Pre- and Post-Survey Means



Note. Mean scores for the revised intervention's pre- and post-surveys.

Gains in teacher efficacy and confidence toward the inquiry process in science class were mainly due to the intervention's PLC and instructional coaching. Additional efforts are needed to sustain science education's progress at XYZ Elementary School. Improvement to teaching and learning is a continuous process. Vertically aligned instruction, collaborative lesson planning, informed decision-making, reflective curriculum documents, and instructional coaching became essential components of the research setting's culture. Future action is detrimental to sustaining teacher efficacy and improving STEM practices. Decisions should consider assumptions and beliefs but focus on users and data. Administrators can use data from this study's surveys, metrics, and interviews to guide daily practice and professional learning on inquiry-based learning and content subjects.

Post-Intervention Interview Results

Qualitative data provided insight into the effects of the study's revised intervention on teachers' self and collective efficacy toward STEM practices and the inquiry process. Five empathy interviews were conducted before and after the 12-week intervention. The school's principal and curriculum specialist were interviewed in both rounds. Three classroom teachers (one from each grade level) were also interviewed. Teacher representatives varied from pre- and post-interviews. Interview questions centered on participants' attitudes toward professional learning, inquiry-based teaching, curriculum guides, common assessments, and the intervention in general. See Appendix W for a list of interview questions. Post-intervention interview transcripts were assigned open codes and then grouped into themes (see Table 35).

Table 35

Themes Identified from Post-Intervention Interview Data

Theme #	Theme
1	Team trust
2	Vertical alignment
3	Balanced curriculum
4	Equitable student learning experiences
5	Peer coaching

Note. Five major themes emerged from open coded interview data collected at the end of the improvement cycle.

Many of the emerging themes from post-interviews focused on collaborative school culture. Participants' comments reflected ideas associated with shared goals, teamwork, and collective efficacy. This study implemented a curriculum-based PLC and instructional coaching to enhance teachers' attitudes and efficacy toward inquiry-based science instruction. Increased teacher efficacy was the catalyst for major improvements to science education at XYZ Elementary, including common assessments, curriculum guides, and inquiry-based teaching practices. In *Cultures Built to Last: Systematic PLCs at Work*, DuFour and Fullan (2013) write:

> When the PLC process drives an entire system, participants come to have a sense of identity that goes beyond just their own piece of the system. They identify in palpable ways with the overall organization, unleashing the energy of mutual allegiance and competition for common good. (p. 18)

Evidence from post-interview data suggested that this study's PLC and instructional coaching improved participants' overall sense of efficacy and job satisfaction. Here is what a first grade teacher said about the intervention, "I love that we have been able to collaborate and just learn so many new things from one another as science educators." Collaboration was a common term used by interviewees. Agreed-upon goals and collaborative tasks are what improved teachers' classroom instruction. The first grade teacher went on to say:

> One of my big takeaways as far as my general thoughts and feelings is that it is really to stress the importance of letting the kids investigate first. I feel like in the past, we have spoon-fed so many scientific facts, and we don't give the kids time to just explore as we have done in the Science Squad with that phenomenon and posting pictures as some kind of hook. And just letting them investigate and delve into it for themselves and letting the scientific facts just come through that investigation.

Other participants' comments confirmed the impact of the ongoing collaboration and coaching on teacher efficacy and STEM teaching practices. A second grade teacher remarked, "I feel more comfortable teaching science. It's not like a chore now. You can actually make it interactive, engaging, and fun and allow the students to explore."

A new perspective and increased self-confidence toward science teaching influenced school-wide priorities. The school principal talked about the importance of sustaining the work and energy of PLC members:

> Unless teachers are collaborating and unless teachers are communicating with one another, then they are just a silo out in a field, and we don't know what's inside of

> it. The Science Squad united people come from different grade levels. They made things happen. The website that has been developed has been awesome because it is *there*. It's not going away. It's not something that can be filed on the shelf. I mean, it's a part of XYZ Elementary. Teachers can jump on the Google Site and pull resources whenever they need to. The next steps are to make sure that they continue using it.

Many activities associated with the intervention's PLC will continue to sustain participants' enthusiasm for developing inquiry-based science instruction. For instance, newly designed curriculum guides gave "balance" to core and content subjects. The school's curriculum specialist expressed the intervention's impact on teaching and learning:

> [Before this study] we didn't even have really a good curriculum map or a common resource that we based our learning progressions on or the scope and sequence of the [science] standards. Also, I think I would venture to say that there were some people who still didn't have a really good grasp of the science standards. So with all of that said, where we were was pretty mediocre to poor in our science focus, rigor, and pedagogy. Now, I feel like we have moved at least above or to a more balanced curriculum. At least it is in the forefront of people's minds in wanting to work on it.

Teachers from all grade levels found the revision of science curriculum documents to be of great import. Interviewees mentioned curriculum maps and pacing guides helped them to understand the Next Generation Science Standards (NGSS) more broadly. Participants planned science instruction in ways that promoted cross-curricular connections and helped students develop 21st century skills (e.g., critical thinking, creativity). Curriculum documents have made science instruction more manageable for teachers. Because of teachers' positive perception of science education, more students have greater access to standards-based STEM education. According to the study site's curriculum specialist, "With the curriculum map and the pacing guide, I feel like students are going to have equitable access to science instruction that is rigorous and well thought out and planned." During a post-interview, a classroom teacher spoke to science education's impact on student equity:

> Science kind of levels the playing field for everyone. So, everyone has the ability to wonder and question. Even those that might struggle academically kind of pick this up and are more willing to work in science. For some, this is their one chance to ask questions and be an expert. Others might get to go to a museum or go on vacation, but some kids can't, and science can give it to them.

The presence of the NGSS assessments and curriculum documents does not guarantee equitable learning experiences for all students. Students' *access* to STEM instruction relies heavily on teachers' collaborative work to design assessments, review student work, and develop action plans. The collaborative design of common performance assessments improved participants' understanding of the NGSS and engineering practices. Teachers used student data and anecdotal evidence to adjust instruction. Participants who volunteered to lead the design of common assessments discovered the power of the collective. A second grade teacher suggested collaboration as a means to improve science assessments:

> I think we could work more together and know where our kids are going to be if there was a common assessment. We could also bounce ideas off each other. We would be able to see where we went wrong and see what we could do to better serve our students.

As the intervention progressed, participants began to develop personal goals in addition to collective SMART objectives. Individual aspirations originated not just from participants' gains in knowledge but on the foundations of trust. One interviewee taught strictly online during the intervention because of COVID-19. The participant set a goal to make online science instruction hands-on and interactive. She trusted that PLC meetings, coaching sessions, and positive peer relationships would support her ambition. The collaborative pursuit of knowledge helped the teacher reach personal goals:

> So now I've started using what I call probes or what we called a phenomenon to hook the kids or get them to ask questions. I want them to do their own thinking instead of me giving them all of the facts upfront.

The analytical process of coding interviews, categorizing codes, and comparing themes across this intervention led to meaning construction and theory development (Elliott, 2018; Fereday & Muir-Cochrane, 2006; M. Williams & Moser, 2019). This study's overarching themes aligned with the following theory-driven codes: content knowledge, collaboration, cohesive curriculum, and collective efficacy. Theory-driven codes were clustered into themes. Codes and thematic clusters signified an overarching (core) theme (see Table 36).

Table 36

Corroborating and Legitimating Coded Themes to Identify a Core Theme

Theory-driven codes	Clustered themes	Core theme
Content knowledge Collaboration	Subject-based professional development based on experiential learning and reflective practices improve classroom pedagogy and curriculum resources.	A high level of collective efficacy in a subject or skill fosters ongoing collaboration that supports shared *and* personal goals.
Cohesive curriculum Collective efficacy	A collaborative learning culture builds the capacity of its members, which expands the continuous improvement of programs.	

Note. Coded interview data and clustered themes led to an overarching theme that signified the import of a collaborative learning culture.

The following statement by XYZ Elementary School's curriculum specialist reflects the core theme identified from coding qualitative data:

> I think [teachers] are much more enthusiastic about it [teaching science]. I think that comes with resources; it comes with a common plan. We have a common vocabulary with the 5E inquiry model, and we have a common vocabulary—a common theme. We have a common driving force. We know kids need modeling; we know kids need to be engineering; we know kids need to be critical thinking. I think we have found what that looks like because it is very different than how we were taught science. Moving away from, 'You got to get all this science

knowledge' to 'here's resources that have science knowledge, now can you apply it.'

This study's constructivist approach to professional learning enhanced teachers' content knowledge and capacity to implement STEM teaching practices. The experiential nature of the intervention and its focus on inquiry-based instruction improved classroom pedagogy. Empathy interviews indicated that the intervention renewed school faculty's interest in science education and instilled confidence in collaborative professional development.

Conclusion Based on Second Round of Intervention

Many factors contributed to participants' gains in comprehending science content and refining inquiry-based teaching strategies. Data suggest that this study's subject-focused PLC, instructional coaching, curriculum development, and peer observations directly benefited science education at XYZ Elementary. Factors outside the context of this intervention also influenced participant growth. It is not so much the activity, resource, or circumstance that improved participants' attitudes toward science instruction. Ongoing collaboration and support are what increased teacher self and collective efficacy.

This study's curriculum-based PLC's main goal was to improve teachers' self-efficacy in teaching science. Participants' immersion in a hands-on STEM curriculum spirited collective action. The processes used in this intervention influenced teachers' selection of classroom strategies and resources. The intervention's inputs (e.g., grade-level representatives, guest speakers, digital learning materials) fostered interdisciplinary instructional unit design.

The inputs, processes, and results associated with the second round of intervention centered on collaboration. Continuous improvement of science education and teachers' efficacy toward inquiry-based learning depends on the group's collective efforts. Ongoing collaboration must occur between educators within departments, among grade-level teams, and beyond physical school boundaries. Professional learning is ineffective when done in isolation. According to DuFour and Fullan (2013), "Educators must build a collaborative culture in which they work together interdependently and assume collective responsibility for the learning of all students" (p. 39).

This study based its interventions on multiple theories and best practices of professional learning. Each strategy aimed to deliver meaningful and personalized professional development that instilled a team culture. The curriculum-based PLC established itself on shared goals that members developed together. Participants articulated collective commitments regarding the actions needed to achieve their shared vision (DuFour & Fullan, 2013). The revised intervention aligned its structure and activities with theories laid out in the study's theory of action. SMART goals, collaboratively designed assessments, renewed curriculum guides, peer observations, keynote speakers, instructional coaching, and personalized feedback were enriched by the intervention's constructivist approach to professional development.

Participants' immersion in instructional design and curriculum resources development nurtured collaboration and increased trust among educators from different backgrounds and grade levels. Results of the revised intervention corroborated the benefits of a PLC and instructional coaching at the local level. Extending this study's PLC process to personnel across the school district is key to systemic improvement.

Vertical teaming and personalized support systems will prepare educators to meet today's challenges and address the challenges of tomorrow.

CHAPTER V: CONCLUSIONS

Introduction

The purpose of this mixed methods research study was to gain a better understanding of the use of a curriculum-based professional learning community (PLC) on teachers' self-efficacy using the 5E Inquiry-Based Instructional Model of science instruction. The quantitative and qualitative data collected indicated that this study's drivers (i.e., vertical teaming, instructional coaching) empowered teachers and increased their self and collective efficacy levels. This section presents information about the improvement science process, findings from both rounds of intervention, recommendations for future practice, and implications.

Improvement Science Process

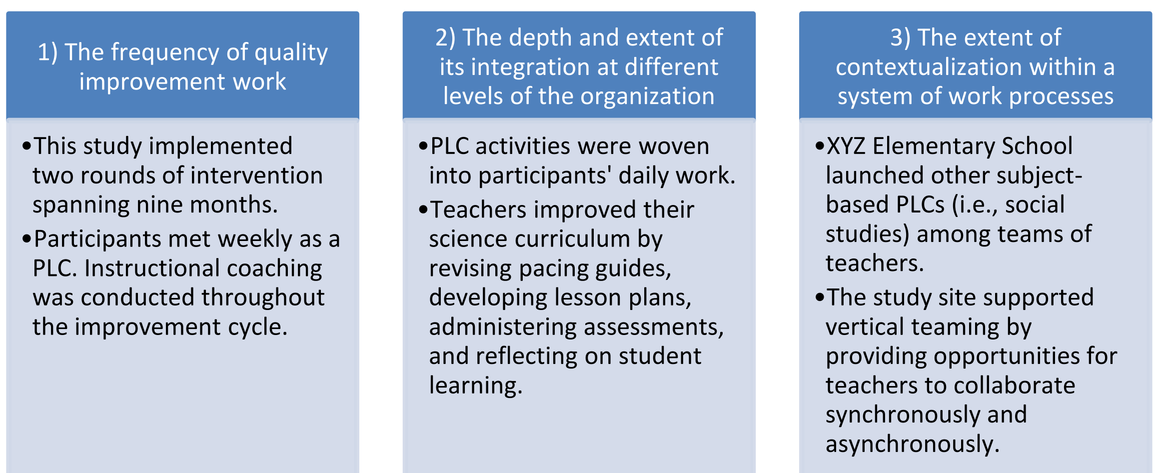
Education is constantly being re-shaped through revisions in pedagogy, advancements in technology, and policy reforms. It is widely understood that *change* does not necessarily denote *improvement.* Nevertheless, schools often hope for continuous improvement through drastic changes that take place as a result of an innovative idea or resource. After all, radical change is exciting, palpable, and time-bound. Yet, breakthrough change in an organization often experiences high resistance levels, especially if the initiative disrupts staff members' routines. Stakeholders are less likely to support a change effort if they do not see how it benefits their day-to-day tasks and responsibilities.

Rather than focusing on breakthrough change, this study embraces continuous *incremental* improvement. According to Bhuiyan and Baghel (2005), "often, major improvements take place over time as a result of numerous incremental improvements"

(p. 761). Incremental change encounters less resistance from an organization’s members, chiefly because staff are active participants in project design and implementation. Park et al. (2013) suggest three continuous improvement features (i.e., frequency, depth, and system contextualization). Without these characteristics, an organization’s attempt at school improvement will likely fail to make a lasting impact. Figure 95 depicts how the present study’s intervention aligned with essential characteristics of quality improvement work.

Figure 95

Essential Characteristics of Quality Improvement Work



Note. This study’s intervention design adhered to characteristics of quality improvement work. From “Continuous improvement in education,” by S. Park, S. Hironaka, P. Carver, and L. Nordstrum, 2013, *Carnegie Foundation for the Advancement of Teaching*, p. 5. Copyright 2013 by Carnegie Foundation

The essential characteristics of continuous improvement (i.e., frequency, depth, and system contextualization) are ingrained in the improvement science framework used in this study. “Improvement science is an approach to incremental and sustained change championed by the Carnegie Foundation” (Schwartz, 2018, para. 9). Improvement science is an iterative process that gives voice to the users of designs. At the heart of improvement science is collective inquiry that builds on existing research and practical design knowledge (Mintrop, 2018). Mintrop writes, “In education, designs for improvement should be co-design projects in which interventions are not done *to* people, but done *with* people” (p. 13). The present study’s curriculum-based professional learning community (PLC) incorporated as part of the theoretical framework a constructivist approach to learning. PLC members experienced inquiry-based science instruction first-hand by using and developing instructional materials.

The improvement science model bridges the gap between theory and practice. According to Bryk et al. (2010), improvement science:

> aims to meld the conceptual strength and methodological norms associated with translational research to the contextual specificity, deep clinical insight and practical orientation characteristic of action research. (p. 22)

Improvement science recognizes that school reform does not occur solely from theoretical perspectives (Lewis, 2015). This study considered empirical evidence in light of the local site’s users, organizational conditions, and potential improvement drivers. During action research, PreK-12’s scholar-practitioners must never lose sight of “*who is involved* with the improvement process and *who will be impacted”* (Hinnant-Crawford, 2020, Section 1, para. 4). One goal of the present study was to increase students’ access to science instruction. To do so, I focused on increasing teachers’ self-efficacy levels toward the design, implementation, and evaluation of STEM curriculum and inquiry-based learning pedagogy.

The overarching goal of improvement science is to ensure that quality improvement strategies rest on a strong evidence base (Shojania & Grimshaw, 2005). Improvement science, though a complex process, centers on one factor—a contextual need. Organizations use the improvement science framework to address a need through continuous improvement. Carnegie Foundation for the Advancement of Teaching (n.d.) outlines six core principles of improvement:

1. Make the work problem-specific and user-centered.
2. Variation in performance is the core problem to address.
3. See the system that produces the current outcomes.
4. We cannot improve at scale what we cannot measure.
5. Anchor practice improvement in disciplined inquiry.
6. Accelerate improvements through networked communities. (The Six Core Principles of Improvement section, para. 1–6)

The core principles and processes of improvement science guided this study's design, execution, and intervention cycles. Improvement methods are iterative in nature. It is likely that even when improvement efforts begin with outreach and collaboration with networked communities, the organization will need to return to the problem for additional analysis. In an effort to give improvement science structure and practicality, Hinnant-Crawford (2020) presents the continuous improvement process in five steps:

1. Define the problem
2. Develop a change

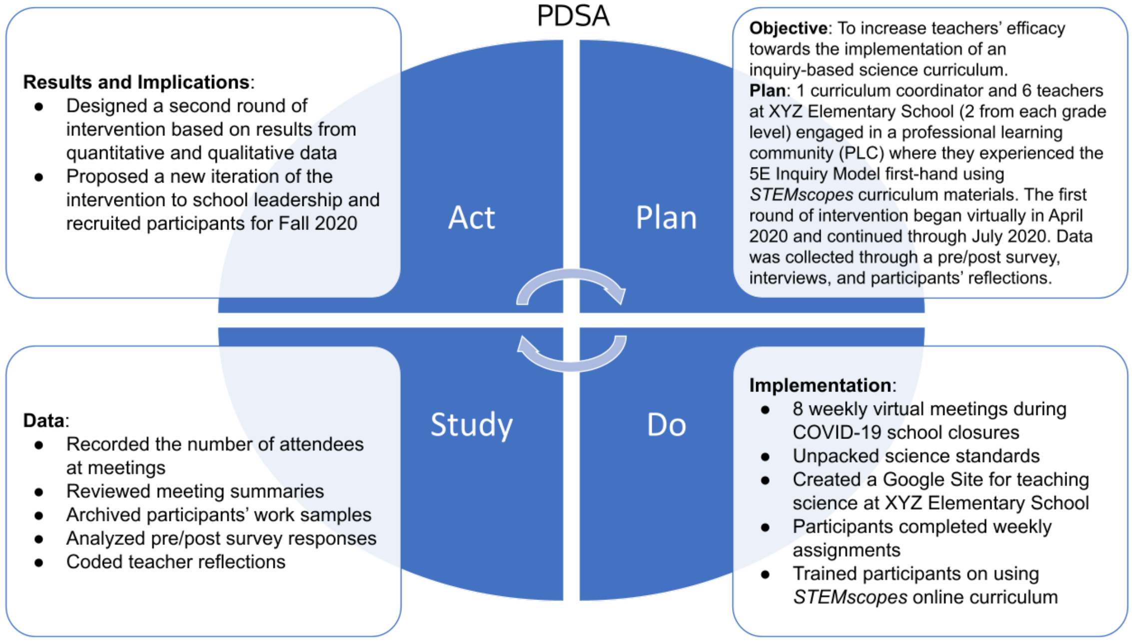
3. Implement a change
4. Test a change
5. Spread improvement (Section 1, para. 8)

The Plan-Do-Study-Act (PDSA) cycle encapsulates the principles and “steps” of improvement science. The aim of the PDSA cycle is incremental achievement improvement (Crowfoot & Prasad, 2017). PDSA cycle provides a way to learn how a change works on a small scale before trying it on a large scale. This chapter will present the intervention’s implications for instructional practice, educational leadership, and school policy.

The present study’s drivers of change centered on the overarching question: What promotes or hinders the implementation of science instruction in the early grades? This study included two rounds of the PDSA cycle. My analysis of needs assessment data and consultation with the professional knowledge base of scholar-practitioners directed each improvement cycle. Even though some intervention components varied between iterations, the purpose was ultimately the same—to increase teachers’ efficacy toward inquiry-based science teaching. For the first intervention, I facilitated a curriculum-based professional learning community (PLC) which consisted of six classroom teachers and the school’s curriculum specialist. The PDSA cycle in Figure 96 depicts the improvement science process for the first round of intervention.

Figure 96

First Round of Intervention Plan-Do-Study-Act Cycle

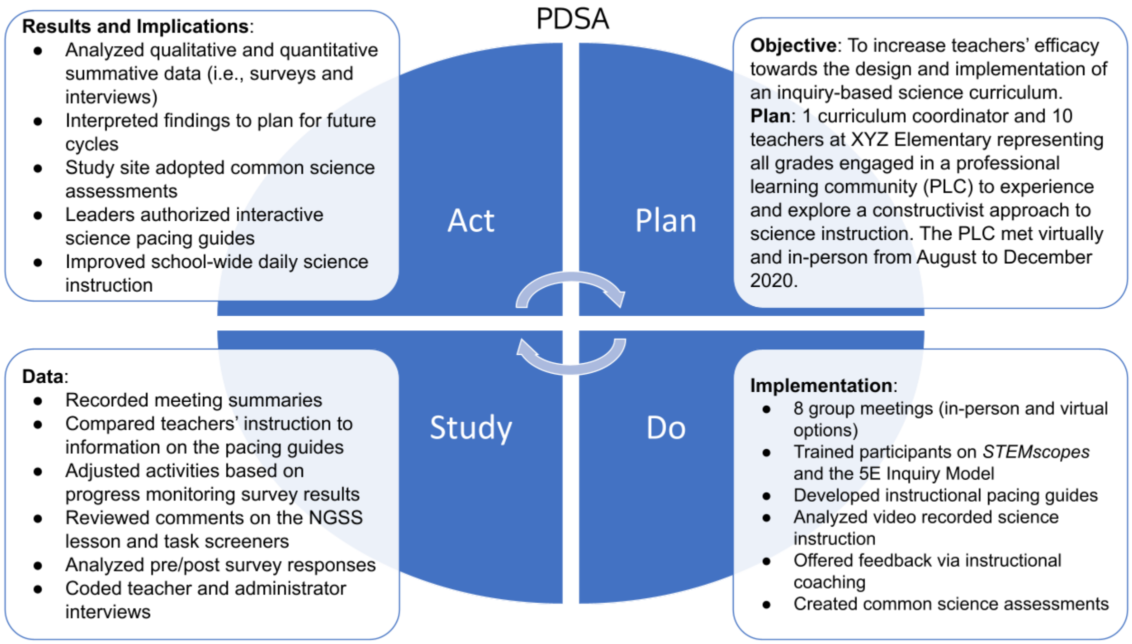


The goal of PDSA is to pursue effective process changes that favorably affect outcomes (Speroff & O'Connor, 2004). Both PDSA improvement cycles involved building participants' capacity for change and development (Harris, 2001, p. 261). I projected that teachers would integrate science standards more frequently in the curriculum by increasing teacher self-efficacy toward STEM instruction. The intervention's design was similar between improvement cycles, but the PLC's strategies and tasks varied based on formative and summative metrics data.

Frequent testing and reflection throughout the PDSA cycle informed this research of its progress and overall impact. This study used numerous metrics to monitor participants' attitudes toward inquiry-based science instruction. The next section will discuss the present study's methods and how quantitative and qualitative data informed revisions to the intervention. The PDSA cycle in Figure 97 imparts a holistic representation of the second round of intervention.

Figure 97

Second Round of Intervention Plan-Do-Study-Act Cycle



Using improvement science, teachers and administrators realize some form of agency. Faculty members *inside* today's schools can use continuous improvement science principles to build teacher capacity and advance student outcomes. The lessons learned from this study give XYZ County Schools access to research-based strategies that support curriculum-based professional learning for elementary school teachers. Evidence from this continuous improvement cycle will guide future iterations at XYZ Elementary School and potentially help other schools interested in increasing teachers' efficacy toward using an inquiry model to teach science.

Discussion of First Round of Intervention Findings

The Office of Occupational Statistics and Employment Projections predicts STEM occupations to increase 8% by 2029, compared to a 3% increase for non-STEM jobs (U.S. Bureau of Labor Statistics, 2020). Our nation's innovation and economic stability depend on future generations of qualified candidates for STEM-related career fields. Early childhood education influences student interest and achievement in STEM (Chesloff, 2013). The more students learn about STEM subjects in the early grades, the more interested and prepared they will be for STEM-related occupations. Elementary school-aged children of all backgrounds and skill levels need daily access to science instruction so they can gain STEM knowledge and competencies.

Despite the growing need for early childhood STEM instruction, there are many obstacles to implementing the subject in the primary grades. This study's problem of practice was inadequate standards-aligned science instruction at XYZ Elementary School. Factors contributing to the lack of inquiry-based science instruction at the study's site included students' limited schema, school priorities focused on other subjects, historically weak STEM standards, insufficient professional development, and low teacher-efficacy levels. The present study sought to increase elementary school students' access to STEM education by improving teachers' attitudes and confidence toward the design and implementation of inquiry-based science instruction. The primary driver for improvement was a curriculum-based professional learning community (PLC) with integrated instructional coaching.

The curriculum-based PLC supported and monitored instructional design and assessment practices to increase teacher efficacy and effectiveness toward inquiry-based science instruction. The intervention's curriculum-based PLC was learner-centered.

Participants constructed the meaning of inquiry-based pedagogy and science standards through active and hands-on interactions with sources and materials. The PLC consisted of various tasks and projects, including:

- design of a Google Site dedicated to science instruction and assessment
- revision of grade-level pacing guides
- development of common science assessments
- training on using the *STEMscopes* curriculum's online platform

The intervention's change drivers were tested throughout the improvement cycle and used for formative and summative purposes. Summative measures included participant surveys and interviews. According to pre- and post-mixed methods data collection, participants' self-efficacy levels increased toward the inquiry process and the Next Generation Science Standards. Increased mean scores for Student Technology Use and Elementary STEM Instruction scales indicate that participants' implementation of inquiry-based science instruction increased, though only slightly, in the first round of intervention (see Table 37 and Figure 98 for pre- and post-intervention mean score data).

Table 37

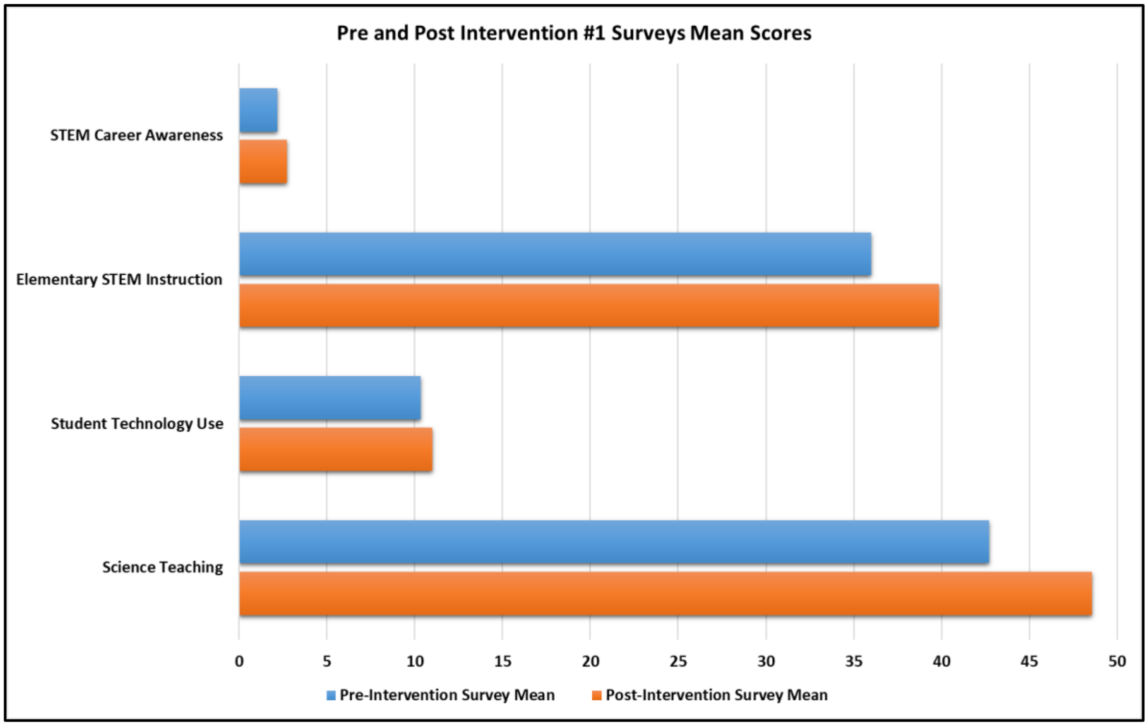
First Round of Intervention Pre- and Post-Survey Mean Scale Scores

Scale	*M (Pre)*	*M (Post)*
Science Teaching	42.71	48.57
Student Technology Use	10.33	11.00
Elementary STEM Instruction	36	42.71
STEM Career Awareness	2.17	2.71

Note. Pre- and post-mean scores increased for all scales of the T-STEM survey.

Figure 98

First Round of Intervention T-STEM Survey Scales Means



Note. Stacked bar chart of mean scores for the first round of intervention pre- and post-surveys.

Post-intervention interview data indicated the areas in which the curriculum-based PLC was effective and the areas needing improvement. Interviews were conducted with the school's curriculum specialist and three teachers (one teacher from each grade level at XYZ Elementary School). Content analysis of interview data provided insight into what worked well during the first intervention and what needed to be improved (Akran & Asiroglu, 2018). Table 38 and Figure 99 display the first round of intervention's major themes from qualitative analysis.

Table 38

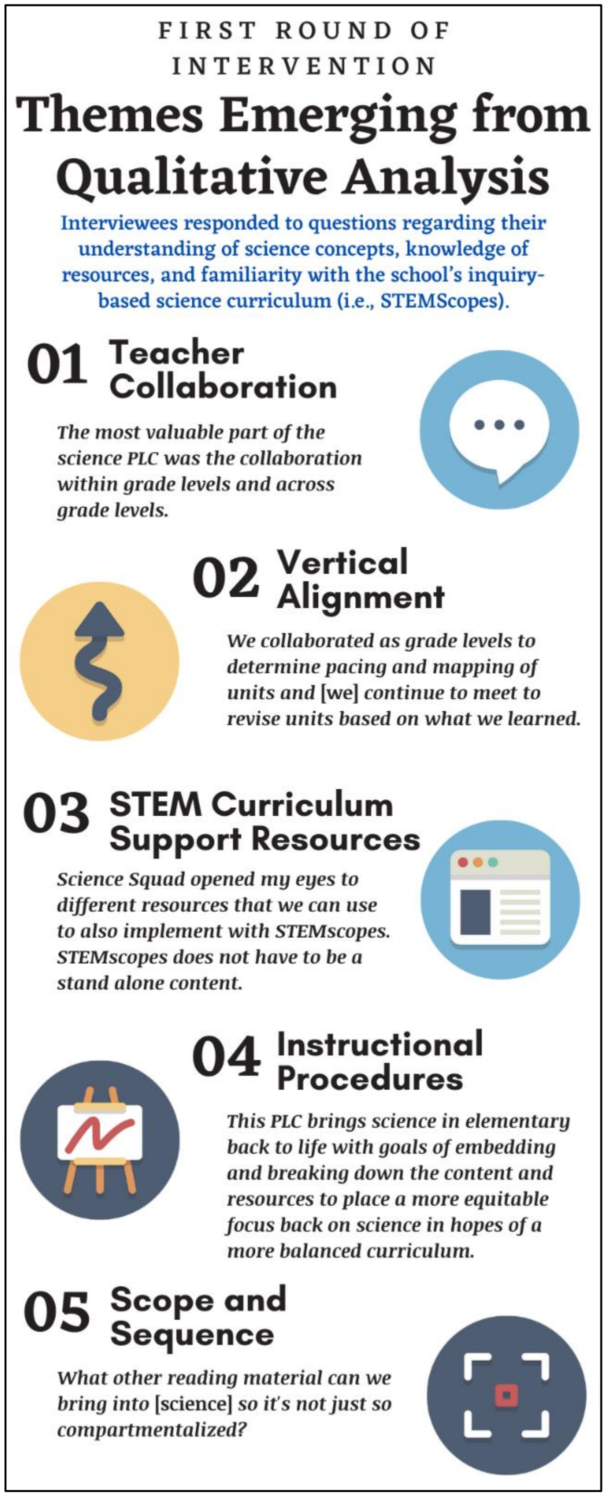
First Round of Intervention Themes

Theme #	Theme
1	Collaboration
2	Vertical alignment
3	Integration of resources in *STEMscopes* (science curriculum)
4	Instructional procedures
5	Scope and sequence

Note. This table lists themes derived from coded interview data.

Figure 99

First Round of Intervention Qualitative Data Findings

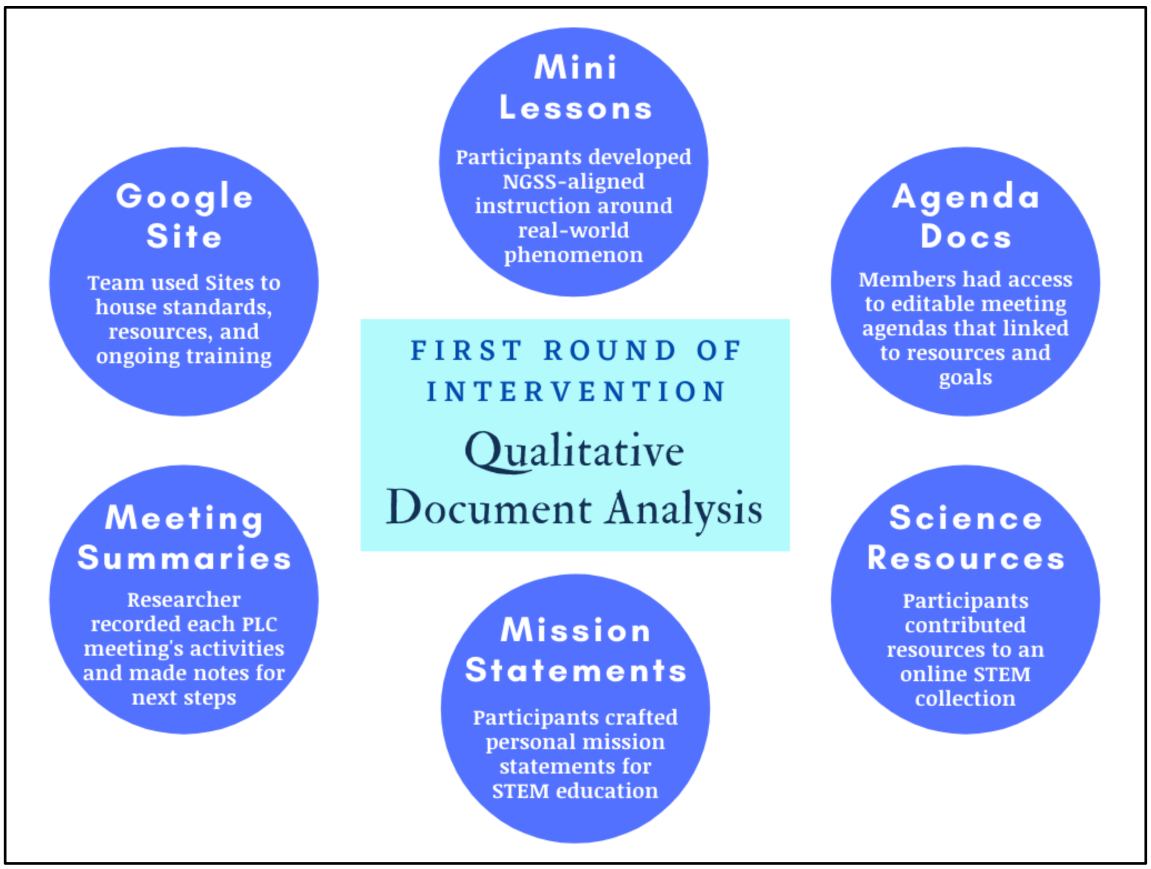


Note. Major themes generated from empathy interviews.

Documents were another qualitative source of data used to assess intervention outcomes. Meeting agendas, mission statements, participant-generated resources, among other artifacts, suggested improvement in teachers' confidence toward STEM instruction. See Figure 100 for the documents and artifacts that contributed to qualitative data analysis.

Figure 100

First Round of Intervention Artifacts that Contributed to Qualitative Data Analysis



Note. Artifacts contributed to qualitative data analysis.

The first round of intervention results are presented within this section relative to the study's three research questions.

Research Question 1

What are the perceptions of elementary school teachers toward the integration of inquiry-based learning in STEM education? The findings from the first round of intervention support three conclusions concerning research question 1.

Teachers perceive science education to be vitally important to students' academic experience. Classroom teachers at XYZ Elementary School valued science education in the early grades. Qualitative data reflected teachers' interest and desire to provide students standards-based science instruction. Teachers, administrators, and district faculty expressed enthusiasm and demonstrated commitment to improving science education at the elementary level. Teachers' optimism toward inquiry-based STEM instruction was evident by their attendance at professional learning community (PLC) meetings, their timely submission of PLC assignments, and their production of numerous outputs.

Teachers value the integration of inquiry-based learning principles to the design and implementation of the NGSS instruction. At the onset of this study, students at XYZ Elementary School infrequently engaged in the inquiry process. Despite the lack of inquiry-based instruction at XYZ Elementary, teachers valued a constructivist approach to learning. Needs assessment data demonstrate participants' desire to plan science instruction based on inquiry models of teaching.

This study's intervention was a PLC that immersed participants in a hands-on preK-12 STEM curriculum called *STEMscopes*. *STEMscopes* is built on the 5E Instructional Model. The 5E Model uses sequences of lessons that incorporate student-centered investigations to assist students' construction of knowledge (Bybee, 2009). One participant noted that the 5E learning model "makes them [students] more excited about science because science is not just sit and get now. We explore to figure out the answer."

During the first round of intervention, teachers learned to compose compelling and supporting questions, which later became part of school-wide science lesson plan templates. Many teachers had scientific inquiry posters hanging in their classrooms to encourage students to ask questions, conduct investigations, and draw conclusions. During classroom teaching and instructional coaching, observations indicated that participants designed instruction around the 5E inquiry process using material from *STEMscopes* and supplementary resources.

Vertical teams increase teachers' understanding of content standards. This study's curriculum-based PLC established a vertical team of teachers who represented multiple grade levels. According to Schlosser (2015), "Vertical teams demand ongoing, consistent collaboration of teachers from both levels [multiple grades] across time" (para. 6). Participants from both rounds of intervention emphasized the value of collaboration with teachers from different grade levels. When asked what would support teachers best in developing and teaching science instruction, a participant commented:

> I think definitely continuing to work collaboratively with other grade levels and other teachers to make sure that you're hitting all the important parts [science standards]. And continuing to have something like *STEMscopes* [science curriculum].

Other study participants affirmed the importance of collaboration with teachers from various grade levels on specific content standards. Vertical collaboration provided participants with new ways of thinking based on the teams' diversity. New perspectives on teaching and learning helped teachers think more deeply about science content. A third grade teacher explained how the vertical science PLC helped "broaden my understanding of the science content as well as my students' understanding."

Dialogue, communication, and collaboration were commonly used words in participants' comments on the first round of intervention's progress monitoring surveys. The following statement makes known how invaluable collaboration is to teachers' pedagogical content knowledge:

> I have found that having a team of people from different grade levels to be the most beneficial. I feel like I have lots of people [PLC members] that I can bounce ideas off of, learn from, etc. I also found that all of the resources are very beneficial for planning science in the future.

Research Question 2

How does immersion in a hands-on preK-12 STEM curriculum impact teachers' self-efficacy beliefs with regard to conducting scientific inquiries? Participants experienced the NGSS-aligned STEM instruction first-hand during the PLC. Results of the first round of intervention support three conclusions in relation to research question 2.

A subject-based professional learning community is implementable in an elementary school setting. This study's intervention was a science-focused PLC. The PLC underwent two improvement cycles spanning two months and four months, respectively. Substantial evidence from the study shows that implementation of the intervention was taking place. For example, I wrote a summary of each team meeting that describes objectives, activities, and resources. See Appendices F and O for copies of both rounds of intervention meeting summaries. Other qualitative data sources indicated continuous implementation of the intervention. The PLC generated a teaching science website, developed the NGSS-performance tasks, curated resources, and more. Under the right conditions and with administrative support, content-specific professional learning communities can be effectively implemented in the primary school setting.

Strong school leadership is crucial to implementing a curriculum-based PLC, but the leader(s) can vary. Strong leadership was present in both rounds of intervention. Administrative support was essential to my PLC's initiation and longevity. The school's curriculum specialist became an active member of both PLC cycles. The specialist played an integral role in planning PLC activities, and she often aided in the facilitation of team sessions. The school principal showed his support of the PLC by attending meetings when his schedule allowed. Teachers felt encouraged by administrators' participation in team planning and action. The principal also helped ensure that the intervention experienced minimal interruptions. For instance, the principal posted PLC meeting times on the school-wide calendar, so events (i.e., faculty meetings) avoided conflicts. XYZ Elementary School's leadership team supported this study by fostering a professional learning environment conducive to collaboration and self-agency.

School reform efforts can come from more places than the positions at the top of an organization. Change drivers can also percolate from the bottom upward (DuFour & Fullan, 2013). This study demonstrates a collaborative culture's impact on sustainable professional development. Members of the curriculum-based PLC worked together interdependently and assumed collective responsibility for improving the science curriculum. The intervention established a shared leadership system comprised of grade-level teachers, the school's curriculum specialist, librarian, and principal. Each participant used their role and strengths to help the team achieve collective SMART goals. The sharing of power and influence during the intervention fostered transformational leadership among all educators at XYZ Elementary School. The present study found that as participants' leadership capacity developed, so did innovation in teaching an inquiry-based science curriculum.

Participation in goal setting fosters teachers' acceptance of group goals. The first two PLC sessions focused on establishing collective and personal goals. Participants are the ones who are doing the work; they need to have a say in the expectations. Goal setting served as a motivational tool, mainly because the intervention's goals were developed based on team members' input (Hallinger, 2011).

During the first PLC meeting, participants shared what they loved about science, their concerns about teaching science, and their hopes for the subject. Information from this activity was used to construct group goals, which participants reflected on at the beginning of each meeting. PLC members also created personal mission statements for science instruction. With permission from participants, I complied the mission statements for all to see.

Acknowledgment of each other's personal goals was an empowering exercise that strengthened the team's collective efficacy. As the PLC facilitator, I made sure that the goals were visible and reflected upon regularly. The goals served as a motivational tool (Hallinger 2011), especially because the intervention's goals were developed based on input from members of the team.

Goal acceptance is important to motivation, but motivation alone does not increase productivity. Outcomes depend on ongoing feedback and support. Due to challenges the PLC faced when COVID-19 forced schools to close, it was difficult to provide participants with frequent feedback. Additionally, many teachers could not implement all the strategies and resources generated in the PLC because of having to teach strictly online for the first time. The second round of intervention operated in a hybrid (digital- and in-person) format. The iterated intervention presented more opportunities for engaging participants in the feedback process.

Individual agency enhances a school's implementation of a curriculum-based PLC at the local level. Any new school initiative presents a risk of failing. Concerns of project implementation usually include limited time, lack of resources, and stakeholder buy-in. This study shows that a best practice of risk mitigation is to nurture people's sense of agency. "Sense of agency refers to the feeling of control over actions and their consequences" (Moore, 2016, para. 1). Members of the intervention's curriculum-based PLC exerted self-control in staying committed to the pursuit of goals.

Participants worked on PLC activities outside of scheduled gatherings and completed tasks on time. Participants' work was purposeful and self-reflective. When teachers spent time designing mini-lessons, constructing compelling questions, and curating resources, they did so intending to use the material to support classroom instruction. The constructivist nature of this study's PLC encouraged participants to take control of their actions. Participants were *not* motivated by deadlines or leaderboards. Instead, they were intrinsically motivated by the desire to give students engaging and hands-on learning experiences in science class.

Research Question 3

How does immersion in a hands-on preK-12 STEM curriculum impact teachers' beliefs related to the constructivist theory of learning/5E Inquiry-Based Instructional Model?

Learning to teach science through inquiry improves teachers' attitudes toward constructivist teaching models (e.g., 5E Inquiry-Based Instructional Model). The intervention helped teachers design and implement constructivist-based science instruction for all students by engaging participants first-hand in the constructivist process. The constructivist theory of learning assumes that students build knowledge as part of a process of making sense of their experiences (Rolloff, 2010). Members of the intervention constructed knowledge by studying the science curriculum and manipulating instructional materials.

XYZ Elementary School subscribes to an online science curriculum called *STEMscopes*. The PLC engaged participants in the 5E inquiry model used by the curriculum developer. The 5E learning cycle leads students through five phases: Engage, Explore, Explain, Elaborate, and Evaluate. Much of the participants' professional learning was driven by their inquiries and connections to classroom instruction. Teachers would then "Explore" new instructional strategies as they curated content for the team's Google Site and completed PLC assignments. Participants' ongoing collaboration in collecting resources and designing instructional procedures improved their attitudes toward constructivism and the 5E Inquiry-Based Instructional Model.

Immersion in a hands-on preK-12 STEM curriculum stimulates and supports teachers' engagement in constructing knowledge through intentional, systematic

inquiry. Participants' immersion in a hands-on STEM curriculum improved their attitudes toward inquiry-based learning and increased their knowledge of science standards and understanding of different pedagogical approaches. The increase in mean scores for the Elementary STEM Instruction scale of the T-STEM survey shows that the first round of intervention improved participants' understanding of science pedagogy (M_{pre} = 36; M_{post} = 39.86). Similar to how students demonstrate science understanding through performance-based assessments, so do teachers when professional learning complies with constructivism principles.

PLC meetings addressed information from science teaching modules provided by the Kentucky Department of Education. However, PLC meeting agendas were planned primarily according to participants' circumstances, interests, and questions. Inquiry is essential to meaningful professional learning. According to Dana and Yendol-Hoppey (2019):

> Teacher inquiry is a vehicle that can be used by teachers to untangle some of the complexities that occur in the profession, raise teachers' voices in discussions of educational reform, and ultimately transform assumptions about the teaching profession itself. (Chapter 1, para. 1)

I implemented the PLC more as an instructional coach than as a facilitator so teachers would learn chiefly through experience and reflection. Because of the intervention's inquiry-based approach to professional learning, participants made changes to science curriculum documents, prepared mini-lessons for virtual and in-person instruction, and generated new resources to supplement the *STEMscopes* curriculum.

Synchronous and asynchronous communication methods expand teacher professional development focusing on pedagogical content knowledge. Traditional professional development (PD) took place in-person between a presenter and attendees. This study took a different approach to PD by convening online. The intervention used Zoom videoconference software to meet synchronously once a week. Zoom enabled participants to exchange ideas, post links in the chat box, and share computer screens to review resources.

Participants also engaged in asynchronous professional learning. For instance, PLC members viewed science teaching videos outside of group meetings. Participants reviewed information uploaded to the team's Google Site. Synchronous and asynchronous communication tools increased teachers' connectivity, suggesting improved collaboration on science education at XYZ Elementary.

Qualitative interview data indicated the benefits associated with synchronous and asynchronous professional learning. Participants commented that the deconstruction of the Next Generation Science Standards (NGSS) during team meetings helped them understand essential concepts and skills. Online learning gave teachers more time to explore the features of the school's *STEMscopes* science curriculum. Members of the PLC received training on the features and structure of *STEMscopes* using various methods, including a scavenger hunt, guided tour, tutorials, and hands-on STEM challenges. Experiencing the science curriculum asynchronously showed teachers new possibilities to integrate science in other subject areas. Participant motivation to engage in asynchronous activities increased by realizing that they would share findings with colleagues at group meetings.

Technology was very influential in planning and implementing the PLC during the onset of the COVID-19 Pandemic and social distancing. Yet, I could not rely on technology alone to satisfy all of my intervention's provisions. I had to consider internal organization factors—task, structure, technology, and people. It was critical that PLC tasks were meaningful and that participants could leverage the structure and technology of the PLC with key goals and activities.

Discussion of First Round of Intervention Theory of Action

Several possibilities emerged from this study that extends beyond the findings produced regarding the three research questions. These ideas and possibilities are discussed within this section. The information focuses on lessons learned in relation to the first round of intervention's theory of action and professional learning in general.

This study's first round of intervention exercised three major educational theories: the constructivist theory of learning, sociocultural learning theory, and transformational coaching. These theories comprised the vehicle for validating actionable knowledge and bringing about change.

Constructivist Theory of Learning

The constructivist theory of learning assumes that people build knowledge as part of a process of making sense of their experiences (Rolloff, 2010; Seimears et al., 2012). Traditionally, teachers may have been in control of the classroom. Some participants had difficulty accepting the fact that students can learn using a constructivist approach. They would rather structure instruction on a whole group model, which can be easier to manage. For teachers to make science instruction constructivist in nature, they must believe in the process. A subject-based professional learning community demonstrates the benefits of a strategy or resource. Ongoing professional development and coaching can help teachers find value in school goals and curriculum objectives (Knight 2007). Teacher buy-in is essential to the enactment and sustainability of a change effort.

Sociocultural Learning Theory

Vygotsky claimed that cognitive development occurs first on a social level and later on an individual level (L. Wang et al., 2011). During the intervention's PLC, participants engaged in planning, discourse, and reflection with other members. Teachers deconstructed science standards, outlined curriculum maps, and developed classroom resources. These kinds of activities made the intervention not only social but also collaborative.

Collaboration amongst teachers from common and different grade levels shaped outcomes that enhanced science education and inquiry-based instruction at XYZ Elementary School. The intervention was not tailored after any bureaucratic model but by educational theory and participant input. Seeking feedback from participants instilled a social learning environment that supported each teacher's inquiry-based STEM practices.

Participants' investment toward enhancing inquiry-based science instruction for students at XYZ Elementary encouraged other teachers to seek information about STEM education and resources. Teachers outside of the PLC accessed information about science instruction from the intervention's Google Site, archived agendas, and the participants themselves. PLC members had the confidence to support colleagues because of their networking and collaboration during the intervention. Principles of sociocultural learning theory were influential to participants' change in attitudes toward XYZ Elementary School's science curriculum and ongoing professional learning.

Transformational Coaching

Transformational coaching strengthened participants' relationships (Crane, 2010). As the intervention's "instructional coach," my role was not to direct orders but to gain insight from participants' conversations and feedback. A coach can learn about their client's behaviors and beliefs through a consistent and intentional layering of learning experiences (E. Aguilar, personal communication, January 1, 2021).

The transformational coaching model follows a holistic approach that focuses on a client's behaviors, beliefs, and ways of being. These things I learned from the Enneagram workshops, Ways of Knowing questionnaires, and one-on-one coaching sessions with participants. I approached coaching sessions with participants' viewpoints and motives in mind. By focusing on teachers' beliefs instead of outputs, participants seemed open and eager to engage in coaching on designing lessons and analyzing student work.

Instructional coaching was effective during the intervention because it was job-embedded. My coaching conversations with participants revolved around reflection and skill (Aguilar, 2020). I helped teachers build resilience by focusing discussions on participants' instructional decisions. Teacher reflections on classroom instruction and student outcomes revealed participants' growth areas and the areas in which they excelled. Reflective discourse on science teaching provided an opening for me to help teachers develop new skills. The transformational coaching process did more than introduce teachers to new resources and strategies. Transformational coaching expanded participants' resilience to provide students with a quality science education.

The transformational coaching model is committed to transforming systems and the people within them (Aguilar, 2020). During the COVID-19 Pandemic, the systems at XYZ Elementary School changed. I was able to apply the principles of transformational coaching to provide participants with ongoing support. For example, to support virtual students' instruction, I would provide teachers feedback on their activities uploaded to the school's learning management system. I also used Google Docs and Slides to tender questions and input on teachers' instructional resources and procedures. We collaborated on these documents in real-time, which made coaching authentic. If a transformational coach plans to stay relevant to a school's needs, they must find alternative approaches to supporting teaching and learning (Aguilar, 2013). While the organization's needs and circumstances are vital to coaching, the focus should always be on the user. The invisible systems in a school (e.g., mental models, biases) will remain unseen if coaching does not explore teachers' emotions, cultures, ideologies, and goals.

Discussion of Second Round of Intervention Findings

Despite the gains made in teacher self-efficacy during the first round of intervention, students' access to inquiry-based science instruction showed little improvement. These and other findings from qualitative and quantitative data informed my revisions to the intervention. Iterations to the study's curriculum-based professional learning community (PLC) embraced principles of collaborative inquiry. "Decision making is usually an iterative, ongoing process whereby the results of one decision provide new information on which to base yet other decisions." (Owens & Valesky, 2014, p. 285). Participants valued their opportunity to collaborate with colleagues across grade levels. The intervention aimed to improve science education in the early grades, but it resulted in much more. I realized that if participants were to make any gains whatsoever, the interventions would need to incorporate culture-building practices (Drago-Severson & Blum-DeStefano, 2018).

Often, interventions focus more on the task, technology, and institutional structure than the human social system. Sociotechnical systems are essential in developing and supporting human behavior inside an organization's infrastructure. The second round of intervention emphasized human relations to encourage teacher buy-in and nurture problem-solving at the classroom level. Owens and Valesky (2014) write, "It matters what people think, how open their communication is, how they deal with conflict, and to what extent they feel involved in their jobs because these kinds of human concerns help determine how much work gets done and how well" (p. 235). This study's revised intervention improved relationship behaviors by specifying goals and exploring individual personalities and preferences. Findings suggest that special attention to each individual's needs while supporting collective goals can improve performance. Participants in the second round of intervention made specific decisions about classroom management, engagement strategies, vocabulary, technology integration, and formative assessment.

Gains in mean scores for all T-STEM survey scales indicate that teachers' attitudes toward inquiry-based science instruction and their implementation of STEM practices improved. Table 39 and Figure 101 present pre- and post-mean score data for all scales of the T-STEM Survey.

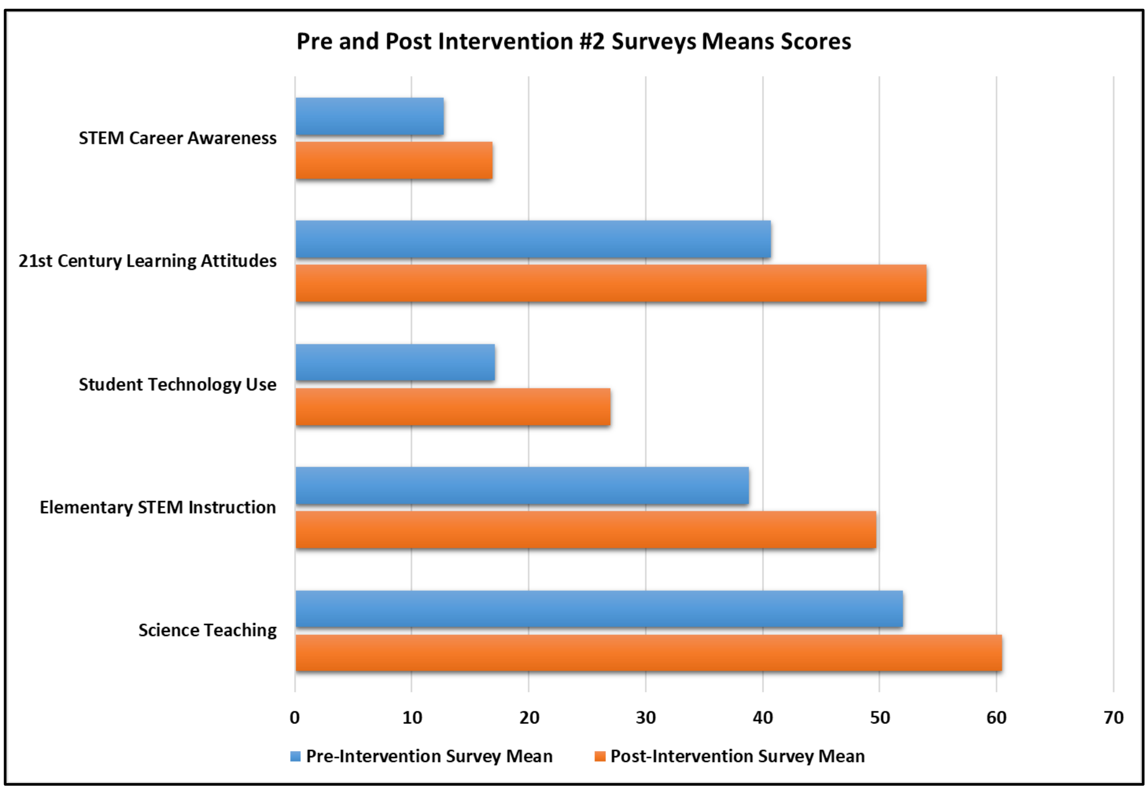
Table 39

Second Round of Intervention Pre- and Post-Survey Mean Scale Scores

Scale	*M (Pre)*	*M (Post)*
Science Teaching	52	60.5
Elementary STEM Instruction	38.8	49.7
Student Technology Use	17.1	27
21st Century Learning Attitudes	40.7	54
STEM Career Awareness	12.7	16.9

Figure 101

Second Round of Intervention Pre- and Post-Survey Scales



Empathy interviews were conducted at the conclusion of iterated intervention's 12-week improvement cycle. Qualitative interview data were collected from the school's principal, curriculum specialist, and a teacher representative from each grade level (n = 5). Post-intervention interview transcripts were assigned open codes and then grouped into themes (Table 40 and Figure 102 display the themes discovered in post-iterated intervention qualitative data).

Table 40

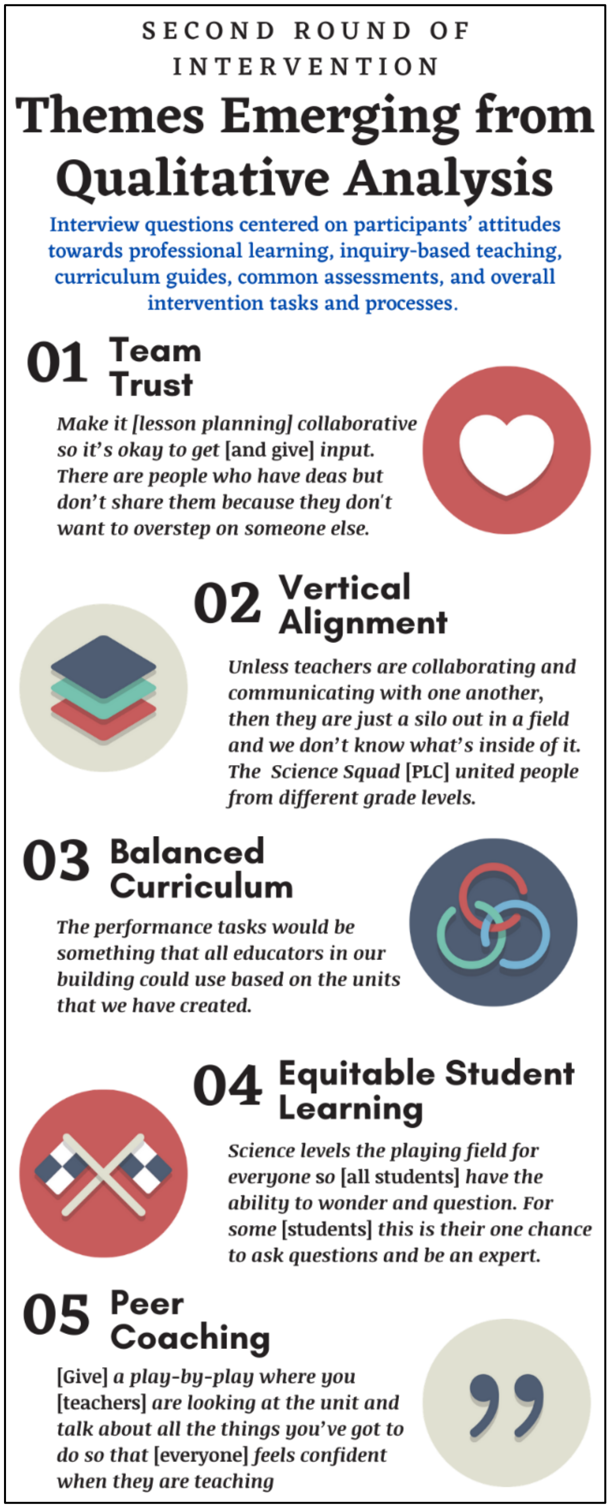
Themes Identified from Post-Intervention Interview Data

Theme #	Theme
1	Team trust
2	Vertical alignment
3	Balanced curriculum
4	Equitable student learning experiences
5	Peer coaching

Note. Five major themes emerged from open coded interview data collected at the end of the improvement cycle.

Figure 102

Second Round of Intervention Qualitative Data Findings

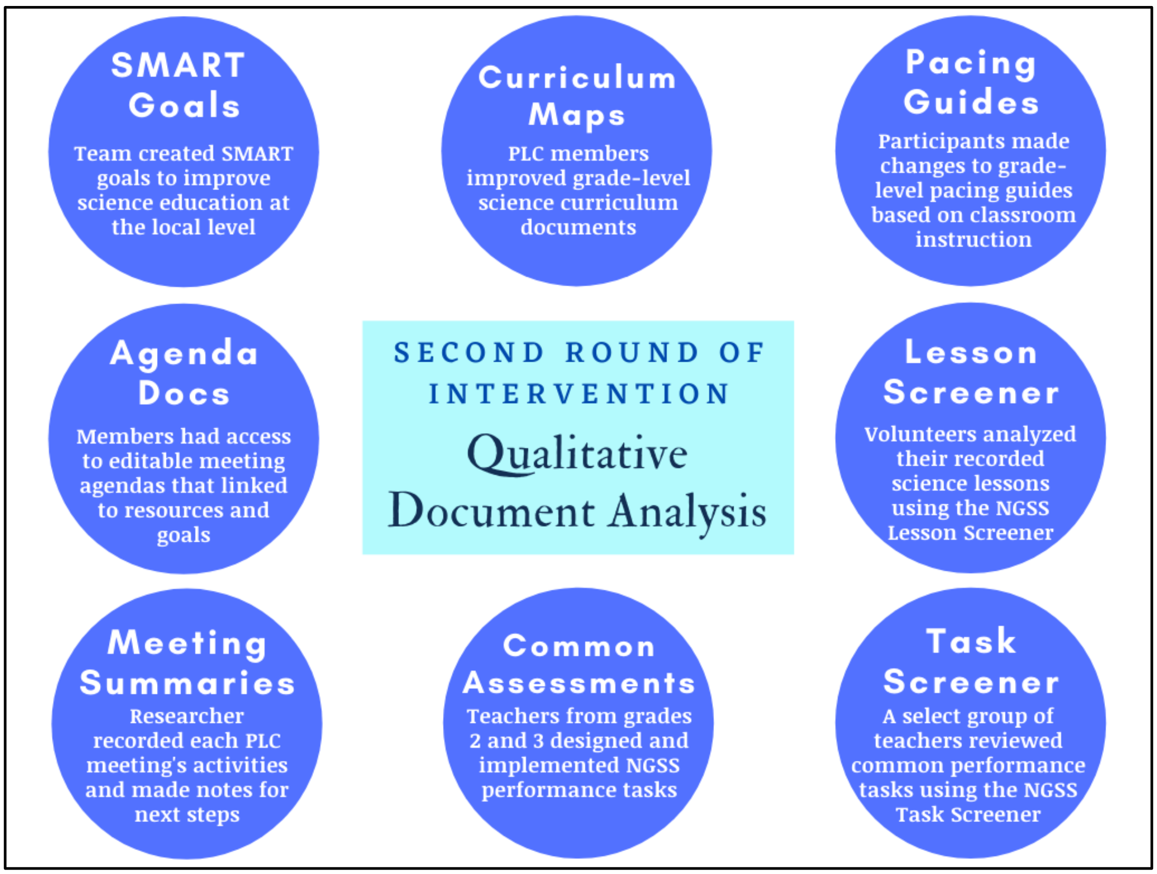


Note. Major themes generated from qualitative data and interviewee statements.

The second round of intervention resulted in numerous outputs. Participants collaborated on the development of curriculum guides, instructional resources, and screening tools for lesson planning and performance tasks. The PLC's documents and artifacts were analyzed to determine the study's key findings. See Figure 103 for a map of the outputs that supported qualitative data analysis.

Figure 103

Second Round of Intervention Artifacts



Note. Artifacts contributed to qualitative data analysis.

Research Question 1 (as revisited after second round of intervention)

What are the perceptions of elementary school teachers toward the integration of inquiry-based learning in STEM education? The findings from the study support two conclusions in relation to research question 1.

Local needs and contextual factors influence teachers' perceptions toward a hands-on preK-12 STEM curriculum (i.e., STEMscopes). The innovation in this study transpired from the implementation of a curriculum-based PLC at XYZ Elementary School. The intervention based its design and iterations on situational factors and a systems perspective rather than on a single leader's orders (Owen & Valesky, 2014). The Teaching and Learning Team at XYZ County Schools supported this study's efforts to improve STEM education and scientific literacy in the early grades. XYZ Elementary School teachers who volunteered in this study's science-based PLC did so with the hope of improving their ability to plan and implement the NGSS-aligned instruction. Consequently, my intervention generated a state of equilibrium between the organization's needs and those of the teacher (Owens & Valesky, 2014).

XYZ Elementary School serves students in grades 1 through 3. Instruction for students in this age range centers on math and reading. Therefore, a STEM curriculum must support teacher goals. For the participants in this study, their priority was promoting students' literacy skills. STEM education challenges students to understand how things work (Bybee, 2010). In learning "how things work," students will develop basic literacy in science, mathematics, and technology (Kesidou & Koppal, 2004). A precursor of any STEM professional development for elementary school teachers should articulate STEM education's effects on students' reading, writing, and speaking skills.

Implementing a curriculum-based PLC as a school-wide reform may enhance overall science education at XYZ Elementary School. This study signifies that curriculum-based PLCs may act as a whole-school professional learning model to improve science education in the early grades. According to DuFour and Fullan (2013), "PLCs can play a central role in dramatically improving the overall performance of schools, the engagement of students, and the sense of efficacy and job satisfaction of educators" (p. 19). The intervention's PLC model provides the ingredients needed for change at the local level: job-embedded training, instructional coaching, quality feedback, coherent curriculum, meaningful assessments, and stakeholder involvement (Houchens, 2018).

School reform may be slow, but there is hope for change in education. The present study's intervention created a positive school culture built on collaborative professional learning. Organizational culture is a driving force behind the work of local actors. Culture shapes people's beliefs, increases their motivation, and encourages participation in the decision-making process (Owens & Valesky, 2014). It matters what people think. Team meetings, small group collaborations, and individualized instructional coaching presented opportunities for participant input and feedback. Open communication, a sense of autonomy, and healthy relationships will bolster reform efforts' effectiveness and longevity. Subject-based PLCs built on collaborative lesson planning, reflective curricular guides, and ongoing coaching can increase students' access to science instruction.

Research Question 2 (as revisited after second round of intervention)

How does immersion in a hands-on preK-12 STEM curriculum impact teachers' self-efficacy beliefs with regard to conducting scientific inquiries?

Ongoing performance feedback increases teachers' goal commitment. This intervention respected participants' autonomy by encouraging them to voice concerns, set goals, and participate in decision-making. In both rounds of intervention, participants collaborated to identify objectives, which they prioritized into PLC goals. Teachers' active participation in goal setting increased their motivation and sustained their commitment to the tasks. According to Owen and Valesky (2014), participative decision-making enhances individuals' motivation, communication, collaboration, and overall group-process skills.

During the study's first PLC meeting, participants shared their love and concerns for science. From conversations about teacher practice and beliefs, PLC members created a long list of goals. In the second round of intervention, participants prioritized objectives and made them into SMART goals. SMART goals focused the intervention's efforts on tasks and inspired an action plan with formative assessment opportunities. Specific and relevant SMART goals resulted in higher performance than long-term performance goals (Latham & Brown, 2006).

The first round of intervention demonstrated a need for more coaching and instructional support. Revisions to the subsequent PLC design focused on improving participants' collective efficacy by applying Bandura's social cognitive theory and personalized instructional coaching. In an attempt to provide personalized support, feedback was based on group goals and individual preferences. Participants' personality types and ways of knowing were explored through the Enneagram and constructive-developmental theory. Authentic and differentiated instructional coaching helped teachers incorporate research-based STEM practices in their classrooms. Findings suggest that teacher commitment to team goals is sustained by ongoing support from peer coaches, curriculum coordinators, and school leaders.

Educators who collaborate in the design of common performance assessments are more likely to implement the tasks during classroom instruction. All PLC members were given information and training on resources and strategies for designing common science assessments. At team meetings, participants reviewed the contents in Through Course Tasks (Next Generation Science Standards (NGSS)-aligned performance tasks) from the Kentucky Department of Education. Teachers discussed how sample Through Course Tasks could be adapted to meet their classroom needs. Yet, not every participant implemented modified versions of the state department's science tasks. The teachers who designed summative performance assessments did so collaboratively outside of scheduled PLC meetings with instructional coaching support.

Four participants volunteered to design and administer a common science assessment. The small group assessment team used several resources to support their work (e.g., *STEMscopes* curriculum materials, literacy graphic organizers, technology tools). The most influential resource in the collaborative design process of common science assessment was the NGSS Task Screener Tool. The assessment screener provided the group "with a common set of features to ground conversations about what it "looks like" for students to demonstrate the kinds of performances expected by three-dimensional [science] standards" (Next Generation Science, n.d.-d, para. 1). Criterion on the screener tool aided in participants' design of common assessments and directed their review of an assessment’s quality post-implementation. Participants recorded suggestions for improving future iterations of the performance tasks (see Appendices T and U). Teacher collaboration on the development of science assessments calibrated student expectations around the NGSS science and engineering practices.

The collaborative design of summative performance tasks gave participants a greater sense of responsibility to administer the instruments with students. Members of this study’s assessment design team supported each other in implementing performance tasks by sharing resources, planning instructional responses, and exploring areas for improvement (Erkens, 2016). Participants especially found it beneficial to reflect with grade-level teammates after each phase of the performance task. Topics of these discussions included but were not limited to introducing directions, modeling techniques, and guided practice strategies. Reflective dialogue opened space for teachers to work through the implications of their science performance assessments. The implementation and reflection that ensued in the design of common summative tasks would have been unlikely without collaboration at the center of the process.

School districts influence the implementation of a curriculum-based PLC at the local level by providing support and resources. Implementation of the intervention’s change drivers involved many systems and actors. My network of individuals with specialized skills helped me plan, monitor, and facilitate the PLC according to local contexts and needs. For instance, school administrators aided in recruiting teacher-leaders for the science PLC. Central office staff granted teachers the choice to use their time engaged in the intervention for professional development credit. XYZ County Schools’ Information Technology Communication (ITC) staff supported the intervention’s use of videoconferencing software and digital learning materials. The school district's Teaching and Learning Team provided participants access to *STEMscopes* training modules. The individuals engaged in this study's curriculum-based PLC extended far beyond the participants in the research setting. School district staff plays an important role in sustaining school reform even if the change idea originates at the local level. Employees in various departments across a school district, from ITC to Finance, can provide the expertise and resources a PLC needs to undergo multiple improvement cycles.

Research Question 3 (as revisited after second round of intervention)

How does immersion in a hands-on preK-12 STEM curriculum impact teachers' beliefs related to the constructivist theory of learning/5E Inquiry-Based Instructional Model?

How a school perceives a constructivist approach to professional development influences the local site's implementation of a subject-based PLC. Teachers at XYZ Elementary School have acknowledged that their learning experiences as P–16 students did not assume a constructivist perspective. Principles of constructivism are becoming more mainstream due to the growing popularity of inquiry-based learning. Nevertheless, most teacher professional development (PD) uses a conventional approach to learning (e.g., lectures, demonstrations). Kentucky legislation requiring certified staff to complete four days or 24 hours of PD has bred teacher complacency. For many educators, PD is another task to be completed rather than a means for growth and innovation. The present study's curriculum-based PLC, on the other hand, is learner-centered. Participants constructed meaning of inquiry-based science instruction through active and hands-on interactions with sources and materials. The constructivist approach to professional learning guarded against teacher complacency and promoted a resolved determination in PLC members to improve students' science curriculum.

This study suggests that most teachers are interested in a collaborative and hands-on approach to PD that endures over time. Participants in this study learned about science teaching practices through various methods. For instance, PLC members engaged in dialogue; they analyzed sample lesson plans, deconstructed state science standards, practiced using STEM resources, developed assessments, and refined curriculum documents. Professional learning opportunities for teachers on science and other subjects should be more than traditional three-hour seminars. Teachers need opportunities to participate in the learning process through study, practice, reflection, and ongoing collaboration.

Instructional coaching gives teachers ongoing support in implementing inquiry-based instructional practices. I served as an instructional STEM coach during both rounds of intervention. Findings suggest that the presence of an instructional coach improves teachers' attitudes and increases teacher outputs. During this study's intervention, participants collaborated during coaching sessions on curriculum development. For instance, I coached teachers through the revisions of science curriculum maps and the development of common science assessments. Coaching engaged participants in reflective exercises after they implemented inquiry-infused science instruction. During post-observation meetings, I asked individuals more questions than I gave feedback. The feedback I did provide was per teacher reflections and their preferred ways of knowing. This inquiry-based style to instructional coaching established rapport between teachers and the PLC facilitator. Many of the outputs generated during this study (e.g., curriculum maps, common assessments, daily lesson plans) resulted from ongoing instructional coaching. Coaching provides teachers with just-in-time support that helps PLCs realize their SMART goals.

A constructivist approach to professional learning increases teachers' engagement in the review and modification of curriculum maps. Revisions to grade-level science curriculum map show how a vertically-aligned PLC can improve school curriculum documents. Participants made revisions to curriculum guides after having reflected on classroom instruction and student learning. The PLC's curriculum development process was user-centered. I did not make curriculum decisions in advance but rather from participant input as they actively used and studied standards, resources, and content from *STEMscopes*. In fact, improving science curriculum documents originated from the SMART goals that PLC members established.

The curriculum maps revised during the present study were created in Google Slides. Slides allowed participants to reflect on daily instruction in real-time. At team meetings, participants could view colleagues' comments to improve their instruction and modify each grade's science curriculum scope and sequence. A constructivist approach to curriculum development was essential to the newly designed scope and sequence science guides at XYZ Elementary. Had participants not created and modified curriculum maps based on their experiences and reflections, passivity would have brought the process to a halt.

Collective agency enhances the implementation of a curriculum-based PLC at the local school level. Participants collaborated on activities that supported PLC goals and aligned with the school district's mission to improve science education. Collaborative inquiry in a vertical team environment instilled in teachers a shared understanding and appreciation for the school's overall organizational structure. Participants became more aware of the systems and actors that tend to inspire change (e.g., district leadership, education policy). Fortunately, participants did not succumb to bureaucracy constraints; they maintained a sense of agency even when presented with new challenges. Rarely does a scientific approach to decision-making work. Problems and challenges require a human element to its remedy. After all, personnel will be the ones who ultimately carry out school reform activities. This study's PLC adapted itself according to interferences and other change factors by embracing each participant's diverse set of ideas and strengths.

The intervention helped teachers build a sense of collective efficacy in various ways. One key approach was having participants come together to complete a system map for science education at XYZ Elementary School. This activity emphasized the holistic nature of the PLC's work and how factors contributed to or hindered our progress. Owens and Valesky (2014) explain, "emphasis on holistic thought—which seeks an understanding of the complexities, interconnections, ambiguities, and uncertainties of educational organizations—might be more fruitful in decision making than the linear and step models proffered in the past" (p. 293). Examining the problem of practice and decisions from individualist and collectivist perspectives revealed the purpose behind our efforts. It was important for participants to remember the intervention's goals, especially when we experienced unforeseen contingencies from the COVID-19 Pandemic. A strong sense of collective kept the team's level of task commitment high.

Discussion of Second Round of Intervention Theory of Action

Implementation of this study's intervention cycles relied on adaptive leadership principles, developmental theories, and adult learning theories. The second round of intervention revised its theory of action using three theories: constructive-developmental theory, Enneagram theory of personality, and social cognitive theory. Principles from these theories comprised the vehicle for generating, testing, and validating actionable knowledge. This section explores lessons learned from iterations to this study's theory of action.

Social Cognitive Theory

Owen and Valesky (2014) proclaim the hallmark of Bandura's social cognitive theory to be "that individuals can proactively control their development and make things happen by taking action" (p. 139). How can you expect a student or teacher to learn something well enough to put it to practice if they never had the experience for themselves? The goal of this study's intervention was to promote teachers' collective efficacy in teaching science by engaging PLC members in scientific inquiry using STEM resources, analyzing student data, making instructional decisions, and developing common science assessments. The keyword here is "engaging." Hence, my reasoning for developing a curriculum-based professional learning community (PLC) which promoted the creation of new knowledge through collaboration and reflection (Sigurðardóttir, 2010).

Participants in this study found value in performing tasks. Teachers were inspired by the process that would make improvement possible. The intervention's design increased team members' perception of the value of their work. Teachers experienced the joys and impacts of inquiry-based learning for themselves first before planning the science curriculum. A positive perception of inquiry-based STEM instruction's import engendered participants' desire to make constructivism a classroom staple at XYZ Elementary.

Enneagram Theory of Personality

The Enneagram proved an effective tool for motivating participants. Teachers were motivated by a deeper understanding and appreciation for their personalities and instinctual biases. Self-awareness of feelings, triggers, and passions helped participants adapt to new situations. PLC members approached tasks from perspectives that best suited their personalities and the preferences of others. Acknowledging colleagues' personality types can help build a positive learning and work environment. The Enneagram results led to reflective discourse about why we care, how we learn, and what we want to accomplish. These factors were instrumental to the planning of intervention meetings and tasks.

Long-term projects can lose sight of their relational norms. This study found it difficult to maintain a focus on participants' Enneagram types. I attempted to re-engage participants in the Enneagram by facilitating introductory exercises at meetings and posting information to the team's digital networks. As time went on, participants became more interested in achieving PLC tasks than building relationships. Teachers assumed their relationships with colleagues were strong. While this may have been true, attention to people's biases and motivations will improve productivity. The effects of curriculum-based PLCs will vary from one organization to the next. The PLCs that calibrate their members' orientations to emotional intelligence are the ones most likely to persevere in the face of adversity.

Constructive-Developmental Theory

Drago-Severson’s ways of knowing helped participants grow as teachers, leaders, and learners. PLC members worked together to design the Next Generation Science Standards (NGSS) instructional procedures and resources. Participants gave feedback to one another based on evidence and their sense-making preferences. Activities such as these may seem small on the surface, but deep down, they boost motivation and collaboration. Paying special attention to individual feedback preferences gave participants a greater sense of purpose in what they do each day in and out of the classroom.

Participants found the process of identifying their preferred way of knowing invaluable. The process spanned multiple PLC sessions so as not to overwhelm participants with too much information and to focus on constructive-developmental theory principles. I realized that teachers needed to practice employing the constructive-developmental theory in the context of feedback. I used participants’ ways of knowing to guide how I delivered instructional coaching support, but teachers never practiced employing the constructive-developmental theory themselves. Experience and reflection with Drago-Severson’s ways of knowing in the context of feedback would illustrate to participants how their sense-making preferences influence professional development. When possible, curriculum-based PLCs should approach processes and tasks using a constructivist approach to learning, from developing curriculum to understanding emotional intelligence.

Limitations

This study produced numerous key findings. As with most research studies, the design of the current study is subject to limitations. This section discusses five primary limitations to this study and explains how these limitations affected the research findings. Discussion of limitations will help guide future research on topics associated with the intervention's curriculum-based PLC and teacher efficacy toward inquiry-based science instruction.

COVID-19 resulted in school closures and changes to the learning environment. The pandemic prevented participants from meeting in person in the spring of 2020. The curriculum-based PLC was facilitated online via Zoom. A constructivist approach to professional development was difficult to implement in a virtual setting. In the 2020 fall semester, students attended school four days a week on a hybrid schedule, which combined in-person teaching with online learning. The hybrid learning model was completely new to participants. Teachers had to learn video production techniques and blended learning strategies. Pandemic learning conditions presented many challenges to teaching and learning. As participants engaged in this study's curriculum-based PLC, they also navigated changes to classroom instruction in the context of COVID-19.

The second limitation was the lack of research relative to virtual professional learning communities. Although I located ample literature regarding professional development (PD) effects on teacher efficacy, research on remote professional learning was not included. Existing research focuses on the impact of massive open online PD, not local learning communities. My two improvement cycles were based primarily on a body of literature about PD's influence on increasing teacher efficacy levels. This study demonstrates a need for more information on virtual professional learning communities that use synchronous and asynchronous digital communication tools.

The third limitation was the sample size. The present study's interventions took place at one research site—XYZ Elementary School in Kentucky. Small sample size makes it difficult to find significant relationships from the data (University of Southern California Libraries., n.d.). Additionally, small studies can sometimes overestimate an intervention or change driver (Hackshaw, 2008). A larger study would have minimized the standard error and increased the confidence levels of summary statistical analysis (Binu et al., 2014).

The fourth limitation concerns the consideration of the amount of time chosen to collect quantitative and qualitative data. Data during the first round of intervention was gathered over eight weeks. Implementation of the professional learning community was conducted during the last two months of school, which limited my analysis of classroom implications. The second round of intervention began at the beginning of the 2020–2021 school term and ended in December 2020. Both intervention cycles' implementation and analysis were performed within a calendar year. A study lasting an entire school year or more would demonstrate the long-term effects of a curriculum-based PLC on teacher efficacy levels.

Additionally, this study's results must be interpreted with caution as I was also a participant and employee at the research site. I undertook actions to minimize bias (e.g., member checking, participant anonymity, statistical testing). "However, wishful thinking is not rare in scientific research" (Simundic, 2013, p. 14). It is possible that, as the researcher, I was unintentionally biased toward results that best supported the study's research goals (Simundic, 2013). Despite every effort to maintain the integrity of data collection and analysis processes, my potential bias or subjectivity must be acknowledged.

Confounding factors also presented limitations to this study. It is possible that increases in teachers' efficacy levels were not a result of the intervention alone. Confounding factors were also responsible for this study's outcomes. Possible confounders include participants' teaching experience and emotional stability. It is virtually impossible to adjust for all confounding variables (Skelly et al., 2012) but acknowledging their existence can help design future research projects.

Recommendations

This study's interventions presented new insights regarding specific change drivers and their potential to improve teacher efficacy toward content standards and constructivist teaching practices. During this study's curriculum-based PLC, observations and formative data analysis signified alternative possibilities for improving teacher efficacy toward STEM instruction. This section discusses recommendations to advance teacher professional development, collaborative inquiry, school culture, and elementary-aged students' access to standards-based science instruction.

1. Engage PLC members in various protocols to help educators reflect more deeply on student outcomes and classroom practices. In *Learning by Doing: A Handbook for Professional Learning Communities at Work*™, DuFour et al. (2013) describe how protocols can be used to guide collaborative teams' work. Protocols increase teacher participation because they require the input and support of all team members. This study's second round of intervention had success using screening

tools with a small group of teachers. Future PLCs at XYZ Elementary School should use protocols to examine student learning evidence, engage in thoughtful dialogue, and set short-term SMART goals to improve instructional units (DuFour et al., 2013).

2. Provide teachers with formal training on digital learning materials. The majority of a PLC’s work centers on the planning and evaluation of classroom instruction. Instructional strategies and resources are in a constant flux of change, especially since the COVID-19 Pandemic began. Teachers need training on how to use educational technology’s features and applications. Digital learning coaches should demonstrate blended learning strategies for classroom instruction. Without proper teacher training and support structures on digital learning materials, a PLC’s change drivers will lose momentum over time no matter how significant their results are initially.
3. Utilize synchronous and asynchronous communication tools to support teachers’ professional growth. Professional development at XYZ Elementary School should include online learning tools such as training videos, self-paced modules, educational podcasts, and of course, videoconferencing software. Innovative communication tools play an essential role in what teachers learn and how they learn. Hassel and Hassel (2012) write, “Digital technology makes it possible for teachers to learn from videos of great teachers, obtain critical and timely feedback on their video-recorded lessons, and connect with other teachers as mentors or peer-helpers” (p. 20). The demand for virtual professional development in recent months due to COVID-19 shows no signs of stopping. Schools need to embrace

innovations associated with digital learning materials when supporting teaches' professional growth.

4. Allocate time and resources for PLC members to observe each other's classroom instruction. "Peer-to-peer observations involve teachers identifying goals and watching colleagues teach to expand their knowledge, practice and pedagogy" (Hamilton, 2013, p. 42). It can be difficult for XYZ Elementary School to embrace a model of peer observation because of scheduling conflicts and teacher isolation. But the rewards are well worth the effort. The peer observation process is a viable means toward team unity and teacher growth (Venables, 2011). Allowing every PLC member to observe and be observed by fellow classroom teachers would help prioritize PLC protocols and lesson screeners around student learning.
5. Invite teachers from other schools in the district to participate in subject-specific PLCs. Collaboration across school buildings is easier than ever because of advancements in digital communication tools and teachers' efficacy toward using educational technology. Districtwide PLCs would expand collective action and efficacy on improving STEM instruction in all grades, including early childhood education. According to Van Clay and Soldwedel (2011), authors of *Aligning School Districts as PLC*, vertical teams "raise [educators'] professional aspirations, expand their approaches to teaching, and deepen their commitments to learning" (p. 82).

Implications

The major finding of this study was that teacher efficacy is at the core of curriculum reform. Data suggest that a constructivist approach to professional learning can increase elementary school teachers' efficacy toward science teaching. The design, implementation, and iterations supporting this study's improvement project have several implications. Findings from both rounds of intervention indicate a curriculum-based PLC's potential to impact practice, leadership, and future research.

Implications for Practice

Traditionally, professional learning communities (PLCs) at XYZ Elementary School consisted of grade-level teams of teachers who coordinated efforts to improve classroom instruction. This study's improvement cycles engaged teachers from various grade levels in ongoing professional learning on a specific subject (i.e., science). The common theme throughout the study was the need for a vertical teaming approach to professional development (PD). Qualitative data indicate teachers' desire for more communication across grade levels. Vertical teaming fosters organizational learning and supports school reform efforts. According to Ng (2017):

> Vertical teams have the potential to increase teachers' awareness of the interdependence of their work, to leverage human capital within under-resourced schools, and to engage teachers in developing school-wide improvement strategies. (p. i)

Even if most PLCs at XYZ Elementary School continue to operate as grade-level teams, PD should be collaborative and constructivist in nature. The more teachers experience curriculum resources and instructional strategies in a social environment, the better prepared they will be to implement new practices with their students. The most effective professional learning models are those that endure over time and engage teachers in collaborative inquiry. In the present study, the curriculum-based PLC and instructional coaching increased teachers' sense of self and collective efficacy. Similar professional learning opportunities at XYZ Elementary can further support collaborative inquiry through shared SMART goals, exploratory approaches to instruction, and reciprocal feedback exchange.

Social cognitive theory adopts a perspective in which collective agency is exercised through shared beliefs in the power to produce effects by collective action (Bandura, 2000). Results from this study suggest that collective agency also inspires individual action. Perceived collective efficacy gave participants a stronger sense of personal agency. "Collective efficacy fostered groups' motivational commitment to their missions, resilience to adversity, and performance accomplishments" (Bandura, 2000, p. 75).

Participants' growing sense of positive interdependence influenced action to integrate change drivers. For example, participants collaborated on interdisciplinary curriculum design. A team of teachers from the intervention deconstructed English Language Art (ELA) standards and made connections to science concepts. Next, the team aligned the Next Generation Science Standards (NGSS) with skills and topics found in stories from *Journeys* which is the comprehensive ELA program used by all teachers at XYZ Elementary. Teachers created their own integrated ELA/Science curriculum map and contributed resources in a shared Google Drive. Participants continued collaborating on science curriculum development well after the official end of the study. Teachers' increased levels of efficacy toward STEM instruction powered and sustained collective and personal action.

Interactive pacing guides build teachers' reflective capacity through thoughtful analysis of instruction implementation and student outcomes. Typically, a curriculum pacing guide is developed at the beginning of the school year and is seldom revisited. The interactive Google Slides science pacing guides used in this study encouraged teachers to reflect more deeply on a unit's standards, when the unit occurs, and how it could be improved next year. To maximize digital curriculum documents' potential, PLC meetings and coaching sessions should dedicate time each month to revising content areas' pacing guides. By prioritizing the review and revision of curriculum maps and pacing guides, teachers can provide in-depth, cross-curricular instruction that targets meaningful learning goals.

A vertical curriculum-based PLC establishes a coaching culture where members feel valued and respect other people's beliefs. Participants' behaviors and attitudes were what created a coaching culture in this study. PLC members worked together to "develop discussion techniques, information sharing, observation protocols, lesson plan formats, and other tools [e.g., pacing guides, curriculum maps] that can be differentiated to meet each teacher's needs" (Kise & Russell, 2010, p. 41–42). Teachers in this study developed a common language for discussion, they understood their colleagues' preferences and personality types, and they acknowledged the need to differentiate PLC objectives, tasks, and feedback. Hence, all teachers get what they want and need (Kise & Russell, 2010).

As participants began to implement and reflect more on inquiry-based STEM practices, they soon realized the need for outside input on what happened inside their classrooms. Teachers in the study accepted and appreciated the support they received from peers. When teachers understand their colleagues' strengths, personality types, and sense-making preferences, they will be more likely to seek peer support. This study proves that a peer coaching culture can be established through continuous professional learning. In all teacher professional development efforts, peer coaching should be the chief goal. For peer coaching to be effective and sustainable, leadership must focus school reform and improvement efforts on a transformational coaching model.

Implications for Leadership

This study's leadership framework was situated on adaptive leadership. "Adaptive leadership is a practical leadership framework that helps individuals and organizations to adapt to changing environments and effectively respond to recurring problems" (Mulder, n.d. para. 1). Findings reveal that adaptive leadership theory is, indeed, very influential to the implementation of professional development reform efforts. It is also apparent that transformational leadership was equally as influential to this study's design and implementation. This section discusses the implications of adaptive leadership and transformational leadership on teachers' professional development.

Adaptive Leadership

Adaptive leadership theory is very influential to the implementation of professional development reform efforts. According to Heifetz et al. (2009), "The single most important skill and most undervalued capacity for exercising adaptive leadership is diagnosis" (p. 12). Participants in this study's curriculum-based PLCs worked together to develop a system map related to the lack of science instructional time at XYZ Elementary School. Thoughtful discourse on the factors that influence inquiry-based STEM supported the development of SMART goals and PLC activities. Acknowledgment of what contributed to the problem of practice was an important first step in participants' understanding of the systems that affect school improvement. No one is more caught up in what happens in the classroom than the teaching staff. Adaptive leadership helped teachers achieve some distance from “on-the-ground” events and view the learning environment holistically (Heifetz et al., 2009). Administrators and teacher-leaders must consider the systems in place, the contextual factors, and the stakeholders’ needs when implementing a course of action.

The design of this study’s curriculum-based PLC was based on data from multiple metrics. I engaged teachers and administrators in conversations about survey data, interview themes, and document analysis findings. Reviewing data as a team provided a unique perspective on the PLC’s effectiveness and possibilities for improvement. All professional learning opportunities at XYZ Elementary School should encourage teachers to “diagnose” problems and formatively assess progress using various data sources. Evidence-based decision-making will help school leaders address specific challenges and achieve organizational goals.

“Adaptive leadership is the practice of mobilizing people to tackle tough challenges and thrive” (Heifetz et al., 2009, p. 31). The educational landscape seems to be in a constant state of transformation. Schools, as was the case in this study, experience multiple changes to the learning environment (e.g., virtual, hybrid), new instructional models (e.g., 5E inquiry model), and variation in teachers’ abilities (e.g., self-efficacy levels). My science curriculum-based PLC took a constructive approach to professional development (PD), as should other projects seeking to lead adaptive change. Improvement is an iterative process—so is leadership. Multiple rounds of experimentation will give faculty time to reflect, learn from mistakes, and refocus goals and behaviors. Adaptive leaders who adopt an experimental mindset improvise as they go, seek new alternatives, and acquire resources (Heifetz et al., 2009) so faculty are engaged in growth rather than PD credit.

Both rounds of intervention were implemented during one of the most challenging times of participants' professional careers—COVID-19 Pandemic. Adaptive leadership was instrumental to how the intervention addressed adaptive challenges associated with pandemic learning conditions. Through collaborative inquiry, experimentation, and instructional coaching, the curriculum-based PLC increased teachers' efficacy toward science and created a coaching culture. The following statement by Heifetz et al. (2009) in *The Practice of Adaptive Leadership* articulates the impact adaptive leadership has on problem-solving and culture building:

> Mobilizing people to meet their immediate adaptive challenges lies at the heart of leadership in the short term. Over time, these and other culture-shaping efforts build an organization's adaptive capacity, fostering processes that will generate new norms that enable the organization to meet the ongoing stream of adaptive challenges posed by a world ever ready to offer new realities, opportunities, and pressures. (p. 36)

This study found adaptive leadership invaluable to the curriculum-based PLC's navigation of teacher training demands and challenges. PLC members took time to explore issues from multiple angles, investigate new developments, seek different ways of thinking, and design thoughtful plans. Adaptive leaders maintain a growth mindset as they lead their organization through unforeseen contingencies and unexpected setbacks. As the context changes so do their leadership style.

Effective leaders realize that their approach to leading change will vary depending on the situation at hand. Throughout the seminal text *Organizational Behavior in Education: Leadership and School Reform*, Owens and Valesky (2014) make the case that there is no one best way of managing problems and leading change. According to Hallinger (2011), "Leaders must adapt their styles to changing circumstances and highlights the need for leadership development that enhances flexibility in leadership styles and strategies" (p. 135). I had to adapt leadership styles many times during the intervention. I found the principles of transformational leadership to be especially impactful to my decision-making.

Transformational Leadership

Transformational leadership is not unlike adaptive leadership. Both models focus on organizational goals. According to Changing Minds (n.d.), transformational leadership is defined as a process where leaders and followers engage in a mutual process of raising one another to higher levels of morality and motivation. The process of transformational leadership gives meaning and purpose to an organization. Integration of transformational leadership in this study's intervention helped me earn participants' trust. Findings show that leaders can build trust when focusing on goals, communication, relationships, and motivation.

Transformational leaders are goal-focused. They want to serve the vision. Teachers and administrators (i.e., curriculum specialist, principal) involved in this study's PLC were motivated by a common purpose. The team established SMART goals early into the intervention. Participants discussed objectives at the beginning of each PLC meeting. These conservations clarified assumptions, provided direction, and instilled collective self-confidence (Heifetz & Laurie, 2001). Goal setting activities revealed each participant's strengths and potential for personal growth. Consequently, participants began looking for support from their peers instead of solely depending on the PLC facilitator. A leader's attention to the vision of a reform effort unites employees around a common front.

Randy Dobbs, Chief Executive Officer at American Vision Partners, suggests that the biggest key to effective transformational leadership is the communication process (Dobbs & Walker, 2010). The increase in participants' self-efficacy levels toward inquiry-based science instruction resulted from many factors, all of which relied on communication. First, the vision and SMART goals of the science PLC were frequently reviewed and discussed. Never losing sight of objectives demonstrated to participants that the intervention's work was vital to the organization. I embedded creative communication tools to expose goals and promote collaborative learning. For instance, I designed a dashboard in Google Docs to be accessible by participants to view meeting summaries, progress notes, and task descriptions. The dashboard and interactive meeting agendas motivated participants to complete duties to serve the PLC's vision.

Transformative leaders do much more than *communicate* information. In transformational leadership, communication is a reciprocal process. I used constructive-developmental theory to discover participants' sense-making and feedback preferences. Leaders should devote professional development to exploring staff's personality types (i.e., Enneagram) and ways of knowing (i.e., sense-making preferences). Teacher-leaders and other employees involved in change need meaningful and consistent feedback and reinforcement. Instead of solely giving feedback, transformative leaders seek first to understand employees' perspectives.

In transformational leadership's "individualized consideration" principle, leaders demonstrate two-way communication. Gardner (2013b) writes that communication and influence flow in both directions: leader to follower and follower to leader. This aspect of leadership is extremely important when leading for equity and school improvement. When teachers are in tune with school goals, problems, and decisions, school leaders have a better chance to mobilize staff toward a common purpose. Teachers need to feel comfortable sharing concerns with the organization about student wellbeing and achievement. If teachers do not call attention to issues of social justice, the problem will only get worse. Two-way communication between followers and leaders is essential to the continuous improvement process.

Coaching sessions, small group discussions, electronic messaging, and hand-written notes were a few of the communication methods used in this study to elicit participant motivation. I quickly realized that the study's efforts to improve science instruction at XYZ Elementary School would have been short-lived without motivation. The PLC intervention's activities were designed to spark participant motivation and rouse collective action to achieve common objectives. If a school is to *truly* change teachers' attitudes and improve student-learning outcomes, leadership must establish a growth culture. The key to an effective organizational culture is enabling followers to learn continuously and find meaning in their work and relationships (Fullan, 2013).

Participants in this study found meaning in their work because of team goal-setting, participative decision-making, and effective communication methods. The user (i.e., teacher) was at the center of every PLC activity. Participants were the ones who helped shape a positive professional learning culture at XYZ Elementary School (Gruenert & Whitaker, 2017). Lessons learned from this study demonstrate the potential to generate a school culture built on trust, collaboration, and a growth mindset.

Implications for Future Research

The present study's main finding was that a constructivist approach to professional development (PD) increases teacher efficacy. Participants expressed an appreciation for the intervention's vertically aligned professional learning community (PLC). Subject-specific vertical teams are irregular at the elementary school level. Practitioners, school administrators, and policymakers need to investigate the conditions and circumstances that will support curriculum-based vertical PLCs. Future studies could reveal more about what is required for vertical teams to support every teacher's PD and growth.

Education is a constantly evolving field. There are new trends in pedagogy, advances in technology, policy changes, and yearly alterations to procedures and systems at the local level. Teachers need responsive and personalized PD to adapt to the changes and embrace new opportunities. Future research could focus on the effects of teacher-led PLCs. In most elementary schools, PLCs are led by the principal or curriculum coordinator. This study's curriculum-based PLC was facilitated by the school's library media specialist. Findings from this improvement science project and corroborating evidence from future studies will emphasize the benefits of teacher-led PD. Case studies and survey methods would be instrumental in developing our understanding of how teacher-led, subject-focused, vertical PLCs work. Future research studies have important implications for school policy and PD reform.

During summer 2020, I designed and facilitated a PLC with teachers from different schools in the district (XYZ Elementary School and XYZ Intermediate School). Collaboration with other institutions gives schools the push needed to try new things—to "disrupt" the status quo. Halla (2015) states, "Colleagues at a school site become so familiar with one another that they often settle into a predictable rhythm" (Section 2, para. 2). Districtwide PLCs have the potential to guarantee a viable science curriculum for every student (Eaker et al., 2021).

Social media, virtual meetings, learning management systems, and asynchronous communication methods offer staff countless opportunities to grow their professional learning networks. The PLC between schools was quite similar to this study's intervention as it focused on teaching science using the 5E Inquiry-Based Instructional Model. I facilitated five online sessions with educators from the district's elementary and intermediate schools. Vertical team members engaged in discourse with colleagues from different grade levels in Zoom breakout rooms. Teachers collaborated on deconstructing science standards across grade levels and developing inquiry-based instructional procedures. Unfortunately, vertical teaming between schools is difficult to sustain. Once the new school term commenced, teachers returned to school-level PLCs. Future research studies might focus on semester-long or year-long professional learning communities between multiple schools. With advancements in educational technologies, district-level PLCs are a real possibility. Empirical research on the concept of vertical teams between schools will support this type of professional learning's enactment and sustainability.

The science curriculum PLCs implemented at XYZ Elementary School contained a number of routine practices. These practices included but were not limited to the development of group norms, the configuration of agendas, and the facilitation techniques of team meetings and individualized coaching. Not only did routines differ in themselves, but they may also have differed between the two rounds of intervention. Future studies could focus more on the *practices* that seem to spawn participant interaction, peer coaching, and self-reflection, which this study found increased teacher efficacy. Research on what practices contribute to subject-based PLCs' effectiveness would be invaluable to elementary schools wishing to start vertical teacher teams.

This study's intervention design focused on improving teacher efficacy toward STEM instruction. Research is needed to investigate the impact of subject-specific vertical teams on elementary students' learning and interest in STEM subjects. Future studies' guiding question could be: *To what extent do components of a curriculum-based PLC in the early grades affect student outcomes?* Collective case study research involving multiple classrooms at XYZ Elementary would provide detailed accounts of how a vertical PLC affects individual teacher's science instruction and student achievement (R. B. Johnson & Christensen, 2017).

The process of vertical teaming exemplifies the need for systemic change efforts related to teacher professional development. Further research is warranted to understand leadership characteristics, support services, and teacher behaviors that optimize subject-focused vertical teaming. Knowledge gained through studying the implementation of content-specific vertical teams in different settings can continue to inform future cycles of collective inquiry. Future research might address:

- What variations of a curriculum-based PLC model might work better to serve the needs of educators who teach intermediate, middle, or high school students?
- What approaches to instructional coaching are most beneficial to members of a collaborative team?
- What district structures have the effect of producing collaborative inquiry among teachers from different grade levels?
- What PLC protocols best serve the curriculum and student learning needs of different content areas?
- What student data collection processes help vertical teams make instructional decisions?

Answers to these questions, in addition to this study's findings, would further corroborate the implications of vertical teaming and peer coaching on teacher efficacy toward inquiry-based learning.

PLCs cannot flourish without strong school leadership and district support (David & Cuban, 2010). It is the leadership's responsibility to support vertical teams by articulating a school-wide vision on professional growth and protecting time for teacher collaboration (Van Clay & Soldwedel, 2011). A systemic approach to vertical teaming faces many challenges. For one, educational leaders are under constant scrutiny. No decision is made lightly. To truly reform professional development policies and procedures, policymakers need substantial evidence to back their decisions. Future research can add to the body of literature on vertical teaming and inform policy to improve teacher professional development.

Conclusions

This study was designed with a mixed-methods approach to investigate teacher efficacy toward standards-based science instruction in the early grades. Quantitative and qualitative data expanded the evidence base for subject-specific vertical teams and instructional coaching. Interview data led to overarching themes on teacher content knowledge, collaborative professional development, curriculum cohesiveness, and collective efficacy. Survey data indicated gains in teacher attitudes toward STEM instruction and inquiry-based learning principles. Observations and document analysis demonstrated improvements to school curricular guides, lesson planning templates, and science performance tasks. Results from this study's metrics have implications for science scope and sequence resources, classroom interactions, peer coaching, and policy professional learning reform.

This study's primary purpose was to improve teacher efficacy toward designing and implementing a constructivist approach to science instruction. Findings suggest that participating teachers became more confident teaching a standards-based science curriculum that follows the 5E Inquiry-Based Instructional Model. Teachers gained a strong grasp of techniques that cut across subjects. They created connections between literacy, math, reading, writing, science, and social studies. Participants tied these all back to standards and resources to make the most of their short time with students (Northern, 2020). The answer to school reform is not in one initiative or one aspect of an organization. Change endures when efforts address the whole organization. Educational leaders must consider all the systems that configure their organization's culture, but never forget the most crucial change agent: personnel.

"Recent studies of professional learning communities where teachers work together regularly on instructional problems find not only increases in student achievement but also changes in school and classroom environments" (David & Cuban, p. 152, 2010). Findings from this study's improvement cycles demonstrate the impact and potential of vertical teacher teams in the early grades. Subject-based PLCs with teachers from across grade levels foster a culture of inquiry and growth. The intervention has helped shift XYZ Elementary School's culture toward one that "actively supports the view that much of the knowledge needed to plan and carry out change in schools is possessed by people in the schools themselves" (Owens & Valesky, 2014, p. 233).

"[Professional learning communities] PLCs are cultures that constantly implement current priorities well, but also pursue next-generation innovations" (DuFour & Fullan, 2013, p. 42). This study's teachers and administrators became well-grounded in collaborative inquiry because of the intervention's social constructivist paradigm. Participants' commitment to continuous improvement extended into areas beyond science education at XYZ Elementary School. The intervention's constructivist approach to professional learning inspired vertical collaboration, peer coaching, and teacher leadership. The more participants witnessed their accomplishments in understanding the NGSS instructional design, developing viable science curricular, and integrating the 5E inquiry model, it seemed the more excited the team became in completing tasks. The improvement cycles for each round of intervention may have "ended," but collaboration on improving science did not. Teachers and leaders at XYZ Elementary School continue to search for new ideas, strategies, and resources that support standards-based STEM instruction.

Science, Technology, Engineering, and Mathematics (STEM) make up a fast-growing industry. Evidence of STEM innovations can be seen all around us in our everyday lives. STEM professionals design and manufacture the latest smartphone. STEM fields provide first responders with the equipment that helps save people's lives. As society's reliance on STEM innovations has increased, so has the growing number of STEM careers. The high demand for STEM-related occupations signifies the need for STEM education. According to the U.S. Department of Education (n.d.):

> If we want a nation where our future leaders, neighbors, and workers can understand and solve some of the complex challenges of today and tomorrow, and to meet the demands of the dynamic and evolving workforce, building students' skills, content knowledge, and literacy in STEM fields is essential. (para. 1).

The need for STEM education is arguable. However, published strategic plans for STEM education and schools' implementation of said plans are two separate things.

Many factors result in the lack of effective STEM instruction in the early grades, and it is not due to a lack of direction. The Kentucky Academic Standards establish science learning goals for students in grades for P–12. Kentucky's state testing system provides critical information about student performance in STEM subjects. There are books and websites dedicated to the use of STEM strategies during early childhood learning. As the demand for qualified candidates in STEM industries grows, so will the literature on best practices in elementary STEM programs. Teachers are not driven to plan and implement STEM instruction from the *information* in science standards, curriculum programs, and teacher professional development. What matters is educators' locus of control. Do teachers have a sense of autonomy in the curriculum? Do they get a say in the materials and texts students will use to investigate science topics? This study approached research questions, a theory of action, and PDSA improvement cycles with what Houchens (2018) claims can help schools to do better: “through focusing on teacher effectiveness, rigorous curriculum, meaningful assessment, and strong, safe school cultures and community involvement” (Blending urgency and humility section, para. 2).

The curriculum-based professional learning communities (PLCs) initiative can transform how elementary schools view, approach, and support science education. Improvements to science instruction in the early grades begin with an investigation of teacher attitudes. Increasing teacher efficacy is the first step to increasing students’ access to an inquiry-based science curriculum. This study reveals the influence of a constructivist and collaborative approach to professional development on teacher attitudes and confidence. Vertical PLCs and instructional coaching build teachers’ capacity to create a strong framework for student achievement in science. Every student, regardless of their background and abilities, needs and deserves a quality STEM education. If forming subject-specific vertical PLCs can enhance students’ learning experience, the effort is worthwhile. Our nation’s economy, security, and global competitiveness depend on the next generation of STEM innovators’ talents and skills.

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Appendix A

Teacher Survey (Science Instruction)

1. About how much time do you spend on science instruction per day?
Mark only one oval.

- 0 minutes
- 15 minutes
- 30 minutes
- 45 minutes
- 1 hour
- Other:

2. How would you rate the amount of time your students spend learning science standards?
Mark only one oval.

- Not Enough
- Just Right
- More Than Enough

3. How comfortable are you with providing science instruction?
Mark only one oval.

- Very Uncomfortable
- Uncomfortable
- Somewhat Comfortable
- Comfortable
- Extremely Comfortable

4. How would you rate the resources your students currently use to master science standards?
Mark only one oval.

- Not Very Effective
- Somewhat Effective
- Effective
- Extremely Effective

Appendix B

2019–2020 Schedule at XYZ Elementary

1st Grade	1st Grade	2nd Grade	2nd Grade	3rd Grade	3rd Grade
Morning Work 8:00-8:15	Morning Work 8:00-8:15	Morning Work 8:00-8:20	Morning Work 8:00-8:15	Morning Work 8:00-8:15	Morning Work 8:00-8:15
Core Reading 8:15-9:00	Core Reading 8:15-9:00	2nd Gr. Specials 8:20-9:10	Core Reading 8:15-9:15	Core Reading 8:15-9:15	Core Math 8:15-9:15
Core Math 9:00-9:45	Core Math 9:00-9:50	Core Reading 9:15-10:15	2nd Gr. Specials 9:20-10:10	Flex RTI Reading 9:15-10:00	Flex RTI Math 9:15-10:00
Flex Reading 9:50-10:35	Flex Reading 9:55-10:40	Recess 10:18-10:38	Core Math 10:20-11:20		Writing 10:05-10:30
Flex Math 10:40-11:25	Flex Math 10:45-Lunch	Core Math 10:40-Lunch	Flex Math 11:25-12:00	Specials 10:10-11:00	Lunch 10:33-11:09
Lunch 11:30-12:03	Lunch 11:15-11:51	Lunch 11:48-12:24	Lunch 12:03-12:36	Lunch 11:05-11:37	3rd Gr. Specials 11:10-12:00
Recess 11:55-12:27 20 min. p/cl.	Flex RTI 11:50-12:15	Flex Math 12:25-1:15	Recess 12:27-12:56 20 min. p/cl.	Recess 11:30-11:58 20 min. p/cl.	Core Reading 12:10-1:10
1st Gr. Specials 12:35-1:25	Writing, Sci., S.S., PLCS 12:20-1:20	Flex Reading 1:20-2:10	Flex Reading 1:00-1:55	Core Math 12:10-1:10	Flex RTI Reading 1:15-2:00
Writing, Sci, SS, 1:30-2:50	1st Gr. Specials 1:25-2:15	Writing, Sci, SS 2:15-2:55	Sci, SS, Writing 2:00-2:50	Flex RTI Math 1:15-2:00	Recess 2:05-2:25
	Recess 2:30-2:50	*RTI w/ Interventionist @ 2:05	*RTI w/ Interventionist @ 2:05	2:05-2:55 Writing, Sci, S.S.	Sci, SS, 2:25-2:55
Read Aloud Review of Skills/Targets	Read Aloud Review of Skills/Targets	Read Aloud Review of Skills/Targets	Read Aloud Review of Skills/Targets	Read Aloud Review of Skills/Targets	Read Aloud Review of Skills/Targets

Appendix C

Needs Assessment Interview Questions

Interview Questions:

1. What is the teacher's role in improving a student's learning in Science?

2. What factors attribute to minimal student learning in Science?

3. Which context factors make it harder or easier to teach science (i.e. collegial support, lack of resources, time allocated for science in the curriculum, and the time and effort needed to prepare science lessons)?

4. How can a teacher improve his or her science instruction and science knowledge?

5. What are some obstacles to implementing career education in the classroom?

6. How do hands-on, inquiry-based activities impact student learning?

7. How do you think technology can support students' learning in science?

8. How do assessments influence teaching?

9. Overall, how do you think we can improve science education at XYZ Elementary School?

Appendix D

Needs Assessment Survey

#	Field	Min.	Max.	Mean.	Std. Dev.	Var.	Count
1	I am continually improving my mathematics teaching practice.	1	5	4.25	0.97	0.94	32
2	I know the steps necessary to teach mathematics effectively.	1	5	4.19	0.81	0.65	32
3	I have the necessary resources to teach mathematics effectively.	1	5	3.94	0.83	0.68	32
4	I am confident that I can explain to students why mathematics experiments work.	1	5	3.69	0.88	0.78	32
5	I am confident that I can teach mathematics effectively.	1	5	4.03	0.88	0.78	32
6	I wonder if I have the necessary skills to teach mathematics.	1	5	2.56	1.09	1.18	32
7	I understand mathematics concepts well enough to be effective in teaching mathematics.	1	5	4.03	0.85	0.72	32
8	Given a choice, I would invite a colleague to evaluate my mathematics teaching.	1	5	3.66	0.96	0.91	32
9	I am confident that I can answer students' mathematical questions.	1	5	4.09	0.76	0.58	32
10	When a student has difficulty understanding a mathematical concept, I am confident that I know how to help the student understand it better.	1	5	4	0.71	0.5	32

Appendix D (continued)

11	When teaching mathematics, I am confident enough to welcome student questions.	1	5	4.19	0.77	0.59	32
12	I know what to do to increase student interest in mathematics.	1	5	3.66	0.92	0.85	32
13	When a student does better than usual in mathematics, it is often because the teacher exerted a little extra effort.	2	4	3.31	0.63	0.4	32
14	The inadequacy of a student's mathematics background can be overcome by good teaching.	2	4	3.44	0.66	0.43	32
15	When a student's learning in mathematics is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	2	5	3.78	0.74	0.55	32
16	The teacher is generally responsible for students' learning in mathematics.	2	4	3.47	0.66	0.44	32
17	If students' learning in mathematics is less than expected, it is most likely due to ineffective mathematics teaching.	2	4	2.63	0.7	0.48	32
18	If students' learning in mathematics is less than expected, it is most likely due to insufficient instructional time.	2	5	3.16	1	1.01	32
19	Students' learning in mathematics is directly related to their teacher's effectiveness in mathematics teaching.	1	4	3.09	0.84	0.71	32

Appendix D (continued)

20	When a low achieving child progresses more than expected in mathematics, it is usually due to extra attention given by the teacher.	2	5	3.63	0.65	0.42	32
21	If parents comment that their child is showing more interest in mathematics at school, it is probably due to the performance of the child's teacher.	2	5	3.28	0.84	0.7	32
22	Minimal student learning in mathematics can generally be attributed to their teachers.	1	4	2.59	0.74	0.55	32
23	I am continually improving my science teaching practice.	2	5	3.41	1.03	1.05	32
24	I know the steps necessary to teach science effectively.	2	5	3.34	0.85	0.73	32
25	I have the necessary resources to teach science effectively.	2	5	3.13	0.96	0.92	32
26	I am confident that I can explain to students why science experiments work.	1	4	3.22	0.86	0.73	32
27	I am confident that I can teach science effectively.	1	5	3.34	0.85	0.73	32
28	I wonder if I have the necessary skills to teach science.	1	4	3.03	0.92	0.84	32
29	I understand science concepts well enough to be effective in teaching science.	2	4	3.22	0.82	0.67	32
30	Given a choice, I would invite a colleague to evaluate my science teaching.	1	4	2.97	1.07	1.16	32

Appendix D (continued)

31	I am confident that I can answer students' science questions.	2	5	3.41	0.74	0.55	32
32	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	2	4	3.19	0.77	0.59	32
33	When teaching science, I am confident enough to welcome student questions.	2	5	3.47	0.75	0.56	32
34	I know what to do to increase student interest in science.	1	4	3.31	0.85	0.71	32
35	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	2	5	3.19	0.81	0.65	32
36	The inadequacy of a student's science background can be overcome by good teaching.	2	4	3.34	0.73	0.54	32
37	When a student's learning is science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	2	5	3.34	0.81	0.66	32
38	The teacher is generally responsible for students' learning in science.	1	5	3.34	0.81	0.66	32
39	If students' learning in science is less than expected, it is most likely due to ineffective science teaching.	2	4	2.84	0.67	0.44	32
40	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	2	5	3.47	1	1	32

Appendix D (continued)

41	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2	4	3	0.75	0.56	32
42	When a low achieving child progresses more than expected in science, it is usually due to extra attention given by the teacher.	2	5	3.41	0.78	0.62	32
43	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	2	5	3.31	0.85	0.71	32
44	Minimal student learning in science can generally be attribute to their teachers.	1	4	2.88	0.74	0.55	32
45	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	1	4	2.94	0.97	0.93	32
46	My students use technology to communicate and collaborate with others, beyond the classroom.	1	3	1.59	0.61	0.37	32
47	My students use technology to access online resources and information as part of activities.	1	4	2.81	0.88	0.78	32
48	My students use the same kinds of tools that professional researchers use, e.g. simulations, databases, satellite imagery.	1	6	1.63	1.02	1.05	32

Appendix D (continued)

49	My students work on technology-enhanced projects that approach real-world applications of technology.	1	3	1.63	0.6	0.36	32
50	My students use technology to help solve problems.	1	4	2.44	0.83	0.68	32
51	My students use technology to support higher-order thinking, e.g. analysis, synthesis and evaluation of ideas and information.	1	4	2.03	0.88	0.78	32
52	My students use technology to create new ideas and representations of information.	1	5	2.13	0.99	0.98	32
53	How often do your students ask questions about their learning?	1	5	3.16	1.03	1.07	32
54	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	1	4	2.22	0.74	0.55	32
55	How often do your students work in small groups?	2	5	3.69	0.73	0.53	32
56	How often do your students make predictions that can be tested?	1	4	2.28	0.76	0.58	32
57	How often do your students make careful observations or measurements?	2	4	2.28	0.62	0.39	32
58	How often do your students use tools to gather data (e.g. calculators, computers, computer programs, scales, rulers, compasses, etc.)?	1	4	2.5	0.75	0.56	32

Appendix D (continued)

59	How often do your students recognize patterns in data?	1	4	2.19	0.63	0.4	32
60	How often do your students create reasonable explanations of results of an experiment or investigation?	1	4	2.06	0.79	0.62	32
61	How often do your students choose the most appropriate methods to express results (e.g. drawings, models, charts, graphs, technical language, etc.)?	1	5	2.31	1.01	1.03	32
62	How often do your students complete activities with a real-world context?	2	4	2.75	0.75	0.56	32
63	How often do your students engage in content-driven dialogue?	2	5	3.28	0.91	0.83	32
64	How often do your students reason abstractly?	1	4	2.13	0.7	0.48	32
65	How often do your students reason quantitatively?	1	5	2.41	1	0.99	32
66	How often do your students critique the reasoning of others?	1	5	2.41	0.78	0.62	32
67	How often do your students learn about careers related to the instructional content?	1	5	2.53	0.87	0.75	32
68	I think it is important that students have learning opportunities to engage in hands-on learning.	3	5	4.38	0.6	0.36	32
69	I think it is important that students have learning opportunities to take control of their own learning.	3	5	4.19	0.63	0.4	32

Appendix D (continued)

70	I think it is important that students have learning opportunities make connections between classroom instruction and the real-world.	3	5	4.31	0.58	0.34	32
71	I think it is important that students have learning opportunities to take risks.	3	5	4.28	0.51	0.26	32
72	I think it is important that students have learning opportunities that lead others to accomplish a goal.	3	5	4.25	0.56	0.31	32
73	I think it is important that students have learning opportunities to encourage others to do their best.	3	5	4.22	0.54	0.3	32
74	I think it is important that students have learning opportunities to produce high quality work.	3	5	4.34	0.54	0.29	32
75	I think it is important that students have learning opportunities to respect the differences of their peers.	3	5	4.25	0.56	0.31	32
76	I think it is important that students have learning opportunities to help their peers.	3	5	4.19	0.58	0.34	32
77	I think it is important that students have learning opportunities to include others’ perspectives when making decisions.	3	5	4.28	0.57	0.33	32
78	I think it is important that students have learning opportunities to make changes when things do not go as planned.	3	5	4.31	0.53	0.28	32
79	I think it is important that students have learning opportunities to set their own learning goals.	3	5	4.19	0.53	0.28	32

Appendix D (continued)

80	I think it is important that students have learning opportunities to manage their time wisely when working on their own.	2	5	4.09	0.72	0.52	32
81	I think it is important that students have learning opportunities to choose which assignment out of many needs to be done first.	2	5	3.97	0.81	0.66	32
82	I think it is important that students have learning opportunities to work well with students from different backgrounds.	3	5	4.25	0.56	0.31	32
83	I think it is important that teachers administer common assessments in every subject.	1	5	3.56	1	1	32
84	I think it is important that teachers prepare students for state-mandated assessments.	1	5	3.81	0.92	0.84	32
85	I think it is important that teachers communicate learning goals with students' families.	3	5	4.22	0.65	0.42	32
86	I think it is important that teachers communicate student achievement with the students' families.	3	5	4.28	0.67	0.45	32
87	I think it is important that teachers engage in professional development on new teaching strategies.	2	5	4.16	0.79	0.63	32
88	I think it is important that teachers learn more about the content they teach.	2	5	4.13	0.74	0.55	32
89	I think it is important that teachers engage in scientific inquiry before implementing the inquiry process in the classroom.	2	5	3.97	0.81	0.66	32

Appendix D (continued)

90	I think it is important that teachers collaborate with other educators on the design of STEM instruction.	2	5	4.09	0.68	0.46	32
91	I think it is important that teachers take responsibility for all students’ learning.	2	5	4.16	0.75	0.57	32
92	I think it is important that teachers communicate vision to students.	3	5	4.19	0.58	0.34	32
93	I think it is important that teachers use a variety of assessment data throughout the year to evaluate progress.	3	5	4.25	0.61	0.38	32
94	I think it is important that teachers use a variety of data to organize, plan and set goals.	3	5	4.25	0.61	0.38	32
95	I think it is important that teachers establish a safe and orderly environment.	3	5	4.41	0.61	0.37	32
96	I think it is important that teachers empower students.	3	5	4.53	0.61	0.37	32
97	I know about current STEM careers.	1	5	2.78	0.99	0.98	32
98	I know where to go to learn more about STEM careers.	2	5	2.97	0.95	0.91	32
99	I know where to find resources for teaching students about STEM careers.	2	5	2.81	0.92	0.84	32
100	I know where to direct students or parents to find information about STEM careers.	2	5	2.69	0.88	0.78	32

Appendix E

First Round of PLC Intervention Interview Questions

<u>Interview Questions:</u>

1. What are your general thoughts and feelings about the Science Squad PLC?

2. What was the most valuable part of the Science Squad PLC?

3. How did the Science Squad impact your understanding of science concepts?
    a. Would you say that your attitude towards Science changed in any way?

4. Which activity or activities from the Science Squad did you find to be the most beneficial?

5. Did the Science Squad increase your knowledge of resources that will support science teaching?

6. Did the Science Squad help you see connections between instructional practices and *STEMscopes*?

7. What is one thing you would have changed about the Science Squad PLC?

8. What do you think should be the next steps for improving science education at XYZ Elementary School? (Any questions or concerns about science education at XYZ based on our PLC work?)

Appendix F

First Round of PLC Intervention Dashboard

Meeting Date	Attendance	Goal	Summary	Assignment
4/1/2020	6/7	To reflect on my values and strengths when it comes to science instruction.	Discussed a TedTalk about science teaching. Listed needs, priorities, and goals of science education.	Complete a Google Slide that describes your mission, strengths, and what you can contribute to the PLC.
4/15/2020	7/7	To know and appreciate each person's strengths and goals for improving science instruction.	Discussed "Teaching Isn't Rocket Science" podcast and shared mission and strengths assignment.	SES Science Google Site scavenger hunt.
4/22/2020	6/7	To identify the various departments, personnel, and factors that impact inquiry-based science instruction.	Explored the Google Site. Completed a systems map as they related to science education at XYZ County Schools.	Find an image of a phenomenon that relates to a performance expectation for your grade level.
4/29/2020	7/7	To improve the use of questioning techniques by examining compelling and supporting questions.	Reviewed compelling and supporting questions. Shared anchoring phenomena assignment.	Write 1 compelling question and 2 supporting questions for Seasonal Patterns background information.
5/6/2020	7/7	To anchor learning with questions, phenomena, and crosscutting scientific and engineering concepts.	Shared questions. Looked at prompts for integrating crosscutting concepts (CC) into instruction	Write a compelling question for a performance task and choose 3 prompts for crosscutting concepts.
5/13/2020	5/7	To use 3D learning to support students' understanding of standards and concepts.	Shared CC prompts. Observed a recorded lesson for science and engineering practices.	Watch a science lesson from *Teaching Channel* and record your reflections.
5/20/2020	4/7	To create equitable learning environments by encouraging students to make sense of topics new content.	Shared observations and feedback from video lesson. Discussed sense making and scientific literacy.	STEMscopes scavenger hunt.

Appendix F (continued)

5/27/2020	7/7	To use STEMscopes and the 5E Inquiry Model to align instruction with standards and best teaching practices.	Reviewed formative assessment practices. Toured STEMscopes online platform.	View a playlist of STEMscopes tutorials. Outline a science curriculum map for each grade level.

Appendix G

IRB Approval Form

WKU® INSTITUTIONAL REVIEW BOARD
OFFICE OF RESEARCH INTEGRITY

DATE:	October 23, 2019
TO:	Sam Northern
FROM:	Western Kentucky University (WKU) IRB
PROJECT TITLE:	[1492902-1] Effects of an Inquiry-Based STEM Curriculum on Teachers' Attitudes and Self-Efficacy
REFERENCE #:	IRB 20-094
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	October 23, 2019
EXPIRATION DATE:	February 20, 2020
REVIEW TYPE:	Expedited Review

Thank you for your submission of New Project materials for this project. The Western Kentucky University (WKU) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a *signed/implied* consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

This project has been determined to be a MINIMAL RISK project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of February 20, 2020.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact Robin Pyles at (270) 745-3360 or irb@wku.edu. Please include your project title and reference number in all correspondence with this committee.

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Appendix H

First Round of PLC Intervention Pre-Survey

#	Field	Min.	Max.	Mean.	Std. Dev.	Var.	Count
24	I know the steps necessary to teach science effectively.	4	4	4	0	0	7
25	I have the necessary resources to teach science effectively.	2	5	3.57	0.9	0.82	7
26	I am confident that I can explain to students why science experiments work.	3	4	3.86	0.35	0.12	7
29	I understand science concepts well enough to be effective in teaching science.	2	4	3.57	0.73	0.53	7
30	Given a choice, I would invite a colleague to evaluate my science teaching.	2	4	3.57	0.73	0.53	7
31	I am confident that I can answer students' science questions.	3	4	3.71	0.45	0.2	7
32	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	3	4	3.57	0.49	0.24	7
34	I know what to do to increase student interest in science.	3	4	3.71	0.45	0.2	7

Appendix H (continued)

35	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	3	4	3.57	0.49	0.24	7
36	The inadequacy of a student's science background can be overcome by good teaching.	2	4	3.57	0.73	0.53	7
37	When a student's learning is science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	3	4	3.43	0.49	0.24	7
38	The teacher is generally responsible for students' learning in science.	2	4	3.14	0.83	0.69	7
39	If students' learning in science is less than expected, it is most likely due to ineffective science teaching.	2	4	3	0.53	0.29	7
40	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	3	5	4	0.76	0.57	7
41	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2	3	2.86	0.35	0.12	7

Appendix H (continued)

43	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	2	4	3	0.53	0.29	7
45	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	2	4	3.33	0.75	0.56	6
46	My students use technology to communicate and collaborate with others, beyond the classroom.	1	2	1.67	0.47	0.22	6
47	My students use technology to access online resources and information as part of activities.	2	4	3	0.82	0.67	6
49	My students work on technology-enhanced projects that approach real-world applications of technology.	1	4	2.33	0.94	0.89	6
50	My students use technology to help solve problems.	2	4	2.5	0.76	0.58	6
51	My students use technology to support higher-order thinking, e.g. analysis, synthesis and evaluation of ideas and information.	1	4	2.17	0.9	0.9	0.81

Appendix H (continued)

52	My students use technology to create new ideas and representations of information.	2	4	2.33	0.75	0.56	6
53	How often do your students ask questions about their learning?	2	5	3.67	1.25	1.56	6
54	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	2	4	2.67	0.75	0.56	6
56	How often do your students make predictions that can be tested?	2	4	2.83	0.9	0.81	6
57	How often do your students make careful observations or measurements?	2	4	3.17	0.69	0.47	6
58	How often do your students use tools to gather data (e.g. calculators, computers, computer programs, scales, rulers, compasses, etc.)?	2	4	2.67	0.75	0.56	6
59	How often do your students recognize patterns in data?	2	4	2.83	0.9	0.81	6
60	How often do your students create reasonable explanations of results of an experiment or investigation?	2	4	2.67	0.94	0.89	6

Appendix H (continued)

61	How often do your students choose the most appropriate methods to express results (e.g. drawings, models, charts, graphs, technical language, etc.)?	2	4	2.83	0.69	0.47	6
62	How often do your students complete activities with a real-world context?	2	5	3.33	1.11	1.22	6
63	How often do your students engage in content-driven dialogue?	2	5	3.83	0.9	0.81	6
65	How often do your students reason by making connections between claims and evidence?	2	4	2.83	0.69	0.47	6
66	How often do your students critique the reasoning of others?	1	5	2.67	1.25	1.56	6
67	How often do your students learn about STEM careers?	2	3	2.17	0.37	0.14	6
99	I know where to find resources for teaching students about STEM careers.	2	5	3.67	0.94	0.89	6

Appendix I

First Round of PLC Intervention Check-In Survey #1

#	Field	Min.	Max	Mean	Std. Dev.	Var.	Count
1	The Science Squad PLC has helped me to better understand the steps necessary to teach science effectively.	3	5	3.71	0.7	0.49	7
2	The Science Squad PLC has helped me to know about resources that will support my science teaching.	4	5	4.14	0.35	0.12	7
3	The Science Squad PLC has increased my understanding of science concepts.	3	5	3.86	0.64	0.41	7
4	The Science Squad PLC has improved my ability to connect science concepts to real-world phenomena.	3	5	4.14	0.64	0.41	7
5	The Science Squad PLC has helped me write questions that will engage students in deeper levels of thinking.	3	5	4.14	0.64	0.41	7

Appendix I (continued)

6	How has the Science Squad PLC helped you learn?	• It has helped me understand how the curriculum is set up in the science documents and become more comfortable in using it. • The meeting about questions in science instruction was beneficial to help me plan for questions in science. • I have enjoyed the phenomenon activity to tie science content to real-world examples. I also enjoyed learning of the crosscutting concepts for questioning. • The Science Squad has connected me to more resources to better enhance my understanding on the standards. It has also helped me find resources to better engage my students. • Creating compelling questions.
7	What should the Science Squad PLC do differently to help you learn better?	• Doing well currently. • I feel like it went well and I learned a lot! Thank you! :-) • I hope we have a break this summer to absorb what we've learned and apply it to create some resources to use in the 2020 - 21 SY. • LET'S START PLANNING!! I feel that we need to start laying out a day by day plan for each unit in science. Once we have these plans then we can look at our curriculum map. Unfortunately, I know that we will not be able to get through ALL of the science units because we have to also teach social studies and writing during this time.

Appendix J

First Round of PLC Intervention Check-In Survey #2

#	Field	Min.	Max	Mean	Std. Dev.	Var.	Count
1	The Science Squad PLC has increased my confidence in helping students understand science concepts.	4	5	4.43	0.49	0.24	7
2	The Science Squad PLC offered strategies that will help my students engage in content-driven dialogue.	4	5	4.71	0.45	0.2	7
3	The Science Squad PLC has improved my skill in seeing and hearing students' ideas and reasoning as connected to science (as opposed to being off-topic).	3	5	3.86	0.64	0.41	7
4	The Science Squad PLC has supported my design of instruction that will allow students to solve problems through investigations.	3	5	4.43	0.73	0.53	7
5	The Science Squad PLC provided information and activities that enhanced my ability to use *STEMscopes* (an online, inquiry-based learning environment).	4	5	4.57	0.49	0.24	7

Appendix J (continued)

6	What have you found to be the most valuable part of the Science Squad PLC?	• Learning how to evaluate the science standards better. • Forming a group of people with the end goal of increasing and prioritizing science instruction. • I enjoyed some of the hooks we learned such as the phenomena hook with a visual and compelling questions. • Communicating across grade levels. • I have found that having a team of people from different grade levels to be the most beneficial. I feel like I have lots of people that I can bounce ideas off of, learn from, etc. I also found that all of the resources are very beneficial for planning science in the future. • The dialogue was helpful to assist in discussion for the classroom.
7	What is one thing you would have changed about the Science Squad PLC?	• Nothing • Nothing • More talk about what activities we could do with the *STEMscopes* lessons. • More time to actually plan and look at our curriculum maps.

Appendix K

First Round of Intervention PLC Post-Survey

#	Field	Min.	Max.	Mean.	Std. Dev.	Var.	Count
24	I know the steps necessary to teach science effectively.	4	5	4.43	0.49	0.24	7
25	I have the necessary resources to teach science effectively.	4	5	4.43	0.49	0.24	7
26	I am confident that I can explain to students why science experiments work.	3	5	4	0.53	0.29	7
29	I understand science concepts well enough to be effective in teaching science.	3	5	4.14	0.64	0.41	7
30	Given a choice, I would invite a colleague to evaluate my science teaching.	3	5	4.14	0.83	0.69	7
32	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	3	5	4	0.53	0.29	7
34	I know what to do to increase student interest in science.	4	5	4.57	0.49	0.24	7
36	The inadequacy of a student's science background can be overcome by good teaching.	4	5	4.29	0.45	0.2	7

Appendix K (continued)

37	When a student's learning is science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	3	5	3.86	0.64	0.41	7
40	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	3	4	3.86	0.35	0.12	7
41	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	3	5	3.86	0.64	0.41	7
43	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	2	4	3	0.53	0.29	7
45	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	2	5	3.29	1.03	1.06	7
46	My students use technology to communicate and collaborate with others, beyond the classroom.	1	3	2	0.76	0.57	7
47	My students use technology to access online resources and information as part of activities.	2	5	3	1.07	1.14	7

Appendix K (continued)

52	My students use technology to create new ideas and representations of information.	2	5	2.71	1.03	1.06	7
53	How often do your students ask questions about their learning?	3	5	3.71	0.7	0.49	7
54	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	2	4	3.14	0.64	0.41	7
56	How often do your students make predictions that can be tested?	2	5	2.86	0.99	0.98	7
57	How often do your students make careful observations or measurements?	3	4	3.57	0.49	0.24	7
58	How often do your students use tools to gather data (e.g. calculators, computers, computer programs, scales, rulers, compasses, etc.)?	2	4	3	0.53	0.29	7
59	How often do your students recognize patterns in data?	3	5	3.43	0.73	0.53	7
60	How often do your students create reasonable explanations of results of an experiment or investigation?	3	4	3.29	0.45	0.2	7

Appendix K (continued)

61	How often do your students choose the most appropriate methods to express results (e.g. drawings, models, charts, graphs, technical language, etc.)?	2	4	3	0.76	0.57	7
62	How often do your students complete activities with a real-world context?	2	5	3.57	0.9	0.82	7
63	How often do your students engage in content-driven dialogue?	3	5	4	0.53	0.29	7
65	How often do your students reason by making connections between claims and evidence?	2	4	3.43	0.73	0.53	7
66	How often do your students critique the reasoning of others?	2	4	2.86	0.99	0.98	7
116	How often do your students critique the reasoning of others?	2	4	2.86	0.99	0.98	7
118	How often do your students learn about STEM careers?	2	4	2.71	0.7	0.49	700

Appendix L

Ways of Knowing Questionnaire

Ways of Knowing

Directions: Select an option that best finishes each sentence. There are no right or wrong answers. Choose the response that best represents YOU. Results will give you and your PLC insight into how you prefer to receive and give feedback. An understanding of your and others' "ways of knowing" can enhance the way you grow as a teacher, leader, and learner.

Adapted from: Drago-Severson, E., & Blum-DeStefano, J. (2017). Tell me so I can hear you: A developmental approach to feedback for educators. Harvard Education Press.

* Required

Email address *

____

Your Grade Level: *

Check all that apply.

☐ 1st
☐ 2nd
☐ 3rd
Other: ☐ ________________________

1. When receiving feedback I... *

Mark only one oval.

◯ Need to understand the rules - that's what helps me in my work.
◯ Internalize others' feelings and assessments of me and my instructional practice as my own.
◯ Listen and yet feel that I still hold firm to my own values and beliefs.
◯ Seek to grow myself further through interconnection with the person offering feedback. I want to grow myself.

Appendix L (continued)

2. When receiving feedback, I am most concerned about... *

Mark only one oval.

- Ensuring that others think highly of me and like me regardless of my work.
- Demonstrating my competencies and sharing my perspectives.
- Seeing deeper into myself and my practice with trusted others. I want to talk with my supervisor. I want to grow from our conversation.
- Meeting my own needs and getting it "right." It's important to me.

3. When receiving feedback, I wonder... *

Mark only one oval.

- How will your feedback better help me reach my goals? Do your suggestions and ideas align with my own understanding of next steps to grow my practice and myself?
- How might you see into me and my practice in new and important ways? How can I learn from your perspective?
- What's in it for me? What did I do right? What did I do wrong? What do I have to do to get a reward and/or avoid punishment?
- What do you think of me? Do you still like me even when I'm not teaching as you think I should? Do you think I'm doing a good job? Do you think I'm a good person?

4. When receiving feedback, I feel most supported when you... *

Mark only one oval.

- Invite me to collaboratively reflect on my practice and yours, and when we explore new ideas, alternatives, and paradoxes together. It feels supportive to me, and I hope it does to you as well.
- Offer me concrete suggestions, models, and examples so that I can get things right in my practice of teaching. Clear and explicit expectations really help me. I need to know so that I can get better.
- Offer me sincere appreciation for my work and contributions. It feels supportives and I feel good about it and you. Personal and professional validation means a lot to me.
- Explicitly recognize me and my competence and expertise. It feels like you respect me. Opportunities to discuss my own ideas and develop my own goals when we meet feel supportive to me. I appreciate that a great deal.

Appendix L (continued)

5. When receiving feedback, it feels challenging when... *

Mark only one oval.

- ( ) I am asked to reflect on competing alternatives or decide between multiple options when there is no clear answer. I would like you to tell me what I need to do, please.
- ( ) I am asked to share my thinking without knowing how you or other leaders feel first - especially if I am given negative or critical feedback about my performance.
- ( ) I am presented with ideas or perspectives that directly oppose my own, or that call my competency into question.
- ( ) Others do not include me in the processes of feedback or planning for next steps. It's hard for me when there are so many rules and when we do not address paradoxes - both systemic and on our team. While I understand that conflicts and differences of opinions are part of our work, it's still hard for me.

6. When receiving feedback, I think I need to get better at... *

Mark only one oval.

- ( ) Taking in constructive criticism without experiencing it as dislike of me personally.
- ( ) Navigating, exploring, and "hearing" seemingly opposing viewpoints or ideas that are so different from my own thinking.
- ( ) Accepting that I cannot solve every problem and conflict; I really want harmony. Recognizing when I need to hold back in hierarchical systems and structures.
- ( ) Understanding others' feelings and perspectives; acknowledging when challenges may not have one right answer. I wish everyone would just follow the rules.

7. In relation to giving feedback, I... *

Mark only one oval.

- ( ) Stay true to my own values and beliefs.
- ( ) Seek interconnection and co-constructions of meaning.
- ( ) Adhere firmly to tangible rules and policies.
- ( ) Prioritize others' feelings and opinions.

Appendix L (continued)

8. When giving feedback, I am most concerned about... *

Mark only one oval.

- Inviting others into a shared and mutually reflective space.
- Meeting my own personal goals or organizational goals and objectives.
- Maintaining positive relationships and feeling liked.
- Guiding individuals and groups in accordance with my values and larger vision.

9. When giving feedback, I often wonder... *

Mark only one oval.

- Are you doing things the right way? How can I get you to do what I need or want?
- How will you feel if I tell you what I really thing? What will you think of me if I do this?
- How can I get you to subscribe to my vision or belief system?
- How can I best support you as a growing, learning human being?

10. When giving feedback, I feel most comfortable... *

Mark only one oval.

- Offering praise and "glows."
- Sharing my own assessments and suggestions that align with my beliefs.
- Engaging in mutual reflections and open-ended discussions.
- Assessing what colleagues have done "right" and "wrong." I am good at offering concrete directions.

Appendix L (continued)

11. When giving feedback, I find it challenging... *

Mark only one oval.

- ◯ To support adults who do not share my beliefs about education and/or thinking about best practices; to question my own theories about what needs to be changed.
- ◯ When I cannot meet others in their thinking and feeling in ways I would like; when adults hold back or are overly defensive in demeanor.
- ◯ To see the "gray" in seemingly black and white situations; to understand how others think and feel about my feedback.
- ◯ When I need to have hard conversations or share ideas that I know will upset or disappoint colleagues.

12. In terms of giving feedback, I think I need to get better at... *

Mark only one oval.

- ◯ Recognizing when it would be helpful to step in and offer direct solutions and when I need to step back and allow others to find their own way.
- ◯ Standing in my colleagues' "shoes" and better understanding their perspectives.
- ◯ Sharing my true thinking and feeling with others, as I know this is also an expression of care.
- ◯ Recognizing that others may bring different and important ideas to the table that I could also learn from.

Appendix M

Ways of Knowing Reflection Form

Your "Way of Knowing" Follow-Up

Before completing this form, reflect on the different "ways knowing" while paying special attention to your values, personality, experiences, and goals.

* Required

1. Email address *

____

2. Rank your "ways of knowing" (most preferred to least preferred). Select each "way of knowing" only once. *

Mark only one oval per row.

	Instrumental (rule-based)	Socializing (other-focused)	Self-Authoring (reflective)	Self-Transforming (interconnecting)
My #1 (most preferred) way of knowing	⬭	⬭	⬭	⬭
My 2nd way of knowing	⬭	⬭	⬭	⬭
My 3rd way of knowing	⬭	⬭	⬭	⬭
My 4th (least preferred) way of knowing	⬭	⬭	⬭	⬭

Appendix M (continued)

3. Did the results of the survey match your preferred "way of knowing?" *

Mark only one oval.

- Yes
- No

4. What did this exercise teach you about yourself or confirm what you already believed? *

5. How will an understanding of your and others' "ways of knowing" enhance the way you grow as a teacher, leader, and learner? *

6. *Optional, but very helpful!* Please share your thoughts, concerns, or questions regarding the "ways of knowing" and/or this reflective exercise in general.

Appendix N

Sample PLC Agenda

Science Squad

SCS Science for Elementary Google Site

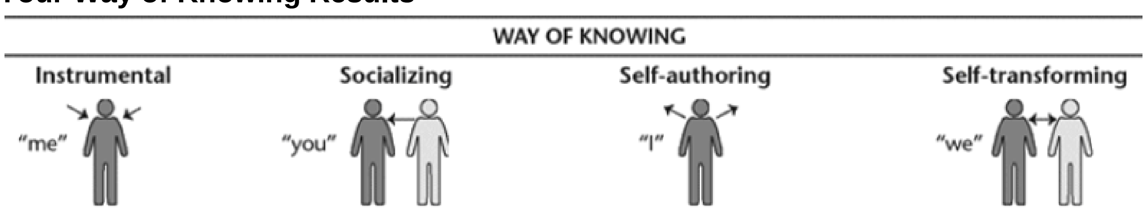
Schoology

September 23, 2020

"Our future depends on a public that can use science for personal decision-making and to participate in civic, political, and cultural discussions related to science" (http://stemteachingtools.org/brief/43).

- **Today's Slideshow**

Your Way of Knowing Results



- After considering your results and reflecting on the information in the chart, **complete this short Google Form**.

Pacing Guides 2020-21
- **1st Grade**
- **2nd Grade**
- **3rd Grade**

Interactive Pacing Guides for Science 2020-21
- **1st Grade Pacing Guide**
- **2nd Grade Pacing Guide**
- **3rd Grade Pacing Guide**

Planning Your Next Unit
- **Start in STEMscopes (Log-in here)**
    - **1st Grade Planning Template**
    - **2nd Grade Planning Template**
    - **3rd Grade Planning Template**

Things to consider:
- **Review the "Teacher Background" information in STEMscopes**

Appendix N (continued)

- **Tasks that can be made "virtual-friendly"**
- **Divide & Conquer**
- **Schedule a time to work with Sam in the Library :-)**

Goals:

- **Develop standards-based instruction using STEMscopes and other resources**
- **Focus on coaching and collaboration**
- **Plan to meet at least six times as a Squad**
- **Develop at least 1 common science assessment for each grade level**
- **Outline a science pacing guide for each grade level**
- **Share student work samples and evaluate learning**
- **Support teachers on your team with science**

Appendix O

Second Round of PLC Intervention Dashboard

Date	Attendance	Summary	Goals/Tasks
9/1/20	Two 3rd Grade Teachers	Developed instructional plans for science. Demonstrated how to use STEMscopes for online learning.	Reviewed STEMscopes resources for 3rd grade's first unit on life cycles.
9/8/20	Team Meeting	Administered the pre-Intervention T-STEM survey. Shared timeline of what the first PLC in the spring accomplished. Participants experienced a daily science lesson for online learning. PLC viewed a sample unit for each grade level and gave feedback via Google Form.	Established a plan for the PLC to meet every Wednesday during the virtual learning schedule. Addressed technical concerns associated with online science. Plan activities on the 5E inquiry model in a virtual learning environment.
9/10/20	One 3rd Grade Teacher	Made preparations for the second scope in the unit. I helped the teacher outline the unit based on the 5E inquiry model. Collaborated with the teacher on activities to be used as formative assessments.	Designed the second scope of the first bundle in STEMscopes about animal development and survival.
9/11/20	Curriculum Coordinator	Examined the current science curriculum map and pacing guide for each grade level.	Created interactive pacing guides in Google Slides.
9/14/20	Two 3rd Grade Teachers	Teachers had concerns about students not completing assignments correctly or having technical issues. We decided to make short instructional videos for each online science lesson.	How can teachers monitor student learning and provide feedback online?
9/16/20	Team Meeting	Introduced the Enneagram and Ways of Knowing. Exhibited the newly developed interactive pacing guides for teaching science, Reviewed a sample unit for each grade level and made revisions. One teacher said that a problem with the current pacing guides is that science and social studies are rotated. Alternating the content areas makes it hard to have coherent instruction. Participants said that the current pacing guide is only used for guidance to what to teach next, *not* for reflection. The new interactive pacing guides will be reflective and help shape science curriculums.	Participants completed the Enneagram personality inventory and Ways of Knowing survey. How do we engage students in 3D tasks that will also support formative evaluation?

Appendix O (continued)

9/18/20	Two 2nd Grade Teachers	I sent an email to the PLC requesting for one representative from each grade level to collaborate on the next science unit. 2nd-grade teachers shared the next unit's topic, Diversity of Living Things Unit.	Created an instructional outline of the impending science unit based on the 5E process. Encouraged teachers to explore and curate resources from STEMscopes.
9/18/20	One 1st Grade Teacher	Continued to collaborate with a teacher from each grade level on planning the next science unit. 1st-grade teachers shared the next unit's topic, Patterns in the Sky.	Explored sources for teaching Patterns in the Sky Unit. Participants and I curated resources on a hyperdoc.
9/21/20	One 2nd Grade Teacher	Shared resources for an upcoming unit titled, Diversity of Living Things. Based instructional sequence off of 5E inquiry model from STEMscopes. The teacher contributed ideas about habitats and interactive activities. The participant suggested a performance-based assessment where students create an online habitat. Students are to make a claim with evidence about their creation.	Finalized daily activities for a 2nd grade unit. How do teachers assess students' understanding in a summative performance-based task (i.e., creating a habitat online)?
9/22/20	One 1st Grade Teacher	Collaborated with the participant on a unit titled, Patterns in the Sky. We started a bibliography of resources in Google Docs. Planned instructional sequence using the 5E inquiry model. The participant updated the interactive pacing guide by merging two scopes (seasons and objects in the sky) into one unit. Incorporated content from a previous 1st grade unit on light as a review and hook for learning about the objects in the sky.	How can we merge two scopes into a unit so content is well scaffolded but assessed formatively and often?
9/23/20	Team Meeting	Disseminated the Ways of Knowing survey results. Participants reflected on their results using additional information on the ways of knowing/constructive-developmental theory. Participants completed a Google Form where they ranked their ways of knowing and reflected on the process. The team updated the interactive pacing guides and started preparation for each grade's next science unit.	The 3rd-grade teacher does not think STEMscopes can be used online. Says finds TPT materials. 3rd grade now teaches science every day (for about 25 minutes) 1st and 2nd-grade interchange science and social units. So science is taught for about 2 weeks every two weeks. I can tell teachers want to follow the 5e inquiry process but it is difficult esp. being virtual. Teachers want ready-made lessons that they can upload to Schoology and easily share with teammates.

Appendix O (continued)

9/24/20	One 1st Grade Teacher	The participant scheduled a meeting to review resources she had collected for teaching seasonal patterns. Participants are becoming more comfortable with the idea of collaborating with a "coach" on the design process of inquiry-based science instruction.	Continue to follow-up with the teacher on plans and implementation to nurture collaboration and enthusiasm on teaching science.
9/25/20	Curriculum Coordinator	The library purchased Science Spin magazines for each grade level. PLC members had the first look at the materials. Their input helped tailor the plans for rolling out the resources to all faculty.	Shared access codes to Science Spin magazines. Devised ways to train and support faculty on using the digital resource.
9/28/20	One 1st Grade Teacher	Shared an interactive and inquiry-based Google activity for science scope named, "Patterns in the Sky." The teacher replied, "These all look great! I like how you merged the *STEMscopedia* to place the text beside the interactive portion!"	Scheduled a meeting to finalize procedures and student materials for the unit.
9/29/20	Curriculum Coordinator	Examined the Kentucky Department of Education's (KDE), Through Course Tasks. Discussed how to make summative/common assessment align with the NGSS 3-dimensional learning. Considered using the "explain" and "elaborate" steps in the 5E framework to measure student mastery.	Modeled for teachers how to do the 5E cycle based on performance tasks and resources from STEMscopes. Show how to monitor student learning and prepare for a summative evaluation task.
9/30/20	Team Meeting	Reviewed Enneagram personality types using descriptions of Disney princesses. Shared each person's Enneagram and Way of Knowing. Hosted KDE's Science Consultant as a special guest speaker (via Zoom):	Focused on essential skills and conceptual understandings during standards-aligned, inquiry-based instruction

Appendix O (continued)

10/1/20	Curriculum Coordinator 1st Grade Teacher	Requested feedback from PLC members about the meeting with KDE's Science Consultant. **<u>Curriculum Coordinator:</u>** •Are there examples of summative assessments in science? •How can we ensure that all students are getting access to high-quality science instruction? (Common assessment? Performance Tasks? Portfolios?) **<u>1st Grade Teacher</u>:** •Commented that the STEMscopes curriculum made her nervous because the science consultant had never heard of it. Needs approval that the curriculum and materials used for science are appropriate.	Forwarded follow-up feedback to the science consultant. Collaborated with teachers on adapting the STEMscopes curriculum to enhance students' learning experience. First grade teacher shared picture books and online resources she uses to supplement STEMscopes activities.
10/2/20	2nd Grade Team	Met with 2nd grade teachers to discuss the progress of their current science unit, "Diversity of Living Things." Teachers commented that virtual instruction has been going well. The PLC has helped teachers develop activities that promote critical thinking but also gives scaffolded support (i.e., videos, teacher modeling).	How can we improve our evaluation of student learning online? Teachers feel pleased and confident with science instruction. What are students' feelings toward virtual science lessons?
10/13/20 (after Fall Break)	Team Meeting	Sent a message to PLC members about scheduling time to collaborate and/or plan co-teaching opportunities. Shared links to resources suggested by KDE's Science Consultant.	Followed-up with 2nd and 3rd grade teachers who expressed interest in co-teaching a science lesson
10/14/20	Co-Teaching (2nd and 3rd Grade Teachers)	Collaborated on a Google Doc to brainstorm standards-based science lessons according to information on the pacing guide.	Brainstormed ideas in a shared document and added comments to guide teachers' thinking toward standards and the inquiry process.
10/15/20	Co-Teaching (2nd and 3rd Grade Teachers)	Planned science lessons for in-person hybrid learning that aligned with virtual students' curriculum. Researcher co-taught science lessons with teachers the week of October 19-23.	Curated resources for classroom instruction. Modified graphic organizers based on students' needs. Printed "Before, During, After" science posters.

Appendix O (continued)

10/16/20	Central Office Leadership Team Meeting	Principal asked me to present the intervention's progress to the district's Central Office Leadership Team during a school site visit. [Superintendent, Chief Academic Officer, Instructional Supervisor, and school leadership team] -Principal was adamant about integrating science and social studies during core Reading and Math classes.	Shared PLC's dashboard, Google Site, and other curriculum documents with the Central Office staff members.
10/19-22/20	Co-Teaching (2nd and 3rd Grade Teachers)	2nd Grade Co-Teaching: • Animal and plant dependence unit 3rd Grade Co-Teaching: • Inheritance and variations of traits unit	Shared co-teaching experiences at the next PLC meeting. Used the NGSS Lesson Screener to reflect on instructional procedures and outcomes. Modeled the reflective process for other participants.
10/23/20	Team Meeting	Modeled using phenomena (bobcat footage from the school's trail cam) to anchor the NGSS instruction. Demonstrated how to use the science investigative poster during a lesson. Shared co-teaching instructional plans from the week. The co-teachers shared reflections based on the NGSS Lesson Screener. The screener was recommended by KDE's Science Consultant.	Planned additional coaching and co-teaching opportunities with participants. Supported teachers on using claim-evidence-reasoning (CER) to monitor student learning The CER writing strategy was a growth area from the first check-in survey.
10/26/20	Co-Teaching 2nd Grade Team	Developed a common science assessment based on a Through Course Task titled "Seeds Dispersal" from KDE.	Analyzed student data based on performance criteria.
10/27/20	Co-Teaching 3rd Grade Team	Implemented a 5E "explore" activity from STEMscopes called, "Random Variations." Reflected on implementation and results of the Claim-Evidence-Reasoning writing strategy.	Used performance criteria to evaluate students learning and provide meaningful feedback
10/28/20	One 1st Grade Teacher	Coaching session on finalizing plans for a 1st grade virtual science lesson titled, "Patterns in the Sky."	Planned daily lessons based on students' questions, discussions, and life experiences.
10/30/20	One 2nd Grade Teacher	Analyzed student evidence and overall results from the "Seeds Dispersal" common assessment.	Reflected on strategies that were effective during implementation of the common science assessment. Gave input on how the process could be improved.

Appendix O (continued)

11/2/20	PLC Members	Uploaded resources about the CER writing strategy to the PLC's Schoology learning management system group: posters, bookmarks, and resources.	Documents supported participants' design of strategies that encourage students to make claims and provide explanations.
11/4-5/20	Two 3rd Grade Teachers	3rd Grade Co-Teaching: • Process and Impacts of Natural Hazards Unit • Co-taught lesson at 11:00-12:00 and 2:15-3:00.	Brainstormed methods for engaging students in hands-on learning while adhering to COVID-19 safe school guidelines.
116/20	Team Meeting	Engaged in a gallery walk activity containing Through Course Tasks (TCT) from KDE for different grade levels. Used the NGSS Task Pre-screener to analyze the quality of TCTs.	Reflected on how tasks could be used as common science assessments.
11/9/20	2nd grade Teacher	Participant is a first year teacher. She decided to schedule her first PGES evaluation with a school administrator during a science lesson.	Supported the teacher as she designed a lesson for her observation.
11/9/20	Two 3rd Grade Teachers	Modified a TCT about animal structures and functions. Worked to connect the performance task with students' interests. Students get to choose which animal to study. Students had the option to select animals captured on the school's trail cam.	Evaluated alterations to the TCT using the NGSS Lesson Plan Screener.
11/10/20	Two 3rd Grade Teachers	Made modifications to a TCT for animal structures. Students observed trail cam footage of animals living around the school.	Curated sites to conduct research on animal structures (i.e., Nat Geo and DK Find Out).
11/12/20	Two 3rd Grade Teachers	Coached participants on best practices for implementing the TCT Animal Structure Performance Task. Teachers decided to use a T-Rex and its structures as an example.	Teachers reflected on the need to model the activity using a sample animal.
11/13/20	Principal	Discussed the progress of the PLC. Brainstormed next steps following data collection and analysis.	How do we sustain instructional coaching and collaboration once the PLC concludes?

Appendix O (continued)

11/16/20	Two 3rd Grade Teachers	Reflected on Animal Structure Performance Task. Teacher said the T-Rex model helped students make connections and increase dialogue. Students were able to think more deeply about the structure of the animals they decided to research because of the teacher model.	Outlined modeling strategies that welcome student input and foster critical thinking.
11/18/20	Two 3rd Grade Teachers	Curated STEMscopes resources for planning the next third grade lesson title, "Environmental Traits."	Aligned instructional procedures with phases in the 5E inquiry model.
11/20/20	Team Meeting	STEMscopes 5E Inquiry Scavenger Hunt. Participants decided which set of materials at each stage in the 5E inquiry model addressed their grade level's standard. • First Grade: Parts of Animals STEMscope • Second Grade: Mapping Our World STEMscope • Third Grade: Plant and Animal Extinction STEMscope	Focused on designing online and in-person instruction that adheres to the inquiry process.
11/20/20	3rd Grade Team	Discussed curriculum map for the year based on what has been taught and what standards remain. Teachers are revising the sequence of instructional units from STEMscopes based on Through Course Tasks, student research projects, and general scaffolding concerns.	Revised the curriculum map during the year instead of at the end of middle to better reflect the needs of teachers and students.
11/23/20	First Grade Team	Collaborated with teachers on the design of choice boards to engage students in learning about animal survival. The school started all virtual learning again on 11/23/20 due to rising COVID cases.	Advocated for student choice and engagement during online learning.
11/24/20	Third Grade	Examined science curriculum maps in comparison to context factors (i.e., content taught, virtual learning because of school closures). Planned a three-week unit on animal habitats that encompassed two bundles from STEMscopes.	Reviewed the first semester's science units. Planned the second semester's instruction by updating the interactive pacing guide for each grade level.
11/30/20	Team (learning management system)	Created a Science Squad PLC Bitmoji Classroom. The virtual classroom contains: pacing guides, Google Science Site, standards, resources, STEMscopes, and performance tasks.	Curated important resources into a hyperlinked Google Slide for easy access by participants.

Appendix O (continued)

12/2/20	PLC Members	Administered the post-Intervention T-STEM survey to all participants.	Compared results to pre-survey data to measure the impact of the study.
12/7-11/20	Post-Interviews	Facilitated post-intervention interviews with select participants.	Coded interview data into categories to determine implications of the intervention.

Appendix P

Second Round of PLC Intervention Pre-Survey

#	Field	Min.	Max	Mean	Std. Dev.	Var.	Count
24	I know the steps necessary to teach science effectively.	3	4	3.7	0.46	0.21	10
25	I have the necessary resources to teach science effectively.	2	5	3.4	1.02	1.04	10
26	I am confident that I can explain to students why science experiments work.	3	4	3.7	0.46	0.21	10
29	I understand science concepts well enough to be effective in teaching science.	3	4	3.4	0.49	0.24	10
30	Given a choice, I would invite a colleague to evaluate my science teaching.	2	4	3.6	0.66	0.44	10
31	I am confident that I can answer students' science questions.	3	4	3.4	0.49	0.24	10
32	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	2	4	3.4	0.66	0.44	10
34	I know what to do to increase student interest in science.	2	4	3.6	0.66	0.44	10
35	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	2	4	3.3	0.64	0.41	10
36	The inadequacy of a student's science background can be overcome by good teaching.	2	5	3.6	0.8	0.64	10

Appendix P (continued)

37	When a student's learning is science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	3	4	3.4	0.49	0.24	10
38	The teacher is generally responsible for students' learning in science.	2	4	3.3	0.64	0.41	10
40	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	2	5	3.5	0.81	0.65	10
41	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2	4	3.4	0.66	0.44	10
43	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	2	4	3.3	0.64	0.41	10
116	How often do your students ask questions about their learning?	1	4	3	1	1	10
118	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	2	4	2.6	0.8	0.64	10
120	How often do your students work in small groups?	2	4	3.5	0.81	0.65	10
122	How often do your students make predictions that can be tested?	2	4	2.5	0.67	0.45	10

Appendix P (continued)

124	How often do your students make careful observations or measurements?	2	4	2.5	0.67	0.45	10
126	How often do your students use tools to gather data (e.g. calculators, computers, computer programs, scales, rulers, compasses, etc.)?	2	4	2.7	0.78	0.61	10
128	How often do your students recognize patterns in data?	2	3	2.4	0.49	0.24	10
130	How often do your students create reasonable explanations of results of an experiment or investigation?	2	4	2.5	0.67	0.45	10
132	How often do your students choose the most appropriate methods to express results (e.g. drawings, models, charts, graphs, technical language, etc.)?	2	4	2.6	0.66	0.44	10
134	How often do your students complete activities with a real-world context?	2	4	2.9	0.83	0.69	10
136	How often do your students engage in content-driven dialogue?	2	4	3	0.89	0.8	10
138	How often do your students reason abstractly?	2	2	2	0	0	10
140	How often do your students reason quantitatively (i.e., use computations and numerical data to explain answers)?	2	3	2.3	0.46	0.21	10
142	How often do your students critique the reasoning of others?	1	4	1.9	0.83	0.69	10

Appendix P (continued)

144	How often do your students learn about careers related to the instructional content?	1	4	2.4	0.92	0.84	10
45	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	2	4	2.6	0.8	0.64	10
46	My students use technology to communicate and collaborate with others.	2	4	2.6	0.66	0.44	10
47	My students use technology to access online resources and information as part of activities.	2	4	2.8	0.75	0.56	10
49	My students work on technology-enhanced projects that approach real-world applications of technology.	1	4	2.1	0.7	0.49	10
50	My students use technology to help solve problems.	1	4	2.4	0.8	0.64	10
51	My students use technology to support higher-order thinking, e.g. analysis, synthesis and evaluation of ideas and information.	1	4	2.3	0.78	0.61	10
52	My students use technology to create new ideas and representations of information.	1	4	2.3	0.78	0.61	10
131	How often do your students engage in hands-on learning?	2	4	3	0.89	0.8	10
133	How often do your students take control of their own learning?	2	4	2.5	0.67	0.45	10

Appendix P (continued)

135	How often do your students make connections between classroom instruction and the real-world?	2	4	3	1	1	10
137	How often do your students take risks?	1	3	2	0.45	0.2	10
139	How often do your students lead others to accomplish a goal?	2	4	2.4	0.66	0.44	10
141	How often do your students encourage others to do their best?	2	4	2.8	0.87	0.76	10
143	How often do your students produce high quality work?	2	4	3	0.77	0.6	10
145	How often do your students respect the differences of their peers?	2	4	2.9	0.94	0.89	10
147	How often do your students help their peers?	2	4	3.1	0.94	0.89	10
149	How often do your students include others' perspectives when making decisions?	2	4	2.6	0.8	0.64	10
151	How often do your students make changes when things do not go as planned?	1	4	2.6	1.02	1.04	10
153	How often do your students set their own learning goals?	1	4	2.5	1.02	1.05	10
155	How often do your students manage their time wisely when working on their own?	2	4	2.9	0.94	0.89	10
157	How often do your students choose which assignment out of many needs to be done first?	1	4	2.3	0.9	0.81	10

Appendix P (continued)

159	How often do your students work well with students from different backgrounds?	2	4	3.1	0.94	0.89	10
160	I know about current STEM careers.	2	4	3.1	0.7	0.49	10
162	I know where to go to learn more about STEM careers.	2	4	3	0.63	0.4	10
164	I know where to find resources for teaching students about STEM careers.	2	5	3.5	0.81	0.65	10
166	I know where to direct students or parents to find information about STEM careers.	2	4	3.1	0.54	0.29	10

Appendix Q

Second Round of Intervention Pre-Interview Questions

<u>Interview Questions:</u>

1. How would you describe your collaboration with other educators on science teaching?

2. What skills do you want students to gain in science class?

3. What factors make it ***easy*** to teach science?

4. What factors make it ***challenging*** to teach science?

5. How do you know when, or if, students achieve mastery of science content?

6. What would support you best in developing and teaching science instruction?

Appendix R

Second Grade NGSS Lesson Screener

A Quick Look at Potential NGSS Lesson Design

The lesson is designed to engage all students in making sense of phenomena and/or designing solutions to problems through student performances that integrate the three dimensions of the NGSS.

Criterion A. Explaining Phenomena or Designing Solutions

1. **Learn about the importance of explaining phenomena and designing solutions** in lessons designed for the NGSS here: www.nextgenscience.org/phenomena. Once you are comfortable with the role of explaining phenomena and designing solutions, use the table below to help gather evidence that either student problem-solving or sense-making of phenomena drives the lesson:

	NGSS designed lessons will look *less* like this:	**NGSS designed lessons will look *more* like this:**
Explaining Phenomena or Designing Solutions	Explaining phenomena and designing solutions are not a part of student learning or are presented separately from “learning time” (i.e. used only as a “hook” or engagement tool; used only for enrichment or reward after learning; only loosely connected to a DCI).	The purpose and focus of the lesson are to support students in making sense of phenomena and/or designing solutions to problems. The entire lesson drives toward this goal.
	The focus is only on getting the “right” answer to explain the phenomenon	Student sense-making of phenomena or designing of solutions is used as a window into student understanding of all three dimensions of the NGSS.
	A different, new, or unrelated phenomenon is used to start every lesson.	Lessons work together in a coherent storyline to help students make sense of phenomena.
	Teachers tell students about an interesting phenomenon or problem in the world.	Students get direct (preferably firsthand, or through media representations) experience with a phenomenon or problem that is relevant to them and is developmentally appropriate.
	Phenomena are brought into the lesson after students develop the science ideas so students can apply what they learned.	The development of science ideas is anchored in explaining phenomena or designing solutions to problems.

Appendix R (continued)

2. **Record evidence** about how explaining phenomena or designing solutions to problems are represented in the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
A. Explaining Phenomena or Designing Solutions: The lesson <u>focuses</u> on supporting students to make sense of a phenomenon or design solutions to a problem.	***This lesson's phenomena focuses on the behavior of bees. I showed the class a picture of a beehive formed around a hanging houseplant. I posted the compelling question: "I know some animals depend on plants, but do plants depend on animals?"***	☐ None ☐ Inadequate ☒ Adequate ☐ Extensive	***Next time, I will challenge students to select the phenomenon by viewing photos of bees and other insects. I will ask students to write observations about what they see. Students will ask questions about one photo that could potentially be used as the anchoring phenomenon for the lesson.***

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion A.

Criterion B. Three Dimensions

1. **Document evidence of *specific grade-banded elements** of each dimension—including what evidence was in the lesson, where it occurs, and why it should be considered to be evidence**. To be considered as evidence, it should be clear how the student learning will develop or apply a specific element in a way that distinguishes it from other grade bands. Use the table below to help gather evidence about how each dimension is used in this lesson:
   * The term "element" indicates the bulleted DCIs, SEPs, and CCCs that are articulated in the foundation boxes of the standards. These elements are summarized in <u>NGSS Appendices F & G</u> for the SEPs and CCCs and *<u>NSTA's DCI matrix</u> for the DCIs. (Note that <u>NGSS Appendix E</u> contains summaries of the DCIs—not the DCI elements).*

Appendix R (continued)

	NGSS designed lessons will look *less* like this:	NGSS designed lessons will look *more* like this:
Three Dimensions	A single practice element shows up in the lesson.	The lesson helps students use multiple (e.g., 2–4) practice elements as appropriate in their learning.
	The lesson focuses on colloquial definitions of the practice or crosscutting concept names (e.g., “asking questions”, “cause and effect”) rather than on grade-appropriate learning goals (e.g., elements in NGSS Appendices F &G).	Specific grade-appropriate elements of SEPs and CCCs (from NGSS Appendices F & G) are <u>acquired</u>, <u>improved</u>, or <u>used</u> by students to help explain phenomena or solve problems during the lesson.
	The SEPs and CCCs can be inferred by the teacher (not necessarily the students) from the lesson materials.	Students explicitly use the SEP and CCC elements to make sense of the phenomenon or to solve a problem.
	Engineering lessons focus on trial and error activities that don’t require science or engineering knowledge.	Engineering lessons require students to acquire and use elements of DCIs from physical, life, or Earth and space sciences together with elements of DCIs from engineering design (ETS) to solve design problems.

Appendix R (continued)

2. **Record specifically where you find each dimension** in the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

<table>
<tr><th>Lessons designed for the NGSS include clear and compelling evidence of the following:</th><th colspan="3">What was in the materials, where was it, and why is this evidence?</th><th>Overall Evidence of Quality?</th><th>Suggestions for improvement</th></tr>
<tr><td rowspan="4">B. Three Dimensions: The lesson helps students develop and use multiple <u>grade-appropriate elements</u> of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) which are deliberately selected to aid student sense-making of phenomena or designing of solutions.</td><td colspan="2">Document evidence for each dimension.</td><td>Evidence?</td><td rowspan="4">☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td><td rowspan="4">I will continue to find ways for students to construct their own models of the lesson's content. My guiding question will be, "How can students demonstrate pollination and seed dispersion with a design of their own?"</td></tr>
<tr><td>SEP</td><td>Students studied an interactive diagram of a bee pollinating a flower. The diagram was viewed on DK Find Out's informational website.</td><td>☐ None
☒ Inadequate
☐ Adequate
☐ Extensive</td></tr>
<tr><td>DCI</td><td>Students drew pictures to represent stages in the pollination process. I created and printed this graphic organizer.</td><td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td></tr>
<tr><td>CCC</td><td>Students wore socks on the outside of their shoes and walked around the playground. Grass and seeds stuck to students' socks. Students sorted the seeds into categories back in the classroom. Students discussed causes and effects of the activity.</td><td>☐ None
☐ Inadequate
☐ Adequate
☒ Extensive</td></tr>
</table>

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion B.

Criterion C. Integrating the Three Dimensions for Instruction and Assessment

1. **Learn more about the importance of the three dimensions working together** in this brief paper. Then, use your evaluation of the lesson for criterion B (three dimensions) to examine the lesson for places that students use the three dimensions together to explain a phenomenon or design a solution to a problem. Use the table below to help gather evidence about three-dimensional learning and assessment in the lesson:

	NGSS designed lessons will look *less* like this:	**NGSS designed lessons will look *more* like this:**
Integrating the Three Dimensions	Students learn the three dimensions in isolation from each other (e.g., a separate lesson or activity on science methods followed by a later lesson on science knowledge).	• The lesson is designed to build student proficiency in at least one grade-appropriate element from each of the three dimensions. • The three dimensions intentionally work together to help students explain a phenomenon or design solutions to a problem. • All three dimensions are necessary for sense-making and problem-solving.
	Teachers assume that correct answers indicate student proficiency without the student providing evidence or reasoning.	Teachers deliberately seek out student artifacts that show direct, observable evidence of learning, building toward all three dimensions of the NGSS at a grade-appropriate level.
	Teachers measure only one dimension at a time (e.g., separate items for measuring SEPs, DCIs, and CCCs).	Teachers use tasks that ask students to explain phenomena or design solutions to problems, and that reveal the level of student proficiency in all three dimensions.

Appendix R (continued)

2. **Record evidence** about how the three dimensions are integrated for instruction and assessment purposes. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	**What was in the materials, where was it, and why is this evidence?**	**Evidence of Quality?**	**Suggestions for improvement**
C. Integrating the Three Dimensions for Instruction and Assessment: The lesson requires student performances that integrate elements of the SEPs, CCCs, and DCIs to make sense of phenomena or design solutions to problems, and the lesson elicits student artifacts that show direct, observable evidence of three-dimensional learning.	***The class went outside and actually experienced the pollination process. I feel that with real life connections, students can relate to the content more. Pollination is such a big concept. For example, people can spread seeds, insects pollinate, we all pollinate. So just for students to see that they can do it and also other insects, I feel like that was really good for them.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***I want to find ways for students to investigate different insects besides bees. Students need to make the connection that seed dispersal is caused by many different organisms.***

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion C.

Criterion D. Relevance and Authenticity

1. **Learn about the importance of making lessons relevant and authentic for all students** in NGSS Appendix D. Once you are comfortable with ideas for making lessons relevant and authentic for all students, examine the lesson through the "lens" of student engagement, and for clear evidence that the lesson supports connections to students' lives. Use the table below to help gather evidence about the relevance and authenticity of the lesson for students:

	NGSS designed lessons will look *less* like this:	**NGSS designed lessons will look *more* like this:**
Relevance and Authenticity	The lesson teaches a topic adults think is important.	The lesson motivates student sense-making or problem-solving
	The lesson focuses on examples that some of students in the class understand.	The lesson provides support to teachers for making connections to the lives of every student in the class.

Appendix R (continued)

	Driving questions are given to students.	Student questions, prior experiences, and diverse backgrounds related to the phenomenon or problem are used to drive the lesson and the sense-making or problem-solving.
	The lesson tells the students what they will be learning.	The lesson provides support to teachers or students for connecting students' own questions to the targeted materials.

2. **Record evidence** about how the lesson is relevant to students and motivates their learning. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
D. Relevance and Authenticity: The lesson motivates student sense-making or problem-solving by taking advantage of student questions and prior experiences in the context of the students' home, neighborhood, and community as appropriate.	***Students were very interested in the activity because they got to go outside to places they were familiar with. Students walked around the playground with socks on the outside of their shoes to collect seeds. Students observed where the grass, leaves, and seeds came from based on their surroundings. The class came back inside and laid their socks out on the desks. A lot of the students actually had little bitty grass seeds on their socks. They didn't realize that they could see seeds like that. It was a great hands-on experience.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***It's important to consider methods in which students can record and compile their questions during the activity. I will be intentional about addressing student-generated questions throughout the unit which will increase relevance and motivation.***

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion D.

Appendix R (continued)

Criterion E. Student Ideas

1. **Examine the lesson for opportunities for *all* students to communicate their ideas** and for the depth to which student ideas are made visible. Use the table below to help gather evidence about how each dimension is used in this lesson:

	NGSS designed lessons will look *less* like this:	NGSS designed lessons will look *more* like this:
Student Ideas	The teacher is the central figure in classroom discussions.	• Classroom discourse focuses on explicitly expressing and clarifying student reasoning • Students have opportunities to share ideas and feedback with each other directly.
	Student artifacts only show answers.	Student artifacts include elaborations (which may be written, oral, pictorial, and kinesthetic) of reasoning behind their answers, and show how students' thinking has changed over time.
	The teacher's guide focuses on what to tell the students.	The lesson provides supports to teachers for eliciting student ideas.

2. **Record evidence** about how ideas are elicited from ALL students during the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
E. Student Ideas: The lesson provides opportunities for students to express, clarify, justify, interpret, and represent their ideas (i.e., making thinking visible) and to respond to peer and teacher feedback.	***The first thing the class did in this lesson was learn about pollination. We used kool aid packets and cotton swabs to simulate pollination. Students actually experienced how pollen moves if connected to a bee. Students witnessed how pollen moves from place to place. Students made predictions before the activity. They recorded observations on the Before-During-After learning poster and completed the pollination drawing activity at the end.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***Students did a great job during this activity. Next time, I will engage students in more peer-to-peer feedback. I would like students to evaluate each other's seed sorting work from the sock experiment.***

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion E.

Criterion F. Building on Students' Prior Knowledge

1. **Learn about the expected learning progressions of each of the three dimensions** in NGSS Appendices E, F, and G. Once you are familiar with the learning progressions, use the table below to help gather evidence about how the lesson builds on students' prior learning in each of the three dimensions:

Building on Students' Prior knowledge	**NGSS designed lessons will look *less* like this:**	**NGSS designed lessons will look *more* like this:**
	The lesson content builds on students' prior learning, but only for DCIs.	The lesson content builds on students' prior learning in all three dimensions.
	The lesson does not include support to teachers for identifying students' prior learning.	The lesson provides explicit support to teachers for identifying students' prior learning and accommodating different entry points, and describes how the lesson will build on the prior learning.
	The lesson assumes that students are starting from scratch in their understanding.	The lesson explicitly works together with students' foundational knowledge and practice from prior grade levels.

Appendix R (continued)

2. **Record evidence** about how the lesson builds on students' prior learning. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
F. Building on Students' Prior Knowledge: The lesson identifies and builds on students' prior learning in all three dimensions in a way that is explicit to both the teacher and students.	***This lesson built on students' prior knowledge because they engaged in something familiar like being outside. Students know what grass is, they know what a flower is. We used the real world connection of what is all around us throughout the lesson. The activity was NOT a simulation that students just watched on the computer. They actually got to do it. Students were never at a loss for words when I asked them questions since they had the real world connections. It was good to see what they really understood. Students were invested in the lesson and very interested in the topic.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***Student engagement was high in this lesson. In addition to connecting learning to students' knowledge and experiences, I want to connect the lesson to other subject areas. My guiding question is, "What opportunities exist for students to use reading skills and practice writing to investigate phenomena and present findings?***

3. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion F.

Appendix S

Third Grade NGSS Lesson Screener

A Quick Look at Potential NGSS Lesson Design

The lesson is designed to engage all students in making sense of phenomena and/or designing solutions to problems through student performances that integrate the three dimensions of the NGSS.

Criterion A. Explaining Phenomena or Designing Solutions

4. **Learn about the importance of explaining phenomena and designing solutions** in lessons designed for the NGSS here: www.nextgenscience.org/phenomena. Once you are comfortable with the role of explaining phenomena and designing solutions, use the table below to help gather evidence that either student problem-solving or sense-making of phenomena drives the lesson:

	NGSS designed lessons will look *less* like this:	**NGSS designed lessons will look *more* like this:**
Explaining Phenomena or Designing Solutions	Explaining phenomena and designing solutions are not a part of student learning or are presented separately from "learning time" (i.e. used only as a "hook" or engagement tool; used only for enrichment or reward after learning; only loosely connected to a DCI).	The purpose and focus of the lesson are to support students in making sense of phenomena and/or designing solutions to problems. The entire lesson drives toward this goal.
	The focus is only on getting the "right" answer to explain the phenomenon	Student sense-making of phenomena or designing of solutions is used as a window into student understanding of all three dimensions of the NGSS.
	A different, new, or unrelated phenomenon is used to start every lesson.	Lessons work together in a coherent storyline to help students make sense of phenomena.
	Teachers tell students about an interesting phenomenon or problem in the world.	Students get direct (preferably firsthand, or through media representations) experience with a phenomenon or problem that is relevant to them and is developmentally appropriate.
	Phenomena are brought into the lesson after students develop the science ideas so students can apply what they learned.	The development of science ideas is anchored in explaining phenomena or designing solutions to problems.

5. **Record evidence** about how explaining phenomena or designing solutions to problems are represented in the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
A. Explaining Phenomena or Designing Solutions: The lesson focuses on supporting students to make sense of a phenomenon or design solutions to a problem.	***I was very intentional with using phenomena during this lesson. We went back to the phenomenon on a regular basis throughout the lesson. Students were able to analyze their leaf and draw a picture of it, what color it is, and also they measured it. They had to answer: where did you find the leaf, what was above your leaf, and I like my leaf because...just always bringing it back to them.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***It is important that learning relates to students—their interests and the world in which the live. Science topics and activities should always address students' needs and passions.***

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion A.

Criterion B. Three Dimensions

4. **Document evidence of *specific grade-banded elements** of each dimension—including what evidence was in the lesson, where it occurs, and why it should be considered to be evidence**. To be considered as evidence, it should be clear how the student learning will develop or apply a specific element in a way that distinguishes it from other grade bands. Use the table below to help gather evidence about how each dimension is used in this lesson:
* The term "element" indicates the bulleted DCIs, SEPs, and CCCs that are articulated in the foundation boxes of the standards. These elements are summarized in NGSS Appendices F & G for the SEPs and CCCs and *NSTA's DCI matrix for the DCIs. (Note that NGSS Appendix E contains summaries of the DCIs—not the DCI elements).*

Appendix S (continued)

	NGSS designed lessons will look *less* like this:	NGSS designed lessons will look *more* like this:
Three Dimensions	A single practice element shows up in the lesson.	The lesson helps students use multiple (e.g., 2–4) practice elements as appropriate in their learning.
	The lesson focuses on colloquial definitions of the practice or crosscutting concept names (e.g., “asking questions”, “cause and effect”) rather than on grade-appropriate learning goals (e.g., elements in NGSS Appendices F &G).	Specific grade-appropriate elements of SEPs and CCCs (from NGSS Appendices F & G) are acquired, improved, or used by students to help explain phenomena or solve problems during the lesson.
	The SEPs and CCCs can be inferred by the teacher (not necessarily the students) from the lesson materials.	Students explicitly use the SEP and CCC elements to make sense of the phenomenon or to solve a problem.
	Engineering lessons focus on trial and error activities that don’t require science or engineering knowledge.	Engineering lessons require students to acquire and use elements of DCIs from physical, life, or Earth and space sciences together with elements of DCIs from engineering design (ETS) to solve design problems.

Appendix S (continued)

5. **Record specifically where you find each dimension** in the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

<table>
<tr><th>Lessons designed for the NGSS include clear and compelling evidence of the following:</th><th colspan="3">What was in the materials, where was it, and why is this evidence?</th><th>Overall Evidence of Quality?</th><th>Suggestions for improvement</th></tr>
<tr><td rowspan="4">B. Three Dimensions: The lesson helps students develop and use multiple <u>grade-appropriate elements</u> of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) which are deliberately selected to aid student sense-making of phenomena or designing of solutions.</td><td colspan="2">Document evidence for each dimension.</td><td>Evidence?</td><td rowspan="4">☒ None
☐ Inadequate
☐ Adequate
☐ Extensive</td><td rowspan="4">I realized how important it is to be intentional with the vocabulary.</td></tr>
<tr><td>SEP</td><td>Students analyzed the structure of the leaf they selected from outside the school.</td><td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td></tr>
<tr><td>DCI</td><td>The compelling question was, “Why do offspring look similar to, but not exactly like their parents?” The lesson makes the connection to traits and plants by having students go outside and find a leaf. Students were asked to be very intentional about the leaf hunt activity. Guiding questions were: where you picked up the leaf, what did the ground feel like underneath it, where did you find it, what was above it?</td><td>☐ None
☐ Inadequate
☐ Adequate
☒ Extensive</td></tr>
<tr><td>CCC</td><td>I constantly made the connection that some traits are inherited from parents and others happen due to the environment.</td><td>☐ None
☐ Inadequate
☒ Adequate
☐ Extensive</td></tr>
</table>

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion B.

Criterion C. Integrating the Three Dimensions for Instruction and Assessment

4. **Learn more about the importance of the three dimensions working together** in this brief paper. Then, use your evaluation of the lesson for criterion B (three dimensions) to examine the lesson for places that students use the three dimensions together to explain a phenomenon or design a solution to a problem. Use the table below to help gather evidence about three-dimensional learning and assessment in the lesson:

	NGSS designed lessons will look *less* like this:	**NGSS designed lessons will look *more* like this:**
Integrating the Three Dimensions	Students learn the three dimensions in isolation from each other (e.g., a separate lesson or activity on science methods followed by a later lesson on science knowledge).	• The lesson is designed to build student proficiency in at least one grade-appropriate element from each of the three dimensions. • The three dimensions intentionally work together to help students explain a phenomenon or design solutions to a problem. • All three dimensions are necessary for sense-making and problem-solving.
	Teachers assume that correct answers indicate student proficiency without the student providing evidence or reasoning.	Teachers deliberately seek out student artifacts that show direct, observable evidence of learning, building toward all three dimensions of the NGSS at a grade-appropriate level.
	Teachers measure only one dimension at a time (e.g., separate items for measuring SEPs, DCIs, and CCCs).	Teachers use tasks that ask students to explain phenomena or design solutions to problems, and that reveal the level of student proficiency in all three dimensions.

Appendix S (continued)

5. **Record evidence** about how the 3-dimensions are integrated for instruction and assessment purposes. Describe in the response form how this evidence is or is not an adequate indicator the criterion is being met. Include suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	**What was in the materials, where was it, and why is this evidence?**	**Evidence of Quality?**	**Suggestions for improvement**
C. Integrating the Three Dimensions for Instruction and Assessment: The lesson requires student performances that integrate elements of the SEPs, CCCs, and DCIs to make sense of phenomena or design solutions to problems, and the lesson elicits student artifacts that show direct, observable evidence of three-dimensional learning.	***It was instantaneous. I could instantly say this child understands that and is drawing back to the offspring looking similar to the parents, but not exactly alike. I could also see if students had misconceptions.***	☐ None ☐ Inadequate ☒ Adequate ☐ Extensive	***Students need to make their learning visible. I will look for ways students can talk about their learning and share ideas with peers.***

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion C.

Criterion D. Relevance and Authenticity

4. **Learn about the importance of making lessons relevant and authentic for all students** in NGSS Appendix D. Once you are comfortable with ideas for making lessons relevant and authentic for all students, examine the lesson through the "lens" of student engagement, and for clear evidence that the lesson supports connections to students' lives. Use the table below to help gather evidence about the relevance and authenticity of the lesson for students:

Relevance and Authenticity	**NGSS designed lessons will look *less* like this:**	**NGSS designed lessons will look *more* like this:**
	The lesson teaches a topic adults think is important.	The lesson motivates student sense-making or problem-solving
	The lesson focuses on examples that some students in the class understand.	The lesson provides support to teachers for making connections to the lives of every student in the class.
	Driving questions are given to students.	Student questions, prior experiences, and diverse backgrounds related to the phenomenon or problem are used to drive the lesson and the sense-making or problem solving.
	The lesson tells the students what they will be learning.	The lesson provides support to teachers or students for connecting students' questions to the targeted materials.

Appendix S (continued)

5. **Record evidence** about how the lesson is relevant to students and motivates their learning. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
D. Relevance and Authenticity: The lesson motivates student sense-making or problem-solving by taking advantage of student questions and prior experiences in the context of the students' home, neighborhood, and community as appropriate.	***One of the most beneficial things was being able to first draw that connection of inheriting traits from your parents. I asked students, "What traits did the animal inherit from their parents and then connect to plants?" I think the leaf really connected to the phenomena with my students. We can look at ourselves and say I got this from my parents. But plants getting traits from their parents is really hard for students to grasp. This lesson brought it all together.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***Next time, I will incorporate other categories to address the phenomena of inherited traits (i.e., birds, reptiles, and insects).***

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion D.

Criterion E. Student Ideas

4. **Examine the lesson for opportunities for *all* students to communicate their ideas** and for the depth to which student ideas are made visible. Use the table below to help gather evidence about how each dimension is used in this lesson:

	NGSS designed lessons will look *less* like this:	NGSS designed lessons will look *more* like this:
Student Ideas	The teacher is the central figure in classroom discussions.	• Classroom discourse focuses on explicitly expressing and clarifying student reasoning • Students have opportunities to share ideas and feedback with each other directly.
	Student artifacts only show answers.	Student artifacts include elaborations (which may be written, oral, pictorial, and kinesthetic) of reasoning behind their answers, and show how students' thinking has changed over time.
	The teacher's guide focuses on what to tell the students.	The lesson provides supports to teachers for eliciting student ideas.

Appendix S (continued)

5. **Record evidence** about how student ideas are elicited from ALL student during the lesson. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	What was in the materials, where was it, and why is this evidence?	Evidence of Quality?	Suggestions for improvement
E. Student Ideas: The lesson provides opportunities for students to express, clarify, justify, interpret, and represent their ideas (i.e., making thinking visible) and to respond to peer and teacher feedback.	***Seeing at first what students know by just telling them the question and phenomena that we will be learning. Having that discussion was beneficial. Students made many connections to the standard of inherited traits as they filled out the graphic organizer.***	☐ None ☐ Inadequate ☒ Adequate ☐ Extensive	***This lesson can be used as a summative assessment. I would like to plan criteria to evaluate students' understanding during the leaf activity and the discussions that ensue.***

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion E.

Criterion F. Building on Students' Prior Knowledge

4. **Learn about the expected learning progressions of each of the three dimensions** in NGSS Appendices E, F, and G. Once you are familiar with the learning progressions, use the table below to help gather evidence about how the lesson builds on students' prior learning in each of the three dimensions:

	NGSS designed lessons will look *less* like this:	NGSS designed lessons will look *more* like this:
Building on Students' Prior	The lesson content builds on students' prior learning, but only for DCIs.	The lesson content builds on students' prior learning in all three dimensions.
	The lesson does not include support to teachers for identifying students' prior learning.	The lesson provides explicit support to teachers for identifying students' prior learning and accommodating different entry points, and describes how the lesson will build on the prior learning.
	The lesson assumes that students are starting from scratch in their understanding.	The lesson explicitly works together with students' foundational knowledge and practice from prior grade levels.

5. **Record evidence** about how the lesson builds on students' prior learning. Describe in the response form below how this evidence is or is not an adequate indicator the criterion is being met. Include detailed suggestions for improvement.

Lessons designed for the NGSS include clear and compelling evidence of the following:	**What was in the materials, where was it, and why is this evidence?**	**Evidence of Quality?**	**Suggestions for improvement**
F. Building on Students' Prior Knowledge: The lesson identifies and builds on students' prior learning <u>in all three dimensions</u> in a way that is explicit to both the teacher and students.	***Students learned about inherited traits by finding and examining a leaf. Students compared inherited traits to variations in traits using the leaves they found in the grass. Students completed a Claim-Evidence-Reasoning prompt to show what they know about plant traits.***	☐ None ☐ Inadequate ☐ Adequate ☒ Extensive	***Next time, I will encourage students to bring in examples of inherited traits. For example, students can share pictures of family members, pets, and animals in magazines.***

6. If you are working in a group, **compare lists of evidence and reasoning and come to consensus** about whether this lesson met Criterion F.

NGSS Lesson Screener: A Quick look at NGSS Lesson Design

Appendix T

Second Grade Science Assessment Task Screener (Participant Comments in Red)

Criterion A.
Tasks are driven by high-quality scenarios that are grounded in phenomena or problems.

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
i. Making sense of a phenomenon or addressing a problem is necessary to accomplish the task.	1) *Is a phenomenon and/or problem present?* Yes. All plants reproduce, and many reproduce by making seeds (not all). Plants often depend on wind, water, and animals to carry their seeds to aid in reproduction. Seed structure plays an important role in the location of plant germination. 2) *Is information from the scenario necessary to respond successfully to the task?* Students work in small groups to sort seed picture cards according to the way that particular seed may travel in the natural world. After working in groups, students come together whole group to create a 3-column organizer to record findings. Students then use evidence from a neighborhood diagram to decide how plant seeds are dispersed.
ii. The task scenario is engaging, relevant, and accessible to a wide range of students.	Features of engaging, relevant, and accessible tasks (Check the appropriate box, then describe rationale with evidence)

Features of scenarios	Yes	Somewhat	No	Rationale
Scenario presents real-world observations	✓	☐	☐	Students use observations to describe patterns or relationships in the natural world in order to answer scientific questions.
Scenarios are based around at least one specific instance, not a topic or generally observed occurrence (e.g., observations related to a specific hurricane rather than "hurricanes" in general)	✓	☐	☐	Scenarios are based on information from the diagram which includes specific details about 2 homes. Students make observations based on the sock seed simulation activity.
Scenarios are presented as puzzling/intriguing	✓	☐	☐	Students investigate why a plant grows in one person's yard and not in their neighbor's yard.
Scenarios create a "need to know"	✓	☐	☐	Students observe first-hand how seeds are dispersed using evidence from the outside "sock" activity/simulation.
Scenarios are explainable using grade-appropriate SEPs, CCCs, DCIs	✓	☐	☐	The neighborhood diagram is sketched with simple details. The picture cards provide specific terms with visuals.

Appendix T (continued)

Criterion A. *continued*

	Features of scenarios	Yes	Somewhat	No	Rationale
	Scenarios effectively use at least 2 modalities (e.g., images, diagrams, video, simulations, textual descriptions)	☑	☐	☐	Modes include picture cards, neighborhood diagram, and seed dispersal sock simulation.
	If data are used, scenarios present real/well-crafted data	☐	☑	☐	Names of plants are provided but lack specific details (i.e. size, lifespan).
	The local, global, or universal relevance of the scenario is made clear to students[2]	☐	☑	☐	A local context is established with simulation and group discussions. Needs connections to how seed dispersal affects global communities.
	Scenarios are comprehensible to a wide range of students at grade-level	☑	☐	☐	Students engage in group discussion. Students examine multiple modalities (i.e. images, diagrams, simulations).
	Scenarios use as many words as needed, no more	☑	☐	☐	Scenarios include explicit but concise directions. Information is presented in charts and diagrams.
	Scenarios are sufficiently rich to drive the task	☐	☑	☐	The neighborhood diagram is grade-level appropriate but rudimentary. The scenario needs real-life photographs.

Across all indicators, there is ____________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☐ Adequate
- ☑ Extensive

1. When considering whether the scenario creates a need to know for students, consider whether the scenario makes the uncertainty associated with explaining a phenomenon or solving a problem central, in ways that are likely to 1) connect with students' own experiences or knowledge, and 2) connect to disciplinary core ideas (regardless of whether those ideas are explicitly named or required by the task).

2. Consider whether an authentic stakeholder group is interested in the outcome of the scenario, and/or whether students are given enough information to answer the question "why should I care?".

Appendix T (continued)

Criterion A. *continued*

Suggestions for improvement of the task for Criterion A:

We connected to the students' lives by going outside and being hands-on. We talked about flowers they may have at home, when they see pollination, they knew it was summer and spring. It matters ***when*** you teach things because you can't talk about pollination in December in Kentucky weather because you're not going to see as much as you would when it is warm. We really need to plan science around the seasons. I'm not saying that you have to completely cut this task out, because you can talk about the changes in pollination and insects during different times.

Criterion B.
Tasks require sense-making using the three dimensions.

<table>
<tr><th>Tasks designed for the NGSS include clear and compelling evidence that:</th><th colspan="2">What was in the task, where was it, and why is this evidence?</th></tr>
<tr><td>i. Completing the task requires students to use reasoning to sense-make about phenomena or problems.</td><td colspan="2">Consider in what ways the task requires students to use reasoning to engage in sense-making and/or problem solving.

This task was designed to elicit evidence of student ability to explain how specific plant types were transported to areas through various dispersal methods. Students support their explanation with evidence based on analysis of seed structures/characteristics and seed dispersal methods, as well as evidence they find as they analyze a scene diagram.</td></tr>
<tr><td rowspan="3">ii. The task requires students to demonstrate grade-appropriate:
• SEP element(s)
• CCC element(s)
• DCI element(s)</td><td>Evidence of SEPs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>(Analyzing and Interpreting Data) Students use observations to describe patterns and relationships of seed dispersal and structure.</td></tr>
<tr><td>Evidence of CCCs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>(Cause and Effect) Students determine what causes plants to grow in certain areas and not in others.</td></tr>
<tr><td>Evidence of DCIs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>This task reinforces the idea that plants have external parts that help them survive, grow & produce more plants (LS1.A at grade 1). It is also directly related to LS2.A at grade 2 which states that plants often depend on animals for pollination or to move their seed around.</td></tr>
<tr><td>iii. The task requires students to integrate multiple dimensions in service of sense-making and/or problem-solving.</td><td colspan="2">Consider in what ways the task requires students to use multiple dimensions together to sense-make and/or problem-solve.

Students construct an explanation for finding different plants in various areas and support their explanation based on: analysis of information provided in a diagram and a chart, relationships between seed structure/characteristics and seed dispersal, and cause and effect reasoning.</td></tr>
<tr><td>iv. The task requires students to make their thinking visible.</td><td colspan="2">Consider in what ways the task explicitly prompts students to make their thinking visible. Look for evidence of how the task surfaces current understanding, abilities, gaps, and problematic ideas.

Students make learning visible by sorting picture cards based on seeds' characteristics. Students also post observations to a Padlet (online bulletin board). Students construct an argument using the Claim-Evidence-Reasoning Writing Strategy.</td></tr>
</table>

Criterion B. *continued*

Across all indicators, there is ___________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☑ Adequate
- ☐ Extensive

Suggestions for improvement of the task for Criterion B:

An improvement of the task would be to elicit student responses using multiple modalities (i.e., speech, visuals, skits) rather than solely written answers. Students may not be able to write out their thinking, but they can verbally tell me and explain their predictions and claims. Most of my students drew pictures as a note-taking means. I had to decode the pictures. So for a lot of pictures, I had to ask students to tell me what their picture was. It was a lot of show and tell because I couldn't decode their writing or pictures. I could assess them verbally. If I could do that all the time they all would be golden because they knew what they were talking about.

Appendix T (continued)

Criterion B.
Tasks require sense-making using the three dimensions.

<table>
<tr><th>Tasks designed for the NGSS include clear and compelling evidence that:</th><th colspan="2">What was in the task, where was it, and why is this evidence?</th></tr>
<tr><td>i. Completing the task requires students to use reasoning to sense-make about phenomena or problems.</td><td colspan="2">Consider in what ways the task requires students to use reasoning to engage in sense-making and/or problem solving.
This task was designed to elicit evidence of student ability to explain how specific plant types were transported to areas through various dispersal methods. Students support their explanation with evidence based on analysis of seed structures/characteristics and seed dispersal methods, as well as evidence they find as they analyze a scene diagram.</td></tr>
<tr><td rowspan="3">ii. The task requires students to demonstrate grade-appropriate:
• SEP element(s)
• CCC element(s)
• DCI element(s)</td><td>Evidence of SEPs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>(Analyzing and Interpreting Data) Students use observations to describe patterns and relationships of seed dispersal and structure.</td></tr>
<tr><td>Evidence of CCCs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>(Cause and Effect) Students determine what causes plants to grow in certain areas and not in others.</td></tr>
<tr><td>Evidence of DCIs (which element [s], and how does the task require students to demonstrate this element in use?)</td><td>This task reinforces the idea that plants have external parts that help them survive, grow & produce more plants (LS1.A at grade 1). It is also directly related to LS2.A at grade 2 which states that plants often depend on animals for pollination or to move their seed around.</td></tr>
<tr><td>iii. The task requires students to integrate multiple dimensions in service of sense-making and/or problem-solving.</td><td colspan="2">Consider in what ways the task requires students to use multiple dimensions together to sense-make and/or problem-solve.
Students construct an explanation for finding different plants in various areas and support their explanation based on: analysis of information provided in a diagram and a chart, relationships between seed structure/characteristics and seed dispersal, and cause and effect reasoning.</td></tr>
<tr><td>iv. The task requires students to make their thinking visible.</td><td colspan="2">Consider in what ways the task explicitly prompts students to make their thinking visible. Look for evidence of how the task surfaces current understanding, abilities, gaps, and problematic ideas.
Students make learning visible by sorting picture cards based on seeds' characteristics. Students also post observations to a Padlet (online bulletin board). Students construct an argument using the Claim-Evidence-Reasoning Writing Strategy.</td></tr>
</table>

Criterion B. *continued*

Across all indicators, there is ___________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☑ Adequate
- ☐ Extensive

Suggestions for improvement of the task for Criterion B:

An improvement of the task would be to elicit student responses using multiple modalities (i.e., speech, visuals, skits) rather than solely written answers. Students may not be able to write out their thinking, but they can verbally tell me and explain their predictions and claims. Most of my students drew pictures as a note-taking means. I had to decode the pictures. So for a lot of pictures, I had to ask students to tell me what their picture was. It was a lot of show and tell because I couldn't decode their writing or pictures. I could assess them verbally. If I could do that all the time they all would be golden because they knew what they were talking about.

Appendix T (continued)

Criterion C.
Tasks are fair and equitable.

Tasks designed for the NGSS include clear and compelling evidence of the following:	What was in the task, where was it, and why is this evidence?
i. The task provides ways for students to make connections of local, global, or universal relevance.	*Consider specific features of the task that enable students to make local, global, or universal connections to the phenomenon/problem and task at hand. Note: This criterion emphasizes ways for students to find meaning in the task; this does not mean "interest." Consider whether the task is a meaningful, valuable endeavor that has real-world relevance–that some stakeholder group locally, globally, or universally would be invested in.* The task's context centers on two neighbors who are curious about the differences in the plants they have growing in their yards. The task prompts students to do research to learn more about the structure of different types of seeds to find out how they get moved around.
ii. The task includes multiple modes for students to respond to the task.	*Describe what modes (written, oral, video, simulation, direct observation, peer discussion, etc.) are expected/ possible for student responses.* Students discuss learning with others when sorting picture cards. Students write notes on a tablet and in the graphic organizers. The sock activity simulates seed dispersal. Students also draw pictures to reflect their understanding of seed structures.
iii. The task is accessible, appropriate, and cognitively demanding for all learners, including students who are English learners or are working below or above grade level.	*Consider how the task supports all learners, including:*

	Yes	Somewhat	No	Rationale
Task includes appropriate scaffolds	☐	✓	☐	Students need more opportunities to communicate understanding besides written arguments.
Tasks are coherent from a student perspective	●	☐	☐	Students are given a clear purpose in the 2 neighbors scenario. Photos, illustrations & simulations support the context.
Tasks respect and advantage students' cultural and linguistic backgrounds	☐	✓	☐	The task could make connections to seeds and plants that grow in different parts of the world, especially places that represent students' backgrounds.

3. For more information about culturally and linguistically responsive classroom assessments, please see this resource.

Appendix T (continued)

Criterion C. *continued*

<table>
<tr><th>Tasks designed for the NGSS include clear and compelling evidence of the following:</th><th colspan="5">What was in the task, where was it, and why is this evidence?</th></tr>
<tr><td rowspan="3">iii. (continued)</td><td></td><td>Yes</td><td>Somewhat</td><td>No</td><td>Rationale</td></tr>
<tr><td>Tasks provide both low- and high-achieving students with an opportunity to show what they know</td><td>●</td><td></td><td></td><td>Students are afforded the opportunity to demonstrate learning via pictures, written arguments, and discussions with the teacher. Students get support from peers during certain activities.</td></tr>
<tr><td>Tasks use accessible language</td><td></td><td>✓</td><td></td><td>Names of seeds are accompanied with photographs. Directions are clear and concise.</td></tr>
<tr><td>iv. The task cultivates students' interest in and confidence with science and engineering.</td><td colspan="5">Consider how the task cultivates students interest in and confidence with science and engineering, including opportunities for students to reflect their own ideas as a meaningful part of the task; make decisions about how to approach a task; engage in peer/self-reflection; and engage with tasks that matter to students.

Students learn about see structures using a char of information, picture cards, and observations from a seed dispersal sock activity. Students gain confidence by collaborating with peers and engaging in small group discussions about seed structures and how they can be dispersed. Students could use a checklist or explicit criteria to gauge their understanding when they sort information and complete graphic organizers.</td></tr>
<tr><td>v. The task focuses on performances for which students' learning experiences have prepared them (opportunity to learn considerations).</td><td colspan="5">Consider the ways in which provided information about students' prior learning (e.g., instructional materials, storylines, assumed instructional experiences) enables or prevents students' engagement with the task and educator interpretation of student responses.

The task prompts students to specifically consider the structure of seeds. Students apply information from the task about seed structures to what they learned in a previous unit about animal and plant interdependence. In that unit, students learned that bees and other pollinators move seeds and pollen so plants can germinate in new places.</td></tr>
</table>

Appendix T (continued)

Criterion C. *continued*

Tasks designed for the NGSS include clear and compelling evidence of the following:	What was in the task, where was it, and why is this evidence?
vi. The task presents information that is scientifically accurate.	*Describe evidence of scientific inaccuracies explicitly or implicitly promoted by the task.* The task includes a chart, containing four different seed types. For each seed type, information is given about its method of dispersal, structure, and other important characteristics (i.e., color, growth).

Across all indicators, there is _____________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☑ Adequate
- ☐ Extensive

Suggestions for improvement of the task for Criterion C:

I wish that the task had been more interactive. My second graders due to circumstances are poor readers. I feel like that is where a lot of misconceptions are coming from because the students can't read. That is related to the pandemic because they basically missed four months of first grade. So, I feel like this needed to be more accommodating for them. I would like the assessments to be hands-on and performance-based and not too heavily text and literacy-based, although you need that in there. I'm not testing their ability to read, I am testing their ability to test the phenomenon. So how can we modify some of the assessments so that it is more hands-on? That is why I decided to integrate the seed dispersal sock activity. In this activity, students bring socks from home. Athletic tube socks work best. Students put a sock on over their shoe and go on a nature walk around the schoolyard or through a nature park. Students walk through weeds and as many different type plants as possible. When students have several seeds stuck to their socks, return to the classroom. Students work in small groups to observe the various types of seeds they have collected on their socks. Using the "Seed Sort" and "Seed Chart" students discuss structures of the seeds they have collected and possible method of dispersal. Students share stories of real-world seed dispersal (pet animals coming home with cockle burrs under their fur, finding a watermelon growing by their mailbox, etc.)

Criterion D.
Tasks support their intended targets and purpose.

Before you begin:

1. Describe what is being assessed. Include any targets provided, such as dimensions, elements, or PEs. :

The overall intent of this task is to elicit evidence of student ability to use cause and effect (structure/function) reasoning in order to explain how seed structures/characteristics are related to various types of seed dispersal and to support their explanation using evidence from provided data (diagram and chart).

2. What is the purpose of the assessment? (check all that apply)

- [x] Formative (including peer and self-reflection)
- [ ] Summative
- [x] Determining whether students learned what they just experienced
- [ ] Determining whether students can apply what they have learned to a similar but new context
- [x] Determining whether students can generalize their learning to a different context
- [ ] Other (please specify) ____

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
i. The task assesses what it is intended to assess and supports the purpose for which it is intended.	*Consider in what ways:* *1) The assessment target is necessary to respond to the task.* Students choose one plant found in Max's yard and one found growing in Teresa's yard. Students explain why the plant can be found growing in Teresa's and Max's yard even though that person did not plant it. *2) Any ideas, practices, or experiences* **not** *targeted by the assessment are necessary to respond to the task. Consider the impact this has on students' ability to complete the task and interpretation of student responses.* To be successful at completing this task, students need to investigate things that move seeds (i.e., wind, insects, animals). *3) The student responses elicited support the purpose of the task (e.g., if a task is intended to help teachers determine if students understand the distinction between cause and correlation, does the task support this inference?).* The student response sheet asks students to make a claim about why plants grow in certain areas. There is space on the sheet for students to support their claim using evidence from task scenarios.

Appendix T (continued)

Criterion D. *continued*

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
ii. The task elicits artifacts from students as direct, observable evidence of how well students can use the targeted dimensions together to make sense of phenomena and design solutions to problems.	*Consider what student artifacts are produced and how these provide students the opportunity to make visible their 1) sense-making processes, 2) thinking across all three dimensions, and 3) ability to use multiple dimensions together[note: these artifacts should connect back to the evidence described for Criterion B].* In this task, students must categorize information. Students make claims based on DCI, SEP, and CCC. Students use observations and data from the scenarios as evidence to support their conclusions.
iii. Supporting materials include clear answer keys, rubrics, and/or scoring guidelines that are connected to the three-dimensional target. They provide the necessary and sufficient guidance for interpreting student responses relative to the purpose of the assessment, all targeted dimensions, and the three-dimensional target.	*Consider how well the materials support teachers and students in making sense of student responses and planning for follow up (grading, instructional moves), consistent with the purpose of and targets for the assessment. Consider in what ways rubrics include:* *1) Guidance for interpreting student thinking using an integrated approach, considering all three dimensions together as well as calling out specific supports for individual dimensions, if appropriate:* Teachers and students have access to scoring criteria for the Claim-Evidence-Reasoning prompt. Students' completed graphic organizers demonstrate their understanding of the topic, cause and effect, and interpreting data. *2) Support for interpreting a range of student responses, including those that might reflect partial scientific understanding or mask/misrepresent students' actual science understanding (e.g., because of language barriers, lack of prompting or disconnect between the intent and student interpretation of the task, variety in communication approaches):* Students can communicate conclusions in multiple ways. Students can write answers, talk with the teacher, post ideas to an online bulletin board (Padlet), and draw pictures. *3) Ways to connect student responses to prior experiences and future planned instruction by teachers and participation by students:* Students learn about pollinators before this assessment. Students connect what they know about animal/plant interdependence to the structure and movement of seeds.

Criterion D. *continued*

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
iv. The task's prompts and directions provide sufficient guidance for the teacher to administer it effectively and for the students to complete it successfully while maintaining high levels of students' analytical thinking as appropriate.	*Consider any confusing prompts or directions, and evidence for too much or too little scaffolding/supports for students (relative to the target of the assessment—e.g., a task is intended to elicit student understanding of a DCI, but their response is so heavily scripted that it prevents students from actually showing their ability to apply the DCI).* The student response sheet includes directions and clearly marked sections to ensure that students answer all parts of the prompt. Sentence starters are also included on the response sheets to initiate student thinking. The task needs additional prompts to elicit students' understanding of structures. The assessment focuses heavily on the movement (dispersal) of seeds.

Across all indicators, there is ____________ evidence of quality of this criterion.

- ☐ No
- ☐ Inadequate
- ☐ Adequate
- ☑ Extensive

Suggestions for improvement of the task for Criterion D:

Students could use a timeline. Like first this, then this, and then pollination. This would connect to other areas like sequencing in reading or multiple-step problems in math. The focus areas of this assessment (patterns, cause and effect) can go across all subjects.

Overall Summary

Consider the task purpose and the evidence you gathered for each criterion. Carefully consider the purpose and intended use of the task, your evidence, reasoning, and ratings to make a summary recommendation about using this task. While general guidance is provided below, it is important to remember that the intended use of the task plays a big role in determining whether the task is worth students' and teachers' time.

The overall intent of this task is to elicit evidence of student ability to use cause and effect (structure/function) reasoning in order to explain how seed structures/characteristics are related to various types of seed dispersal and to support their explanation using evidence from provided data (diagram and chart). The distinction between cause and effect or structure and function in this instance is not critical to obtaining useful evidence of student understanding in reasoning. The task prompts students to specifically consider the structure of the seeds. It is the seed's structure that causes the function (effect).

Final recommendation

- [x] Use this task (all criteria had at least an "adequate" rating)
- [ ] Modify and use this task
- [ ] Do not use this task

Appendix U

Third Grade Science Assessment Task Screener (Participant Comments in Red)

Criterion A.

Tasks are driven by high-quality scenarios that are grounded in phenomena or problems.

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
i. Making sense of a phenomenon or addressing a problem is necessary to accomplish the task.	1) *Is a phenomenon and/or problem present?* Yes, there is a phenomenon present in this task. The assessment centers on T Rex's role as either a predator or scavenger based on fossil records. 2) *Is information from the scenario necessary to respond successfully to the task?* Yes. Students are given a list of T Rex body structures. There is also a table containing characteristics of T Rex. Students are then given information about 4 other animals' structures to determine if they are predators or scavengers.
ii. The task scenario is engaging, relevant, and accessible to a wide range of students.	Features of engaging, relevant, and accessible tasks (Check the appropriate box, then describe rationale with evidence)

Features of scenarios	Yes	Somewhat	No	Rationale
Scenario presents real-world observations	✓	☐	☐	Students investigate a specific animal of their choice including those living around the school.
Scenarios are based around at least one specific instance, not a topic or generally observed occurrence (e.g., observations related to a specific hurricane rather than "hurricanes" in general)	✓	☐	☐	Learning focuses on one animal. Students use information (observations, research) to decide if its traits cause it to be a predator or a scavenger.
Scenarios are presented as puzzling/intriguing	✓	☐	☐	Supporting Q: "Was Tyrannosaurus a scavenger or a predator?"
Scenarios create a "need to know"	☐	✓	☐	The task could relate more to students by focusing on local wildlife.
Scenarios are explainable using grade-appropriate SEPs, CCCs, DCIs	✓	☐	☐	Information is presented as if it came from a 3rd grader's research project.

Appendix U (continued)

Criterion A. *continued*

	Features of scenarios	Yes	Somewhat	No	Rationale
	Scenarios effectively use at least 2 modalities (e.g., images, diagrams, video, simulations, textual descriptions)	✓	☐	☐	The task includes images, lists of animal structures, and tables with evidence about animal traits and behavior.
	If data are used, scenarios present real/well-crafted data	✓	☐	☐	Data are presented in bulleted lists and simply formatted tables. Information is brief but descriptive.
	The local, global, or universal relevance of the scenario is made clear to students[2]	☐	✓	☐	Students need a deeper appreciation for animals' roles in their respective ecosystems.
	Scenarios are comprehensible to a wide range of students at grade-level	✓	☐	☐	Information is presented as lists, through visuals, and in books on students' reading levels.
	Scenarios use as many words as needed, no more	✓	☐	☐	Animal traits are provided as terms with short descriptions often as bullets.
	Scenarios are sufficiently rich to drive the task	☐	✓	☐	More background information is needed to engage students in animal traits and their role in the habitat.

Across all indicators, there is ____________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☐ Adequate
- ☑ Extensive

1. When considering whether the scenario creates a need to know for students, consider whether the scenario makes the uncertainty associated with explaining a phenomenon or solving a problem central, in ways that are likely to 1) connect with students' own experiences or knowledge, and 2) connect to disciplinary core ideas (regardless of whether those ideas are explicitly named or required by the task).

2. Consider whether an authentic stakeholder group is interested in the outcome of the scenario, and/or whether students are given enough information to answer the question "why should I care?".

Criterion A. *continued*

Suggestions for improvement of the task for Criterion A:

We should have started off with the T Rex and spent more time exploring that. Then we can have students research their own animals so that they could have a better understanding of how animal traits influence its role as either a predator or scavenger. Also, independent research for some was just too much at one time. It was great to get students interested in their own animals and letting them have a choice. But maybe we need to give them more connections on what they were supposed to look for in their research so they could have a basis. Several students struggled making inferences about animal traits and functions. Because the notes had set criteria like "eyesight" and "movement," students felt stuck if their resource didn't say it outright. It can be hard for 3rd-grade students to infer, but they need to know how to make inferences.

Criterion B.
Tasks require sense-making using the three dimensions.

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?	
i. Completing the task requires students to use reasoning to sense-make about phenomena or problems.	*Consider in what ways the task requires students to use reasoning to engage in sense-making and/or problem solving.* Students make sense of an animals' inheritance and variation of traits and how they affect their interdependent relationships with elements in the environment.	
ii. The task requires students to demonstrate grade-appropriate: • SEP element(s) • CCC element(s) • DCI element(s)	Evidence of **SEPs** (which element [s], and how does the task require students to demonstrate this element in use?)	(Planning & Carrying Out Investigations) Students use information from the task and research to learn how traits make animals predators or scavengers.
	Evidence of **CCCs** (which element [s], and how does the task require students to demonstrate this element in use?)	(Structure & Function) Students inspect visuals of animals to interpret how bodily structures affect organisms' ability to survive.
	Evidence of **DCIs** (which element [s], and how does the task require students to demonstrate this element in use?)	3-LS4-3 Construct an argument with evidence that in a particular habitat some organisms can survive well & others cannot.
iii. The task requires students to integrate multiple dimensions in service of sense-making and/or problem-solving.	*Consider in what ways the task requires students to use multiple dimensions together to sense-make and/or problem-solve.* In order to construct a sound argument that T Rex was a predator or a scavenger, students must compare its body structures to other creatures. Students must also examine fossils (another 3rd-grade standard). And students must make sense of how an animal's environment affects its ability to survive.	
iv. The task requires students to make their thinking visible.	*Consider in what ways the task explicitly prompts students to make their thinking visible. Look for evidence of how the task surfaces current understanding, abilities, gaps, and problematic ideas.* Students construct an argument using data from the task as evidence to support T Rex as being primarily a predator or primarily a scavenger.	

Criterion B. *continued*

Across all indicators, there is ____________ evidence of quality of this criterion (choose one).

- [ ] No
- [ ] Inadequate
- [ ] Adequate
- [x] Extensive

Suggestions for improvement of the task for Criterion B:

I think it would be good for students to have a gallery walk to make learning even more visible. Since we are on a hybrid schedule because of COVID, we could even show the Tuesday/Thursday group what the Monday/Wednesday group did and vice versa. A gallery walk is a good idea because the class can go around and see other work and especially for the lower students that have a hard time making sense of technical concepts. One improvement I made was curating resources in advance so each students had texts to investigate their selected animal. I assigned students books that were within their reading ranges. For example, one student was researching the red fox and I assigned him a e-book on Epic. He was very excited to make that connection and be able to read a book about something he was researching. Using Epic is another way to tie in the technology piece. I decided to give each kid a Google Slide with a photo of their animal. Then all the students could share or just look through the slide at their own time and see the collection of animals that the class is researching. When students went to one of the websites it was basically like a diagram of the animal. It would be nice for students to do their own version of an animal diagram maybe somewhere online like a Google Slide. Maybe students could put their animal to scale with chart paper. It is fun to be digital but sometimes the students don't understand the size of things because they don't have anything to compare it to. Like the bobcat footage we have at our school from the trail camera outside the playground. Students think that it is a cougar but the bobcat is only 2 to 3 feet. So you have to be able to really show the students what that looks like to scale.

Criterion C.

Tasks are fair and equitable.

Tasks designed for the NGSS include clear and compelling evidence of the following:	What was in the task, where was it, and why is this evidence?
i. The task provides ways for students to make connections of local, global, or universal relevance.	*Consider specific features of the task that enable students to make local, global, or universal connections to the phenomenon/problem and task at hand. Note: This criterion emphasizes ways for students to find meaning in the task; this does not mean "interest." Consider whether the task is a meaningful, valuable endeavor that has real-world relevance–that some stakeholder group locally, globally, or universally would be invested in.* The task makes connections to habitats in students' community as well as habitats across the world and even in pre-historic times.
ii. The task includes multiple modes for students to respond to the task.	*Describe what modes (written, oral, video, simulation, direct observation, peer discussion, etc.) are expected/possible for student responses.* Students write a claim that T Rex was either a predator or a scavenger. Students support their claim with synthesized structure/function information about current living predators and scavengers that they transfer to T Rex based on structural similarities.
iii. The task is accessible, appropriate, and cognitively demanding for all learners, including students who are English learners or are working below or above grade level.	*Consider how the task supports all learners, including:*

	Yes	Somewhat	No	Rationale
Task includes appropriate scaffolds	✓	☐	☐	The task includes teacher modeling, guided inquiry, and personalized instruction.
Tasks are coherent from a student perspective	✓	☐	☐	Students understand that animals have traits to survive, but traits differ among animals.
Tasks respect and advantage students' cultural and linguistic backgrounds	●	☐	☐	Books can be read in English or Spanish. The task could be more intentional about showcasing animals that live near different communities around the world.

3. For more information about culturally and linguistically responsive classroom assessments, please see this resource.

Criterion C. *continued*

Tasks designed for the NGSS include clear and compelling evidence of the following:	What was in the task, where was it, and why is this evidence?
vi. The task presents information that is scientifically accurate.	*Describe evidence of scientific inaccuracies explicitly or implicitly promoted by the task.* Information about T Rex is based on fossil records. The task lists traits of eagles, lions, hyenas, and vultures. Students also collect information on an animal of their choice from "teacher-approved" texts and videos.

Across all indicators, there is ____________ evidence of quality of this criterion (choose one).

- ☐ No
- ☐ Inadequate
- ☐ Adequate
- ☑ Extensive

Suggestions for improvement of the task for Criterion C:

In this performance task, students specifically looking for those body structures and traits. I liked this task a lot because I could connect it back to students' previous learning which was all about inheritance traits so we are able to continue to make connections. This assessment definitely relates to the focus science standard. It also relates to cross-cutting standards. I had one student choose a Burmese Python and couldn't find anything about its sense of smell. I told him to just read a book about snakes and he told me it wasn't the same because one is a Burmese Python and the other one was just a garden snake. I explained to the student that they're all snakes and have similar features. It's like a pattern. A student researching Red Fox realized they are different from other foxes like the Arctic Fox but they do have some similar patterns. For instance, there may be a few different sizes because they live in different places but overall it'll follow the same pattern. Then students can appreciate the differences more if they realize the similarities that animals share. Most third grade students see in black and white; it is either this or that. When students made their own flowers in the previous unit, I don't think that they understood the pattern of flowers having slight variations from each other. Students thought..."Well, that doesn't look like that so they can't be the same; they must be different." It is important to encourage students to identify patterns and make connections from prior learning experiences.

Appendix U (continued)

Criterion D.
Tasks support their intended targets and purpose.

Before you begin:

1. Describe what is being assessed. Include any targets provided, such as dimensions, elements, or PEs. :

Students analyze and interpret data related to identified T Rex body structures as well as structures of living animals that are identified as primarily scavengers and predators within ecosystems. Students look for similarities in the functions of these organisms as they pertain to meeting their need for food. Students reason with data to determine if T Rex is indeed primarily a predator or a scavenger.

2. What is the purpose of the assessment? (check all that apply)

- [x] Formative (including peer and self-reflection)
- [ ] Summative
- [ ] Determining whether students learned what they just experienced
- [ ] Determining whether students can apply what they have learned to a similar but new context
- [x] Determining whether students can generalize their learning to a different context
- [ ] Other (please specify) ____

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
i. The task assesses what it is intended to assess and supports the purpose for which it is intended.	*Consider in what ways:* 1) *The assessment target is necessary to respond to the task.* Students use evidence to make and support a claim about whether T Rex were predators or scavengers. 2) *Any ideas, practices, or experiences* **not** *targeted by the assessment are necessary to respond to the task. Consider the impact this has on students' ability to complete the task and interpretation of student responses.* Students use data, gathered from analysis of multiple sources, as a means for supporting a claim. 3) *The student responses elicited support the purpose of the task (e.g., if a task is intended to help teachers determine if students understand the distinction between cause and correlation, does the task support this inference?).* Yes. The task challenges students to use data and their understandings to infer how structures and traits help organisms survive.

Criterion D. *continued*

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
ii. The task elicits artifacts from students as direct, observable evidence of how well students can use the targeted dimensions together to make sense of phenomena and design solutions to problems.	*Consider what student artifacts are produced and how these provide students the opportunity to make visible their 1) sense-making processes, 2) thinking across all three dimensions, and 3) ability to use multiple dimensions together[note: these artifacts should connect back to the evidence described for Criterion B].* Students craft an argument using the Claim-Evidence-Reasoning Writing Strategy. Students also present their research and conclusions on the animal they chose to investigate using e-books and videos.
iii. Supporting materials include clear answer keys, rubrics, and/or scoring guidelines that are connected to the three-dimensional target. They provide the necessary and sufficient guidance for interpreting student responses relative to the purpose of the assessment, all targeted dimensions, and the three-dimensional target.	*Consider how well the materials support teachers and students in making sense of student responses and planning for follow up (grading, instructional moves), consistent with the purpose of and targets for the assessment. Consider in what ways rubrics include:* *1) Guidance for interpreting student thinking using an integrated approach, considering all three dimensions together as well as calling out specific supports for individual dimensions, if appropriate:* Teachers use agreed-upon criteria for scoring students' CER responses (2, 1, or 0). In the future, the task should include a checklist or rubric to monitor student learning during the investigative phase of the assessment. *2) Support for interpreting a range of student responses, including those that might reflect partial scientific understanding or mask/misrepresent students' actual science understanding (e.g., because of language barriers, lack of prompting or disconnect between the intent and student interpretation of the task, variety in communication approaches):* The assessment includes multiple sources of information to help students develop an understanding of the topics. Sources are assigned to students based on their individualized needs and preferences. *3) Ways to connect student responses to prior experiences and future planned instruction by teachers and participation by students:* Students build on their prior knowledge of inheritance and variation of traits. Students also connect their prior learning on animals' group and social behaviors to this task on body structures and functions.

Criterion D. *continued*

Tasks designed for the NGSS include clear and compelling evidence that:	What was in the task, where was it, and why is this evidence?
iv. The task's prompts and directions provide sufficient guidance for the teacher to administer it effectively and for the students to complete it successfully while maintaining high levels of students' analytical thinking as appropriate.	*Consider any confusing prompts or directions, and evidence for too much or too little scaffolding/supports for students (relative to the target of the assessment—e.g., a task is intended to elicit student understanding of a DCI, but their response is so heavily scripted that it prevents students from actually showing their ability to apply the DCI).* The performance task provides the information teachers need to administer it effectively. The task includes data and terminology for students to use as evidence. The task provides teachers with information on the phenomenon and how it relates to DCI. The assessment suggest ideas for setting up the task with students. Student response sheets (graphic organizers and writing prompts) are prepared in advance.

Across all indicators, there is ____________ evidence of quality of this criterion.

- ☐ No
- ☐ Inadequate
- ☐ Adequate
- ☑ Extensive

Suggestions for improvement of the task for Criterion D:

This task gives students the opportunity to use evidence to demonstrate their understanding of science content. A suggestion for improvement would be to give students more practice crafting claims and supporting their thinking with evidence. For instance, students could design a diagram of their animal to show how its structures and traits make it a predator or scavenger. When students talk about their reasoning, it gives the teacher a chance to evaluate and support students' understanding of the concepts. Learning is not just about what you know from what is written down on paper. This task can be compared to constructing a building. They are working on a part of the assessment every time. Like ok, we've done our research about the animal we chose and now we're going to compare it to the T Rex. Then we are going to use that information to determine is the T Rex a scavenger or predator. Then we will use that to look at our animal. I see value in every third-grade teacher doing a performance task that is similar in nature like this. Then we could talk about planning for ways to support students' understanding and skills. People teach differently you know we don't all teach the same so collaborating and getting ideas from one another is helpful. Even after the first day of this task, my team talked about how we should have modeled how to fill in the chart, how to get data from a picture, and then sent the students off to do their own work. I definitely needed to model instead of just, "Oh here you go." They did do well with it but I think it would've been smoother had I modeled.

Overall Summary

Consider the task purpose and the evidence you gathered for each criterion. Carefully consider the purpose and intended use of the task, your evidence, reasoning, and ratings to make a summary recommendation about using this task. While general guidance is provided below, it is important to remember that the intended use of the task plays a big role in determining whether the task is worth students' and teachers' time.

I think allowing the students to have a choice to research their own animals was powerful. Students loved that because it was important to them and they liked the topic. I had some students who chose an animal that they liked but there was not enough information about it and the students figured out that they had to pick another animal because they could not find what they needed. So that trial and error and allowing them to struggle are good. They did struggle with having to navigate tabs but then they were proud of what they had done. That is good for my group because a lot of times they want to please the teacher and for them to say that they have messed up and need to try again is good growth. But there would be times when I would look up and it will be 3 o'clock and the students were still researching and reading books because they were so engaged since they picked what they wanted to research. Giving them a choice and then having them reflect on connections between inherited traits, variations of traits and even leading into adaptations and environment. It's great because we can think about what we've already done and what we're going to be doing in science isn't just an isolated thing. We bring in vocabulary that we have been using. I also think that their research levels the playing field because it allowed them all in introduction because some of my students chose things that they know like dogs or cats. If I had just started with the T Rex I think students' interest levels would drop because they might not know a lot about the T Rex. So it was great to allow them to choose and say oh I do know things about animals. And then students can take what they already know to learn about animals they are unfamiliar with. Again, patterns come into play because that is such a huge part of life by making connections that we see. I also think the collaboration piece is key because then teachers can talk about how we're going to set things up.

Final recommendation

- [x] Use this task (all criteria had at least an "adequate" rating)
- [ ] Modify and use this task
- [ ] Do not use this task

Appendix V

Second Round of PLC Intervention Post-Survey

#	Field	Min.	Max	Mean	Std. Dev.	Var.	Count
24	I know the steps necessary to teach science effectively.	4	5	4.5	0.5	0.25	10
25	I have the necessary resources to teach science effectively.	2	5	4	0.77	0.6	10
26	I am confident that I can explain to students why science experiments work.	3	5	4.1	0.54	0.29	10
29	I understand science concepts well enough to be effective in teaching science.	3	5	4.1	0.54	0.29	10
30	Given a choice, I would invite a colleague to evaluate my science teaching.	3	5	4.3	0.64	0.41	10
31	I am confident that I can answer students' science questions.	3	5	4.2	0.6	0.36	10
32	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	3	5	4	0.45	0.2	10
34	I know what to do to increase student interest in science.	4	5	4.5	0.5	0.25	10
35	When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	3	5	4	0.77	0.6	10
36	The inadequacy of a student's science background can be overcome by good teaching.	3	5	4.4	0.66	0.44	10

Appendix V (continued)

37	When a student's learning is science is greater than expected, it is most often due to their teacher having found a more effective teaching approach.	3	5	4.1	0.7	0.49	10
38	The teacher is generally responsible for students' learning in science.	2	5	3.9	0.94	0.89	10
40	If students' learning in science is less than expected, it is most likely due to insufficient instructional time.	2	5	3.6	0.92	0.84	10
41	Students' learning in science is directly related to their teacher's effectiveness in science teaching.	2	5	3.4	0.8	0.64	10
43	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	2	5	3.4	1.02	1.04	10
116	How often do your students ask questions about their learning?	2	5	4	0.89	0.8	10
118	How often do your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?	2	5	3.5	0.92	0.85	10
120	How often do your students work in small groups?	1	4	3.2	1.08	1.16	10
122	How often do your students make predictions that can be tested?	2	4	3.3	0.9	0.81	10
124	How often do your students make careful observations or measurements?	2	5	3.4	0.92	0.84	10

Appendix V (continued)

126	How often do your students use tools to gather data (e.g. calculators, computers, computer programs, scales, rulers, compasses, etc.)?	2	4	3.1	0.83	0.69	10
128	How often do your students recognize patterns in data?	2	4	3	0.89	0.8	10
130	How often do your students create reasonable explanations of results of an experiment or investigation?	2	4	3.3	0.78	0.61	10
132	How often do your students choose the most appropriate methods to express results (e.g. drawings, models, charts, graphs, technical language, etc.)?	2	4	3.2	0.75	0.56	10
134	How often do your students complete activities with a real-world context?	3	5	3.9	0.54	0.29	10
136	How often do your students engage in content-driven dialogue?	3	5	4.2	0.6	0.36	10
138	How often do your students reason abstractly?	2	4	2.9	0.7	0.49	10
140	How often do your students reason quantitatively (i.e., use computations and numerical data to explain answers)?	2	4	2.8	0.75	0.56	10
142	How often do your students critique the reasoning of others?	2	4	2.7	0.64	0.41	10
144	How often do your students learn about careers related to the instructional content?	2	4	3.2	0.87	0.76	10
45	My students use a variety of technologies, e.g. productivity, data visualizations, research, and communication tools.	2	5	3.5	0.92	0.85	10

Appendix V (continued)

46	My students use technology to communicate and collaborate with others.	2	5	3.9	0.83	0.69	10
47	My students use technology to access online resources and information as part of activities.	4	5	4.3	0.46	0.21	10
49	My students work on technology-enhanced projects that approach real-world applications of technology.	2	5	3.6	0.92	0.84	10
50	My students use technology to help solve problems.	3	5	4.1	0.54	0.29	10
51	My students use technology to support higher-order thinking, e.g. analysis, synthesis and evaluation of ideas and information.	2	5	3.7	0.78	0.61	10
52	My students use technology to create new ideas and representations of information.	3	5	3.9	0.7	0.49	10
131	How often do your students engage in hands-on learning?	2	5	3.9	0.7	0.49	10
133	How often do your students take control of their own learning?	2	5	3.3	1	1.01	10
135	How often do your students make connections between classroom instruction and the real-world?	2	5	3.9	0.83	0.69	10
137	How often do your students take risks?	2	4	3.1	0.83	0.69	10
139	How often do your students lead others to accomplish a goal?	2	4	3.2	0.75	0.56	10
141	How often do your students encourage others to do their best?	2	5	3.9	0.83	0.69	10
143	How often do your students produce high quality work?	3	4	3.9	0.3	0.09	10

Appendix V (continued)

145	How often do your students respect the differences of their peers?	3	5	4.1	0.54	0.29	10
147	How often do your students help their peers?	3	5	4.1	0.54	0.29	10
149	How often do your students include others' perspectives when making decisions?	3	4	3.7	0.46	0.21	10
151	How often do your students make changes when things do not go as planned?	2	5	3.3	0.9	0.81	10
153	How often do your students set their own learning goals?	1	4	2.8	1.17	1.36	10
155	How often do your students manage their time wisely when working on their own?	2	4	3.6	0.66	0.44	10
157	How often do your students choose which assignment out of many needs to be done first?	2	4	3.1	0.7	0.49	10
159	How often do your students work well with students from different backgrounds?	2	5	4.1	0.83	0.69	10
160	I know about current STEM careers.	3	5	4.1	0.7	0.49	10
162	I know where to go to learn more about STEM careers.	4	5	4.4	0.49	0.24	10
164	I know where to find resources for teaching students about STEM careers.	4	5	4.2	0.4	0.16	10
166	I know where to direct students or parents to find information about STEM careers.	4	5	4.2	0.4	0.16	10

Appendix W

Second Round of Intervention Post-Interview Questions

Interview Questions:

1. What are your general thoughts and feelings about the Science Squad PLC?
    a. What was valuable?
    b. What activity did you find to be especially beneficial?

2. How has your attitude or opinions towards Science changed by working with the Science Squad?

3. What are your thoughts on the use of inquiry-based learning (i.e., 5E model) to teach science?

4. How has the Science Squad influenced your science teaching?

5. What are your feelings toward the present science curriculum map and pacing guide?

6. How has your understanding or utilization of the *STEMscopes* curriculum changed?

7. What would you have changed about the Science Squad, or PLCs in general?

8. What do you think about using performance tasks as common science assessments?

9. What do you think should be the next steps for improving science education at XYZ Elementary School?