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UNDERSTANDING THE IMPACT OF A STEM EXPLANATORY MODEL ON STEM-EDUCATION STAKEHOLDERS’ CONCEPTIONS OF STEM AND STEM INTEGRATION

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UNDERSTANDING THE IMPACT OF A STEM EXPLANATORY MODEL ON STEM-EDUCATION STAKEHOLDERS' CONCEPTIONS OF STEM AND STEM INTEGRATION

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Abstract

While STEM education is recognized as a critical priority for national security, health, and economic prosperity, its various and often conflicting meanings, coupled with excessive use of the acronym as a super discipline, render it increasingly meaningless for many. Without a common and consistent understanding of the STEM acronym from which policy makers, community members, educational administrators, informal educators, and classroom teachers understand STEM education, it is unlikely that common goals for STEM education will be achieved. This study, examined the impact a STEM explanatory model, grounded in the content and practices of STEM discipline, might have on diverse STEM-education stakeholders' conceptions of STEM and STEM integration. A basic qualitative research design was utilized to carry out the study leveraging the voices of participants to understand their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model. The study took place during a workshop offered by a regional STEM alliance center in a large city in a midwestern state. Thirteen diverse STEM-education stakeholders participated in the study representing elementary and middle school STEM teachers, informal STEM educators, and a government official. Data collected through a chronological sequence design with open-ended pre- and-post-survey questions, recorded discussions, and researcher memos were utilized as evidence for the study.

Findings show that participants exhibited a narrowing of their understanding of STEM and STEM integration that was more centered on STEM disciplines, stronger coherence among participants in their identification of the STEM components that comprised a classroom activity, and a lack of deep understanding of disciplines that comprise the STEM acronym. Through this study participants adopted terminology associated with the STEM explanatory model introduced as an intervention in the study. Recorded conversations among participants during the use of the explanatory model indicated that participants constructed new meanings of STEM and STEM integration not possessed prior to exposure to the explanatory model. As a result, participants exhibited shifts in their understanding of STEM and STEM integration by the end of the study.

Chapter 1: Introduction

Since the Soviet Union's surprise launch of the Sputnik spacecraft in 1950, science, technology, engineering, and mathematics (STEM) education has been a priority and focus for the nation, policy makers, and educators. In 2018, the Committee on STEM Education of the National Science and Technology Council (NSTC) published, *Charting a Course for Success: America's Strategy for STEM Education*, which declared that the nation is "stronger when all Americans benefit from an education that provides a strong STEM foundation for fully engaging in and contributing to their communities, and for succeeding in STEM related careers, if they choose" (Executive Office of the President, 2018, p.5). The report went on to state the role STEM education plays for all individuals, not just those who choose a STEM-related career. A STEM-literate population is needed to ensure members of society have the capacity to make informed choices on personal health and nutrition, entertainment, transportation, cybersecurity, financial management, and parenting (Gonzalez & Kuenzi, 2012), reinforcing a long-standing belief of the economic and social benefits scientific thinking and STEM education has on our society.

A strategic plan for STEM education was also produced under previous presidential administrations. In 2011, President Obama called for an "all hands-on deck" effort to improve STEM education in the U.S. in his five-year strategic plan (NCTC, 2011). The goals outlined in the strategic plan aimed at maintaining the United States' preeminent position in the world as a country of innovation and economic prosperity. The strategic plan contended that demand would outpace supply of trained STEM workers and professionals estimating that there would "be one million fewer STEM graduates over the next decade than U.S. industries would need" and that evidence indicated that "current educational pathways would not lead to a sufficiently large and well-trained workforce to achieve this goal" (NCTC, 2011, p.vi.). The acronym of STEM, utilized often and throughout national calls to action for future STEM readiness, has a fatal flaw, it is ill-defined and not well understood by policy makers, business, and industry, and the very educators being called on to improve STEM learning experiences for students (Bybee, 2013; NASEM, 2021; NCTM, 2018; NRC, 2014). Oleson, Hora, and Benbow (2014) found vast disagreement among industry and policy makers regarding what constitutes a STEM job, leading to problematic STEM pipeline projections and needs and therefore ill-informed policy recommendations.

History of STEM Education

Contemporary STEM education originated in the 1990s at the National Science Foundation (NSF) as an acronym for the disciplines of *science, technology, engineering, and mathematics* (Bybee, 2013). Judith Ramaley, who was the director of NSF's education and human resources division from 2001 - 2004, coined the acronym STEM when NSF was working on curriculum projects aimed at enhancing education in the four disciplines (Christenson, 2011). Ramaley saw math and science as bookends for engineering and technology and did not like the way the original acronym of *SMET* sounded, so STEM was born. The two bookends of STEM, science and mathematics, have been disciplinary focal areas for K-12 education since the Committee of Ten's recommendations for the coursework that all students should receive in secondary schools (Mackenzie, 1894). Both disciplines have been under constant examination and assessment at the K-12 level, nationally and internationally, to determine our nation's ability to be competitive with other nations. Many argue that the STEM education frenzy began with the passage of the National Defense Act in 1958 as a response to the Soviet Union's launch of its Sputnik spacecraft (Bybee, 2013; Epstein & Miller, 2011). In successive decades, efforts to improve science and mathematics in grades K-12 have included curriculum development projects, professional development networks, and the creation of national standards (NRC, 2014). However, reports like *A Nation at Risk* (Gardner, 1983) and *Rising Above the Gathering Storm* (America, 2007) continued to create public sentiment and funding for reforms in K-12 STEM education well into the 21st century (Epstein & Miller, 2011). Recent assessments continue to indicate that the majority of U.S. students are not meeting proficiency benchmarks for mathematics or science and remain below proficiency levels of students in other countries (ACT, I., 2018; NCES, 2018; NCES, 2019).

Student STEM Readiness

The National Assessment of Educational Progress (NAEP) conducts common measures every two years of student achievements in various disciplines across the nation. NAEP reports inform the public of the academic achievement of elementary and secondary students in the U.S. In 2019, the National Center for Educational Statistics (NCES) reported that only 41% of fourth grade students and 34% of eighth grade students who took the NAEP mathematics test scored at or above the proficient level. NAEP assessment levels are based on the following indicators: basic level performance indicates partial mastery of prerequisite knowledge; proficient level denotes a solid performance demonstrating competency in challenging subject matter; and advanced level performance equates to a superior understanding of mathematics concepts and skills (NCES, 2019). The 2019 NAEP report also indicated that fourth and eighth grade students' achievement in mathematics remained consistent from the previous assessment in 2015. However, compared to 1990 results student performance has increased in mathematics by 27 points in fourth grade and 19 points in eighth grade (NCES, 2019). Only 24% of twelfth grade students scored at or above proficient on the 2019 NAEP mathematics assessment, down 1% from the previous assessment in 2015.

Results from the 2019 NAEP science test showcased that only 36% of fourth grade students and 35% of eighth grade students scored at or above proficient in science. Fourth grade assessment performance was down 2% while eighth grade assessment performance was up 1% from the previous assessment in 2015. Scores for twelfth grade students remained consistent in 2019 and 2015 with 22% of students scoring at or above proficient. NAEP results indicate that U.S. students are performing slighting better in mathematics and science assessments than previous years. However, with less than half of all students meeting proficiency benchmarks in both areas, the majority of U.S. students continue to lack the mathematics and science content knowledge and skills needed to meet requirements for future STEM careers.

International comparisons of U.S. students' performances in mathematics and science can be made from assessments such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). PISA is coordinated by the Organization for Economic Cooperation and Development (OECD), which comprises 33 countries including the U.S. PISA measures the performance of 15-year-old students from OECD countries in reading, mathematics, and science literacy every three years. PISA benchmarks for mathematics and science literacy proficiency reflect students' abilities to utilize higher order thinking skills in real-world applications of mathematics and science content. The 2018 PISA results reflected an average mathematics literacy score of 478 for U.S. students, which was lower than the OECD's average score of 489 and lower than twenty-four other OECD countries represented in the study (NCES, 2018). The average score in science literacy for U.S. students was reported at 502, which was slightly above the OECD average of 478 and lower than six other OECD countries in the study. Student scores on the PISA exam in the areas of mathematics and science have not increased or decreased significantly since 2000 (NCES, 2018). PISA results indicate that U.S. students are not among the top performers in mathematics and science literacy achievement when compared to other countries.

The 2015 TIMSS revealed that U.S. fourth grade students scored above the TIMSS scale average in both mathematics (535) and science (539) as did eighth grade students scoring 515 in mathematics and 522 in science. The TIMSS international benchmarks for fourth and eighth grade mathematics stated that intermediate level (475-549) students could apply basic mathematical knowledge in straightforward situations and high level (550-624) students could apply their understanding and knowledge in a variety of relatively complex situations. The TIMSS benchmarks for fourth and eighth grade science described student abilities at the intermediate level (475 – 549) as having basic scientific knowledge and applying that knowledge to practical situations through brief descriptive responses, whereas the students who score in the high range (550-624) demonstrate conceptual understanding, the ability to compare, contrast, and make simple inferences using models and diagrams and the use of science concepts in both every day and abstract contexts. Although mathematics and science scores have steadily increased for both fourth and eighth graders on the TIMSS assessment between 1995-2019 (NCES, 2018), students continue to exhibit basic understandings of mathematical and science concepts, with limited abilities to make application of the concepts in every day or abstract contexts.

The NAEP, PISA, and TIMSS test results indicate that U.S. students are lacking the mathematical and scientific skills of critical thinking, problem solving, data analysis, and real-world application needed to be a STEM-literate population capable of pursuing and achieving success in STEM-related careers. According to a recent report by the American College Testing

Inc. Company (ACT, I.) on STEM readiness, over half of all high school graduates surveyed indicated interest in a STEM-related occupation after high school. However, only 20% of the graduates met the ACT STEM Readiness Benchmark (2018), indicating that 20% of high school students who took the ACT were ready and prepared for the mathematics and science courses they will encounter in colleges (ACT, I., 2018).

STEM Improvement Efforts

Efforts to improve science and mathematics education and student achievement are not new. To address concerns related to lack of student achievement, state and federal funds have been funneled into STEM-education programs and initiatives for several years. For over a decade the U.S Department of Education has attempted to improve student achievement in mathematics and science by providing substantial funding to states to increase the content and pedagogical knowledge of mathematics and science teachers through the Math and Science Partnership Grant (Abt Associates I., 2012). States received funding to disseminate competitive grants to Local Education Agencies and Institutes of Higher Education, who then provided sustained professional development to teachers in the areas of mathematics and science (Abt Associates I., 2012). In FY 2011, Federal agencies spent $1.9 billion on education investments for STEM education with approximately $1.1 billion earmarked for improving K-12 STEM education (NCTC, 2013). The estimated federal investment in STEM education programs for 2012 ranged from $2.8 billion to $3.4 billion (Gonzalez & Kuenzi, 2012).

In addition to the allocation of state and federal funds to improve mathematics and science teaching and learning through curriculum projects and professional development, national standards documents have attempted to improve STEM education by providing guidance to states, school districts, and classroom teachers regarding what students should know and be able to do by the end of each grade level or course related to mathematics and science. Most recently, the Common Core State Standards for Mathematics (CCSSM) (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) have emphasized the importance of students learning content through engagement in mathematical, science, and engineering practices. Additionally, the NGSS emphasizes the integration of technology and engineering in K-12 science teaching to support students in gaining skills and content related to the T and E in STEM.

Although STEM education has been a high priority for state and national governments for decades, U.S. students' performance in mathematics and science, the two disciplines of STEM that are traditionally measured through state, national, and international assessments, continues to indicate that a low percentage of students are proficient in the skills and content that would allow them to pursue STEM careers or possess STEM literacy needed to form an informed citizenry. One reason for the lack of discernible improvement might come from the ill-defined nature of the STEM acronym itself, which is often utilized when advocating for more funding, policies, programs, and school reform. The National Research Council (NRC) spotlighted this issue in their 2014 report, *STEM Integration in K-12 Education: Status, Prospectus, and an Agenda for Research* claiming that, "despite the increased attention to STEM in policy and funding arenas, there remains some confusion about STEM, the individual subjects, and the combination of subjects" (NRC, 2014, p.15). If the term being utilized to rally people around an effort for school reform is confusing, it stands to reason that individual and diverse interpretations of that effort will lead to a lack of coherence with the effort (Honig & Hatch, 2004). Such is the case with STEM education. Policy makers, school leaders, educators, and business and community members lack a consistent vision for STEM education, hindering efforts to support student proficiency in STEM disciplines (Bybee, 2010).

Background of the Problem

Despite increasing attention for STEM education, what constitutes STEM education and what it means for classroom instruction, curriculum, and assessments in K-12 education lacks consistency among educators and STEM-education stakeholders (NRC, 2014). Although the acronym of STEM represents the four disciplines of science, technology, engineering, and mathematics, it has come to represent a multitude of conceptions among various individuals. For some STEM education is viewed as an approach to learning or an instructional strategy often replacing, “traditional lecture-based teaching strategies with more inquiry and project-based approaches" (Breiner et al., 2012, p.3). This leads some to believe STEM is an effort to reform the ways in which mathematics and science are taught in K-12 education systems. For others, STEM exists to support critical thinking and problem solving without any relationship to the four disciplines that comprise the acronym (Angier, 2010; Brown et al., 2011). Still others see STEM education as an approach in which “STEM subjects are integrated through an instructional method that uses design-based, problem solving, discovery, and exploratory learning strategies” (Roberts, 2013, p 22). In 2013, Bybee examined the challenges and opportunities of STEM education, proclaiming that “currently STEM is more a slogan than a goal-directed movement” (Bybee, 2013, p.4). There is a need to clarify the purpose of STEM education that is more directly related to the disciplines that compose the acronym and to support students in learning to apply basic content and practices of the STEM disciplines to situations they encounter in life (Bybee, 2013).

The lack of a clear, consistent vision for STEM education has increased the likelihood of uncoordinated actions and less focused and rigorous STEM educational experiences for students (NCTM, 2018; NRC, 2014). The lack of a common and consistent understanding of STEM also makes it difficult for classroom teachers to ensure their students are fully prepared for the science, technology, engineering, and mathematics content and skills necessary to pursue STEM careers or become a STEM-literate population. In a recent poll, 5,000 participants were asked to share their understanding of STEM education, where 86% percent reported not understanding the reference, and many confused it with research related to stem cells, flowers, and even broccoli stems (Angier, 2010). While this study represents the public at large, a study of educators revealed similar misunderstandings and variances in understandings of STEM. Of the over 200 teachers who were asked, “What is STEM?” in an interview, only half were able to define STEM as involving science, technology, engineering, and mathematics (Brown et al., 2011). Many who were able to define STEM admitted that they had Googled the term before the interview. What may be most unsettling is the limited understanding of STEM exhibited by teachers most connected to the STEM discipline, as only 15 of the 36 mathematics, science, and technology teachers interviewed were able to define the term or see their discipline connected in any way. Many provided narrow definitions of STEM or suggested that STEM meant that technology was integrated into the classroom (Brown et.al., 2011). If classroom teachers of STEM disciplines do not see the subjects they teach as associated with or connected to STEM, what might that mean for STEM initiatives that are occurring in K-12 schools? Are the learning experiences reduced to ideals of critical thinking and problem solving absent of intentional connection or focus on individual STEM disciplines? Has STEM become an acronym of a superdiscpline that has little to no connection to the original intent of STEM disciplines?

Those guiding the disciplines of STEM nationally seem to have a stronger sense of STEM. Recently, the National Council of Teachers of Mathematics (NCTM) stated, “a well-designed and effective STEM program is going to have a strong mathematics component, a strong science component, and many opportunities to use mathematical and scientific thinking, reasoning, and modeling across disciplines to tackle real problems that involve any or all the STEM fields” (NCTM, 2018, p.2). NCTM suggests that “an essential feature of integrative STEM activities should be that they support the individual disciplines addressed with integrity using content from grade-appropriate standards that are taught in ways that support pedagogical recommendations from the discipline” (NCTM, 2018, p.2). The National Academies of Science and Engineering devoted an entire report to defining STEM as both the individual disciplines and the integration of those disciplines while discussing the importance of ensuring that the integrity of instruction for individual disciplines be attended to in STEM education (NRC, 2014).

The vision for STEM education cast by such national groups does not appear to be a consistent and well-understood vision of STEM education (Angier, 2010; Brown et al., 2011; NCTM, 2018; NRC, 2014; Siekmann, 2016). Additionally, if STEM persists as a methodology absent of intentional connections to the four disciplines of STEM, students may miss out on valuable instructional time in the STEM subjects, especially if STEM absent of mathematics and science replaces instructional time for these disciplines (NCTM; 2018; NRC, 2014; Siekmann, 2016).

Purpose of the Study

Without a consistent and universal vision for STEM education that includes the guiding principles for effective instruction in the four disciplines of STEM and how the disciplines might be fully present, partially present, or absent in STEM instructional experiences, conceptions of

STEM education will continue to be inconsistent and lack coherence. The absence of a shared vision for STEM education among STEM-education stakeholders could lead to learning experiences that fail to prepare students with the content and skills necessary to achieve proficiency in the disciplines of STEM. The lack of an explanatory model to support discourse and understanding of STEM limits the ability of diverse STEM-education stakeholders to set goals for STEM education instruction and programming that are coherent, focused, and commonly understood by actors in the STEM education system. The purpose of this research study was to investigate the impact an explanatory model for STEM education might have on diverse STEM-education stakeholders' conceptions of STEM and STEM integration. An additional purpose of the research study was to investigate the use of the explanatory model as a framework for identifying and describing components of STEM and forms of STEM integration that might be present in a STEM lesson or classroom activity. Thus, this study addressed two questions: (1) how might an explanatory model of STEM influence STEM education stakeholders' conceptions of STEM and STEM integration? (2) how might an explanatory model of STEM influence the ability of STEM-education stakeholders to identify components of STEM or various forms of STEM integration represented in a lesson or classroom activity?

Significance of the Study

This study is significant in that it attempted to determine if diverse STEM-education stakeholders' conceptions of STEM education change when introduced to an explanatory model of STEM that incorporates the recommendations and guidance for effective teaching and learning for the individual disciplines of science, technology, engineering, and mathematics as well as the integration of one or more of the disciplines. The study aimed to move beyond asking STEM-education stakeholders to consider, “What is STEM?” towards asking them to consider

"What version of STEM education exists?" and "Is it STEM education if the four disciplines comprising the acronym are absent?"

Definition of Terms

The following terms and acronyms were used for this study:

CCSS Mathematics: Common Core Standards for Mathematics, published in 2010 and adopted by several states as their state standards.

Engineering: Both a body of knowledge about the design and creation of human-made products and the process of solving problems through the application of mathematics and science and use of technologies.

Inclusive STEM Schools: Schools that utilize non-selective admission policies and design school curriculum and programmatic experiences to engage students in STEM, with the purpose of seeding interest in STEM in order to expand the number of individuals entering STEM careers.

Interdisciplinary Instruction: The teaching of two or more disciplines of STEM with explicit connection.

Mathematics: The study of patterns and relationships among quantities, numbers, and *space.*

Natural Phenomenon/Phenomena: Observable events of the natural or designed world that can be explained with laws, theorems, and concepts of science.

NGSS: The Next Generation Science Standards, published in 2013 and adopted by several states as their state standards.

Science: The study of the natural world, including the laws of nature associated with physics, chemistry, and biology.

STEM: Stands for science, technology, engineering, and mathematics

STEM Curriculum: Instructional materials, pedagogical practices, and instruction utilized to teach one or more disciplines of science, technology, engineering, and mathematics in a lesson, unit, or full year of coursework.

STEM Education: Instruction students receive when one or more of the disciplinary areas of science, technology, engineering, and mathematics are present in instruction.

STEM-Education Stakeholders: Individuals interested in or concerned with ensuring students experience quality educational experiences in STEM education including educators, school administrators, curriculum coordinators, informal educators, and community members.

STEM Integration: The integration of two or more disciplines of science, technology, engineering, or mathematics in instruction with students.

Technology: Comprises the entire system of people and organizations, knowledge, processes, and devices that go into creating and operating technological artifacts, as well as the artifacts themselves.

21st Century Skills: A broad set of knowledge, skills, work habits, and character traits that can be applied and developed through all academic subject areas in PK-12 education in various ways.

Assumptions, Limitations, and Delimitations

Assumption, limitations, and delimitations include factors that have the potential to impact the outcome or results of the study. Therefore, knowing the assumptions, limitations, and delimitations of the study help to communicate sources of error inherent in the study. For the purposes of the study, it was assumed that the sample population was representative of STEM-education stakeholders in other parts of the state and country; and participants of the study answered questions truthfully.

The limitations of the proposed study included researcher bias, sample size, and diverse representation of the sample population. Researcher bias is determined to be a limitation of this study because the researcher participated in the development of the explanatory model for STEM investigated as an intervention in the study. In order to minimize the impact of researcher bias, the researcher was not the individual who presented the explanatory model for STEM to participants in the study. The second limitation of the proposed study is sample size and representation. Participants of the study were chosen based on their interest and willingness to participate in a professional learning session where the explanatory model for STEM was introduced. It was expected that the level of participant experiences with and expertise in the content areas of science, technology, engineering, and mathematics would vary and impact their initial conceptions of STEM. An attempt was made to mitigate this limitation by selecting multiple formal and informal STEM education stakeholders from the same district. Additionally, representatives from elementary and middle schools were selected to participate in the study to ensure representation from diverse settings representing STEM-education stakeholders from across the state and nation. Despite the assumptions, limitations, and delimitations referenced in the study, the study worked to overcome them and provide useful information about the impact a consistent and common explanatory model for STEM education might have on STEM-education stakeholders' conceptions of STEM.

Conclusion

While STEM education is recognized as a critical priority for national security, health, and economic prosperity, its various and often conflicting meanings, coupled with excessive use of the acronym as a super discipline, render it increasingly meaningless for many. This study was noteworthy as attention and funding continue to be placed on K-12 STEM education. Without a common and consistent understanding of the STEM acronym from which policy makers, community members, educational administrators, informal educators, and classroom teachers understand STEM education, it is unlikely that common goals for STEM education will be achieved.

Chapter 2: Review of Literature

Prioritizing science, technology, engineering, and mathematics, the four disciplines that comprise the STEM acronym, in any goal setting or vision for K-12 STEM education seems logical. However, since the inception of the acronym in the late 1990s, policy makers, educators, and community members have grappled with its meaning (McGarr & Lynch, 2017), with wide variation and often conflicting interpretations. For some, STEM education equates to teaching methodologies that center around critical thinking or problem-solving skills with little or no connection to the disciplines that comprise the acronym (Holmlund et al., 2018; Siekmann, 2016; Tan, 2018). For others, STEM education implies that engineering design processes are incorporated into the curriculum (Johnson et al., 2015). Some focus on thematic approaches to curriculum centered on real-world contexts that integrate two or more STEM disciplines when they refer to STEM education (Roberts, 2013). Still, others advocate for maker-oriented programs such as robotics, coding, and *Maker Fairs* when referring to STEM education (Bevan et al., 2015). Without some shared understanding of STEM education or an explanatory model that serves to provide shared language around STEM and STEM integration, stakeholders may continue to lack a clear and coherent vision for STEM education and the policies, programs, and instructional components needed to ensure all students have access to a high-quality education in STEM (Bybee, 2013). With this in mind, this study proposed to investigate how an explanatory model for STEM education might impact stakeholders' conceptions of STEM and STEM integration and their ability to articulate coherent visions of STEM and STEM integration. Several research areas were examined as part of the literature review to inform the study. Those research areas included:

- Instructional Priorities for STEM Education and School Design

- STEM Workforce Priorities and Student Preparedness
- Crafting a Coherent Vision for STEM Education
- Visions for K-12 Education Associated with Each of the STEM Disciplines
- Existing STEM Education Frameworks

I begin this chapter with a literature review of the instructional priorities for STEM education and school design held by educators of STEM disciplines and other stakeholders associated with Inclusive STEM schools. The literature shows that preparing students in subject areas like mathematics and science, the two bookend subjects of the STEM acronym, is not being prioritized. The literature review also identifies the varied conceptions STEM educators, non-STEM educators, and administrators have regarding priorities for STEM education and school design. Next, I describe the knowledge, skills, and abilities that are needed for STEM occupations and most easily transferable for success in non-STEM occupations. Then, I turn my attention to the steps needed for diverse STEM-education stakeholders to craft coherence and claim that crafting coherence must start with understanding the research-based recommendations for the individual disciplines that comprise the STEM acronym. An analysis of the national recommendations for K-12 teaching and learning for each of the STEM disciplines is then conducted. I then transition to analyses of existing frameworks for STEM education aimed at bringing clarity for educators, curriculum designers, and STEM-education researchers. However, my analysis shows that existing STEM frameworks may not be designed to support STEM-education stakeholders in crafting a coherent vision for STEM education or STEM integration inclusive of the content and practices associated with the STEM disciplines, leaving a gap in the field of research. I conclude with a summary tying each of the areas of literature review together to demonstrate the need for the current study.

Instructional Priorities for STEM Education and School Design

There are varied and conflicting interpretations of appropriate instructional models and school design among STEM-education stakeholders associated with schools focused on STEM education and preparation. A recent study explored stakeholder priorities for designing curriculum and instruction for STEM themed schools. The study asked STEM teachers, non-STEM teachers, administrators, and external partners associated with STEM schools to develop visual models describing critical components of STEM curriculum and instruction (Holmlund et al., 2018). Eighty-five percent of the participants prioritized interdisciplinary instruction (the teaching of two or more disciplines of STEM with explicit connection) in their visual models and 74 % prioritized instructional practices centered on problem-based learning, which, according to teachers, promotes student autonomy, cooperation, and teamwork (Holmlund et. al., 2018). It is important to note that this type of learning or skill development is not unique to problem-based learning models (Nobel et al., 2020). Only 33% of the external partners in the Holmlund et al. study prioritized instructional practices as a critical component of STEM curriculum and instruction. However, all administrators in the study identified instructional practices as a critical component of STEM curriculum and instruction. Fifty-three percent of the study participants indicated that 21st century skills were a critical component of STEM education (Holmlund et al., 2018). Academic standards were only referenced as a critical component by 41% of the participants, with only 20% of non-STEM teachers referencing standards. However, 60% of administrators referenced standards as a critical component, more than any other participant group in the study (Holmlund et al., 2018). As evidenced by this study, there are varied conceptions of the critical components that constitute quality curriculum and instruction designed to engage and prepare students in STEM, indicating the stakeholders lack coherent conceptions of STEM or methods for preparing students in STEM areas.

Although a universal definition or set of guiding principles for curriculum, instruction, and school design do not exist for schools seeking to enhance STEM education, a review of literature on Inclusive STEM Schools indicates common approaches to learning STEM in schools might exist (Peters-Burton et al., 2014). Inclusive STEM Schools utilize non-selective admission policies and design school curriculum and programmatic experiences to engage students in STEM with the purpose of seeding interest in STEM to expand the number of individuals entering STEM careers (Gnagey & Lavertu, 2016; Holmlund et al., 2018). Peters-Burton et al. (2014) analyzed and identified the components of school design commonly incorporated in Inclusive STEM Schools and suggested they represented the most critical components (see Table 1).

Table 1

The 10 Critical Components of Inclusive STEM Schools Design

NAME OF COMPONENT	DEFINITIONS
STEM-focused curriculum	Strong courses in all four STEM areas, or engineering and technology are explicitly, intentionally integrated in STEM subjects and non-STEM subjects
Reform in instructional strategies and project-based learning	STEM classes emphasize instructional practices/strategies informed by research for active teaching and immersing students in STEM content, processes, habits of mind and skills
Integrated, innovative technology use	The school's structure and use of technology has the potential to change relationships between students, teachers, and knowledge and flatten hierarchies
Blended formal/informal learning beyond the typical school day, week, or year	Learning spills into areas regarded as informal STEM education and includes apprenticeships, mentoring, after school clubs, and projects
Real-world STEM partnerships	Students connect to business/industry/world of work via mentorships, internships, or projects that occur within or outside the normal school day/year
Early college-level coursework	School schedule is designed to provide opportunities for students to take classes in institutions of higher education or online
Well-prepared STEM teaching staff	Teachers have advanced STEM content knowledge and/or practical experience in STEM careers.
Inclusive STEM mission	The school's stated goals are to prepare students for STEM, with emphasis on recruiting students from underrepresented groups
Administrative structure	Include strength and organization of school leadership/principal, hiring/recruiting STEM teachers, arrangements/agreements with community, school-level data-driven decisions regarding instruction

Note: Adapted from "Cross-case Analysis of Engineering Education Experiences in Inclusive STEM-Focused High Schools in the United States" by E.E. Peters-Burton, and T. Johnson, 2018, *International Journal of Education in Mathematics, Science, and Technology*, *6*(4), p. 320–342.

A common goal of Inclusive STEM School design is to ensure that students have access to strong courses in all four STEM areas, or to engineering and technology learning experiences that explicitly and intentionally integrate with STEM subjects and non-STEM subjects (Peters-Burton et al., 2014). Additionally, Inclusive STEM Schools prioritize classes that emphasize instructional practices or strategies for active teaching designed to immerse students in STEM content, processes, and habits of mind (Peters-Burton et al., 2014). This indicates that STEM Inclusive Schools prioritize disciplinary content and practices associated with science, technology, engineering, and mathematics. However, an additional study of school leaders of Inclusive STEM Schools indicates prioritizing the disciplinary content and practices associated with science, technology, engineering, and mathematics, may be a less critical component of STEM education and preparation (LaForce et al., 2016). The study revealed that administrators prioritized the following components for curriculum, instruction, and school design in Inclusive STEM Schools:

1. Problem-Based Learning including: staff created curriculum, interdisciplinary teams, teamwork and collaboration among students, connections between content learning and real world.
2. Rigorous Learning including: student engagement, real-world connection and interdisciplinary connections.
3. Personalization of Learning including: differentiated instruction, promotion of student autonomy and flexible scheduling.
4. Career, Technology, and Life Skills including: teamwork, collaboration and career connection and readiness.

5. School Community and Belonging including: a focus on the whole child and positive social and emotional learning environments.
6. External Community including: schools having a community presence and students participating in service learning
7. Staff Foundations Supporting including: supportive leadership and common and individual planning time for teachers.
8. Essential Factors Supporting including: engaging external partners for support, family involvement and professional development for staff.

When examining these critical components, the study authors were surprised to find a "lack of components that relate specifically to the science, technology, engineering, and math disciplines (LaForce et al., 2016, p.9)." When school leaders referred to STEM, they were often referring to instructional practices such as problem-based or student-centered learning and not the disciplinary subjects of STEM. When school leaders were asked about the mission and goals of their schools, "they often described the importance of engaging students with real-world problems and developing them as critical thinkers and active citizens" (p. 9). The authors of the study concluded that Inclusive STEM Schools may have more in common with constructivist-based (non-STEM) school models and have less of a focus on preparing students in the disciplines that comprise the acronym of STEM (LaForce et al., 2016).

A lack of emphasis on the disciplinary content and practices of the disciplines that comprise the STEM acronym is often missing from the priorities that drive STEM-education curriculum, instruction, and school design, reducing efforts to emphasize specific instructional strategies or approaches to learning (Robert, 2013). The National Science and Technology Council (NSTC) disagreed contending that the "best STEM education provides an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world applications; and students use STEM in contexts that make connections between school, community, work, and the wider world” (2018, p.1). National recommendations like these have long prioritized the inclusion of rigorous academic concepts when focusing on STEM preparedness, particularly in areas of mathematics and science (NAESM, 2021; NCTM, 2018; STEM^4, 2018). All too often, STEM education is a synonym for education that prepares students for 21st century skills through instructional models that emphasize problem solving and teamwork absent of or without intentional calls for learning the content and skills associated with the individual disciplines of STEM (Siekmann, 2016). The lack of coherence for STEM education priorities exhibited in the research on STEM stakeholders, further indicates the need for an explanatory model for STEM that can be utilized by STEM-education stakeholders to craft a more coherent understanding of STEM and instruction aligned to a shared vision for STEM education. The literature review also supports the inclusion of disciplinary knowledge and skills for each of the STEM disciplines as components for the explanatory model for STEM education being proposed for this study.

STEM Workforce Priorities and Student Preparedness

A vision for STEM education that focuses less on the academic nature of the individual disciplines and more on instructional approaches aligned to constructivist theories of education may not align with the knowledge and skills needed for STEM occupations and most transferable to non-STEM careers. In 2011, The Center for Education and Workforce commissioned a report analyzing the knowledge, skills, and abilities needed for STEM occupations and most easily transferable for success in non-STEM occupations (Carnevale et al., 2011). The report recognized that the academic disciplines of science, technology, engineering, and mathematics tend to overlap more and more in STEM and non-STEM occupations, but that "each discipline maintains a core set of knowledge and skills" (Carnevale et al., 2011, p. 53). The report identified ten core knowledge domains associated with STEM occupations (see Table 2). *The Center for Education and Workforce Report* found that mathematics knowledge was the most utilized and transferable knowledge in STEM and non-STEM occupations. In addition to the knowledge domains commonly associated with STEM and non-STEM occupations, the report examined the core skills associated with STEM occupations (see Table 3) (Carnevale et al., 2011).

Table 2

Core Knowledge Domains Associated with STEM Occupations

KNOWLEDGE DOMAIN	DEFINITION OF KNOWLEDGE DOMAINS
Production and Processing	Knowledge of raw materials, production processes, quality control, costs, and other techniques for maximizing the effective manufacture and distribution of goods.
Computer and Electronics	Knowledge of circuit boards, processors, chips, electronic equipment, and computer hardware and software, including applications and programming.
Engineering and Technology	Knowledge of the practical applications of engineering, science, and technology. This includes applying principles, techniques, procedures, and equipment to the design and production of various goods and services.
Design	Knowledge of design techniques, tools, and principals involved in production of precision.
Building and Construction	Knowledge of materials, methods, and tools involved in construction or repair of houses, buildings, or other structures such as highways and roads.
Mechanical	Knowledge of machines and tools, including their designs, uses, repair, and maintenance.

Math	Knowledge of arithmetic, algebra, geometry, calculus, statistics, and their applications.
Physics	Knowledge and prediction of physical principles, laws, their interrelationships, and applications to understanding fluid, material, and atmospheric dynamics, and mechanical, electrical, atomic, and subatomic structures and processes.
Chemistry	Knowledge of the chemical composition, structure, and properties of substances and of the chemical processes and transformations that they undergo. This includes uses of chemicals and their interactions, danger signs, production techniques, and disposal methods.
Biology	Knowledge of plant and animal organisms and their tissues, cells, functions, interdependencies, and interactions with each other and the environment.

Note: Adapted from, “STEM: Science, Technology, Engineering and Mathematics” by A.P. Carnevale, N. Smith, and M. Melton, 2011. Washington, DC: Georgetown University Center on Education and the Workforce.

Table 3

Core Skills Associated with STEM Occupations

SKILLS	DESCRIPTION OF SKILLS
Mathematics	Using mathematics to solve problems.
Science	Using scientific rules and methods to solve problems.
Critical Thinking	Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems.
Active Learning	Understanding the implications of new information for both current and future problem solving and decision making.
Complex Problem Solving	Identify complex problems and review related information to develop and evaluate options and implement solutions.
Operations Analysis	Analyzing needs and product requirements to create a design.
Technology Design	Generating or adapting equipment and technology to serve user needs.
Equipment Selections	Determining the kind of tools and equipment and technology to

	serve user needs.
Programming	Writing computer programs for various purposes.
Quality Control Analysis	Conducting tests and inspections of products, services, or processes to evaluate quality or performance.
Operations Monitoring	Watching gauges, dials, or other indicators to make sure a machine is working properly.
Operations and Control	Controlling operations of equipment or systems.
Equipment Maintenance	Performing routine maintenance on equipment and determining when and what kind of maintenance is needed.
Troubleshooting	Determining causes of operating errors and deciding what to do about it.
Repairing	Repairing machines or systems using the needed tools.
Systems Analysis	Determining how a system should work and how changes in conditions, operations, and the environment will affect outcomes.
Systems Evaluation	Identifying measures or indicators of system performance and the actions needed to improve or correct performance, relative to the goals of the system.

Note: Adapted from, "STEM: Science, Technology, Engineering and Mathematics" by A.P. Carnevale, N. Smith, and M. Melton, 2011. Washington, DC: Georgetown University Center on Education and the Workforce.

In STEM occupations, the core skills operate in coordination with knowledge domains and are often reliant on the knowledge domains to utilize the skills purposefully. For example, to utilize a core skill like critical thinking in a STEM occupation to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems, individuals would utilize the knowledge domains of mathematics, physics, or chemistry depending on the context of the problem to be solved (Carnevale et al., 2011). In 95 % of STEM occupations, mathematics skills are seen as important with science skills identified as important, very important, or extremely important in nearly 60% of the STEM occupations (Carnevale et al., 2011).

Mathematical reasoning and deductive reasoning emerge as the two abilities most often utilized in STEM and non-STEM occupations. STEM skills, often associated with 21st century skills and used interchangeably in STEM education, include: (1) foundational literacy like numeracy, scientific literacy, information, and communication literacy; (2) competencies like critical thinking and problem solving, creativity, communication, collaboration; and (3) character qualities like curiosity, initiative, persistence, adaptability, leadership, and social and cultural awareness (World Economic Forum, 2015).

Twenty-first century skills refer to a broad set of knowledge, skills, work habits, and character traits that can be applied and developed through all academic subject areas in PK-12 education in various ways (Siekmann, 2016) and are referenced as goals and objectives in various STEM-education stakeholders' perceptions of STEM (Holmlund et al., 2018). While teaching and learning associated with the individual disciplines of STEM support the development of 21st century skills (Bybee, 2010), STEM skills belong to a specific group of technical skills that include abilities to produce scientific knowledge and use mathematical skills to design and build technological and scientific products (Seikman & Korbel, 2016). Although STEM skills "overlap with basic and higher-order cognitive skills, they merit separate treatment in a policy-oriented context in order to target specific requirements in the education and labor market" (Seikman & Korbel, 2016, p.19). This distinction is important when considering an explanatory model for STEM education, as efforts to impact STEM education that center solely on a broad set of 21st century skills absent of the content knowledge and skills associated with STEM disciplines may limit student acquisition of the 21 century skills desired by employers and leave the workforce ill-equipped for STEM occupations.

Analysis of the unique epistemological characteristics of STEM disciplines shed further light on the importance of emphasizing the unique aspects of each discipline in STEM education and how they are connected or related. Students tend to learn math and science by engaging in the mathematical and scientific practices that allow them to gain formal knowledge of the concepts, laws, theorems, and intellectual devices that make up the field (Herschbach, 2011; NRC, 2010, STEM[4], 2018). Disciplines like engineering and technology use formal knowledge associated with their respective disciplines selectively to address specific problems with engineering and technology tasks that draw from concepts of mathematics and science. Engagement in such tasks might lead to a partial understanding of the formal knowledge of disciplinary concepts associated with mathematics and science if STEM education is reduced to focus solely on technology and engineering education (Herschbach, 2011; NRC, 2014). To further clarify:

> The four STEM fields, in sum, have epistemological characteristics that differ markedly. These characteristics must be fully recognized and accommodated in programming in order to preserve the intellectual integrity of each field. Otherwise, a very limited understanding results that undervalues specific intellectual contributions or ignores the collective value of each (Herschbach, p. 110).

Recent results on college and career readiness assessments showcase the need for STEM education to be inclusive of the unique content and skills associated with the individual disciplines of STEM. According to recent reports by ACT Inc., half of students who express an interest in STEM careers are not ready for the college coursework necessary to pursue the degrees required for STEM careers they are interested in, particularly in areas of math and science (ACT. I., 2017; Mattern, et al., 2015). The same reports indicated that the most popular mathematics and science courses for first-year students majoring in STEM were Calculus for mathematics at 79% and Chemistry, Biology, and/or Engineering for science at 90% indicating that students entering STEM degree programs must have a strong background in science and mathematics, the two disciplines that bookend the STEM acronym. An analysis of coursework required for STEM college career fields indicated higher levels of mathematics and science knowledge and skills are required to be successful (Westrick, 2015b). However, from 2015 - 2019, the percentage of students meeting college career ready benchmarks for mathematics dropped from 28% to 26% and from 38% to 36% in science (ACT. I., 2019). Therefore, it is necessary that STEM-education stakeholders seeking to increase student interest in STEM education also possess a vision for K-12 STEM education that focuses on bridging the gap between interest and the knowledge and skill development required of STEM disciplines, particularly in the areas of mathematics and science (NCTM, 2018; NRC, 2014; NRC, 2021; Rakich & Tran, 2016; STEM[4]). Both can be accomplished by focusing on research-based recommendations for instruction of the individual STEM disciplines, as recommendations call for instruction that engages students in active and student-centered learning connected to real-world contexts for student obtainment of the knowledge and skills associated with the disciplines (Ay Emanet & Kezer, 2021; NCTM; 2000; NGA, 2010; NGSS, 2013; NRC, 2013; NRC, 2018; Reiser et al., 2021).

Crafting a Coherent Vision for STEM Education

If STEM education is going to advance beyond a slogan and increase the number and diversity of students who enter the STEM- related workforce and ensure all students graduate as STEM-literate citizens, STEM-education stakeholders will have to clarify what the acronym means for educational policies, programs, and practices (Bybee, 2010). Without a shared and coherent understanding of STEM, designing and implementing curriculum, instruction, and programming that promotes successful STEM learning for students will continue to be a challenge (Holmlund et al., 2018). The lack of coherent conceptions of STEM threaten to destroy support for any movements STEM-education stakeholders may be seeking now and in the future (Herschbach, 2011). Coherence will only be achieved when there is a shared understanding of the nature of STEM education across the stakeholder groups seeking to impact STEM education (Fullan & Quinn, 2016; Newmann et al., 2001). Crafting coherence in STEM education will require mobilizing STEM-education stakeholders and efforts around a shared understanding of what constitutes STEM and the mechanisms needed to achieve goals for STEM education (Fullan & Quinn, 2016; Honig & Hatch, 2004). Coherent conceptions of STEM education and goals for it will likely require negotiations among STEM-education stakeholders that may need to be revisited (Honig & Hatch, 2004). "Coherent systems, at any level, are the result of people working together both to 'make sense' and 'give sense' to current practice and how it needs to change, in order to achieve a particular vision for practice" (Penuel et al., 2018, p.32). Making sense and giving sense to STEM education can only be met by those seeking to craft coherence if they have the ability to productively discuss their conceptions of STEM.

Siekman (2016) offered a pathway towards coherence by suggesting the need to identify distinct components within STEM in order to provide a high degree of shared understanding of STEM. For the purpose of this study, STEM will be defined as an abbreviation of the words: science, technology, engineering, and mathematics and not a representation of a specific instructional model or a single discipline of STEM. This definition aligns with the National Research Council's conceptions of STEM in, *STEM Integration in K-12 Education: Status, Prospectus, and an Agenda for Research* (2014). Additionally, for the purpose of this study, further meaning of each discipline and the goals for teaching and learning associated with each discipline will be derived from leading national organizations for science, technology, engineering, and mathematics education and their respective recommendations for K-12 learning goals.

Visions for K-12 Education Associated with Each of the STEM Disciplines

The next section explores the research-based, national recommendations for science, technology, engineering, and mathematics education from professional organizations associated with the disciplines of STEM. These recommendations offer a vision for teaching and learning for science, technology, engineering, and mathematics that ensures students gain STEM knowledge and skills through individual and integrated STEM disciplinary curriculum, instruction, and programming. The next section will also showcase how student-centered learning connected to real-world contexts is central to the nature of learning for the STEM disciplines and how recommendations for K-12 science, technology, engineering, and mathematics education, align to priorities and goals of diverse STEM-education stakeholders (Holmlund et al., & Peters-Burton et al).

A Vision for K-12 Science Education

The S in STEM represents science and has long been a discipline taught in K-12 schools. *The Report of the Committee of Ten on Secondary School Studies* (hereafter referred to as The Committee) advocated those concepts associated with chemistry, physics, meteorology, zoology, and botany be taught early and often in elementary and secondary studies (Mackenzie, 1894). The Committee advocated for science teaching and learning that centered on pupils investigating natural or real-world phenomena as early as elementary stating that it was, “urgent that the study of simple natural phenomena be introduced into elementary” (Mackenzie, 1894, p.25). The

Committee also contended that the study of science in elementary and secondary schools, “should be pursued by the pupil chiefly, though not exclusively, by means of experimentation” (p.25). For the next century, guidance and recommendations for how students should be taught science in K-12 schools continued to center on student engagement in investigations and experiments to gain the essential concepts and skills necessary to be scientifically literate (AAAS, 1994; NRC, 1996; NRC, 2005; NRC, 2007; Reiser et al., 2021).

During the 1990s and 2000s several key national documents guided states to develop state standards that would inform K-12 science instruction, curriculum, and assessment. The National Research Council (NRC) published the *National Science Education Standards* (NSES) in 1996, which were designed to help students understand scientific inquiry and possess the skills to do scientific inquiry. The standards conveyed that students must actively participate in scientific investigations by engaging in using evidence, applying logic, and constructing arguments and explanations for the observations made during investigations (NRC, 1996). Much like the Committee’s recommendations, NSES advocated for students to learn scientific concepts by engaging in the practices of scientific investigations as scientists do, rather than simply reading about them in books. Additionally, *America’s Lab Report* (NRC, 2005) and *Taking Science to School* (NRC, 2007), made explicit the need for students to investigate observable phenomena of the world. While there has long been consensus on what constitutes quality science instruction and a call for students to engage in the practices and ways of thinking that scientists use, the majority of students enrolled in science classes in the last century have not engaged in teaching and learning that aligns to this vision (NRC, 2005; NRC, 2007; Trygstad et al., 2018).

Recently, *A Framework for K-12 Science Education* aimed to remedy this by providing updated recommendations and stronger guidance for what students should know and be able to do in the discipline of science when they graduate high school (NRC, 2012). The recommendations in the Framework emphasize students engaging in the three dimensions of science: (1) science and engineering practices, (2) crosscutting concepts, and (3) disciplinary core ideas (NRC, 2012). Academic standards informed by the recommendations, like the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) or other state standards (OSDE, 2019), are designed to guide instruction so that students explore and explain natural phenomenon or design problems as a way to achieve science literacy. In essence the three dimensions can be thought of as what students will do (science and engineering practices) to collect and communicate data and information; the ways students will think and reason (crosscutting concepts) about data or information collected; and the science ideas (disciplinary core ideas) they will utilize in connection with science and engineering practices and crosscutting concepts to explain how natural phenomena work or how solutions for design problems can be achieved (NRC, 2012). Table 4 outlines the components of each of these three dimensions.

Table 4:

The Three Dimensions of Science Education from The Framework for K-12 Science Education

Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting-Concepts
Physical Science PS1: Matter and its Interactions PS2: Motion and stability: Forces and interactions PS3: Energy PS4: Waves and their application in technologies for information transfer **Life Science** LS1: From molecules to organisms: Structures and processes LS2: Ecosystems: Interactions, energy, and dynamics LS3: Heredity: Inheritance and variation of traits. LS4: Biological evolution: Unity and diversity **Earth and Space Science** ESS1: Earth's place in the universe ESS2: Earth's systems ESS3: Earth and human activity **Engineering, Technology and Application of Science** ETS1: Engineering design ETS2: Links among engineering, technology, science and society	1. Asking questions (for science) and defining problems for engineering 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information	1. Patterns 2. Cause and effect: Mechanisms and explanation 3. Scale, proportion, and quantity 4. Systems and system models 5. Energy and matter: Flows, cycles, and conservation 6. Structure and function 7. Stability and change

Note: Adapted from “A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas” by the National Research Council, 2012. Washington, D.C: National Academies Press.

The Framework emphasizes the importance of learning the laws and theories that explain natural phenomena observed in the world and connections between science, technology, engineering, and mathematics through the recommended disciplinary core ideas, science and engineering practices, and cross-cutting concepts (NRC, 2012). The recommendations in the Framework also maintain long-held, research-based curriculum and instructional guidance centered around students learning science by engaging in phenomena and solving problems grounded in real-world context (AAAS, 1994; NRC, 1995; NRC, 2005; NRC 2007). The science and engineering practices were selected because of their ability to prepare students for STEM careers and to function as STEM-literate citizens (NGSS Lead States, 2013; NRC, 2012). The recommendations in the Framework align to the goals for STEM education shared by many STEM-education stakeholders (LaForce et al., 2016; NSTC, 2018).

The Framework and subsequent NGSS also prioritize the integration of science with engineering, technology, and mathematics. Engineering is used “in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems” and technology is used to broadly include, “all types of human-made systems and processes - not the limited sense often used in schools that equates technology with modern computational and communication devices” (NRC, 2012, p.11-12). The science and engineering practices of, *Analyzing and Interpreting Data* and *Using Mathematics and Computation Thinking* prompt the intentional and purposeful use and practice of mathematical skills and knowledge to investigate phenomena or design, explain, or solve problems (NRC, 2012). The science and engineering practices align with current perceptions of the skills necessary to prepare students for citizenry and careers (Carnevale et al, 2011; Gonzalez & Kuenzi, 2012). Engaging students in hands-on investigations of relevant and real-world phenomena and designed problems should be priorities for quality science instruction aligned to the vision of the Framework (Kloser, 2014). Analysis of the NGSS and their introductory and ancillary documents also shows that the NGSS contains significant provisions for innovation and creativity and the integration of science, technology, engineering, and mathematics practices (Hoeg & Bencze, 2017). Therefore, the explanatory model proposed in this study will include research-based recommendations for science education that emphasize both science content and practices.

While the national and state recommendations for what constitutes quality science education seem to align with STEM-education stakeholders' goals, fully realizing the vision of the Framework and NGSS remains challenging. Teachers indicate discomfort with instruction aligned to the standards and the lack of equipment and time for instruction needed to ensure students are provided the learning experiences called for in the standards (Haag & Megowan, 2015; Trygstad et al., 2013; Tyler et al., 2020). Additionally, teachers report lacking instructional materials aligned to the standards (Doan & Lucero, 2021). Although these challenges are not new, added confusion around what constitutes STEM education and the role science does or does not play in K-12 STEM education may have the undesired effect of further reducing instructional time and resources required for quality science education for students (Banilower et al., 2018; Bybee, 2013; NRC, 2014).

A Vision for K-12 Technology Education

The T in STEM represents technology. However, technology may be the least well-understood and researched aspect of K-12 STEM education (Ellis et al., 2020; Wang et al., 2010). In 2007, *The Technology and Engineering Literacy Framework for the National Assessment of Education Progress* (NAEP) recognized that terms like, "technology", "information and technology", and "technology literacy" were ill defined and used differently within and across informal and formal educational settings, standards, professional organizations, and legislation (NAEP, 2018). The third edition of the *Standards for Technological Literacy* outlined what students should know and be able to do in order to be technology literate and described technology as, "how people modify the natural world to suit their own purposes" (International Technology Education Association, 2007*,* p. 2). This definition mirrors the definition for technology literacy provided in the *National Assessment of Educational Progress Technology and Engineering Literacy Framework*, which states that, "technology is any modification of the natural world done to fulfill human needs or desires" (National Assessment Governing Board, 2018, p. XVI). The definition for technology found in the Framework for K-12 Science Education provides a parallel definition, stating that technology represents "any modification of the natural world made to fulfill human needs or desires" (NRC, 2012, p. 202). While the short definitions for technology across all three publications seem fairly uniform, interpretations for instruction and learning goals for K-12 education diverge, becoming less uniform and more challenging to understand.

The Standards for Technological Literacy outlined five broad categories for technology education that encompass 20 cognitive and process standards (ITEA, 2007). The five categories include: the nature of technology, technology and society, design, abilities for the technological world, and the designed world (ITEA, 2007). The standards aim to ensure that students gain a conceptual understanding of technology, its role in society, the technology design process, and how technologies may both solve problems and create new ones. The full set of standards include:

1. The core concepts of technology.

2. The relationships among technologies and the connection between technology and other fields.
3. The cultural, social, economic, and political effects of technology.
4. The effects of technology on the environment
5. The role of society in the development and use of technology.
6. The influence of technology on history.
7. The attributes of design.
8. Engineering design.
9. The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
10. Apply the design process.
11. Use and maintain technological products and systems.
12. Assess the impact of products and systems.
13. Medical technologies.
14. Agricultural and related biotechnologies.
15. Energy and power technologies.
16. Information and communication technologies.
17. Transportation technologies.
18. Manufacturing technologies.
19. Construction technologies.

There are various perspectives of the T in STEM presented throughout literature. Ellis et al. (2020) identified the top four perspectives consistently utilized: (1) technology as vocational education, industrial arts, or the product of engineering, (2) technology as educational or instructional technology, (3) technology as coding or computational thinking, and (4) technology as tools and practices used by science, mathematics, and engineering practitioners. Both the ITEA (2007) and the committee for the *NAEP Framework* (2018) disagree with the perspective that the T in STEM represents the use of technology for educational or instructional purposes, contending that technology education does not encompass students using computers for word processing or students viewing displayed materials on a SmartBoard. The disciplinary core idea, *Links Among Engineering, Technology, Science and Society* from the Framework, represents the fourth perspective of Ellis et al. and outlines the interdependence of science, engineering, and technology, and explores the influence of engineering, technology, and science on society and the natural world. The Framework claims that through this disciplinary core idea students learn that "scientists depend on the work of the engineers to produce the instruments and computational tools they need to conduct research," and that "engineers in turn depend on the work of scientists to understand how technologies work so they can be improved" (NRC, 2012, p. 203). These sentiments are not new. *Science for All Americans* recognized that scientific knowledge allowed those designing new technologies to estimate the behavior of the materials that would compromise technologies or suggest behaviors for new technologies (AAAS, 1990). Without the intentional use of scientific knowledge, production of new technologies would rely on trial-and-error approaches to design rather than scientifically-informed approaches (AAAS, 1990). Conversely, technologies are essential for scientific endeavors, allowing for measurement, data collection, and analysis (AAAS, 1990).

As there are various perspectives for what the T in STEM represents by researchers and professional organizations, it stands to reason that educators, administrators, community members, and policy makers would also internalize diverse conceptions for this STEM discipline

(Ellis et al., 2020). Any attempt to ensure stakeholders have common understandings of STEM and the goals for STEM education, should also have an understanding of the T in STEM and recognize that it includes both technologies being utilized and produced (NRC, 2014). For the purpose of this study, the proposed explanatory model for STEM education will represent technology education as means for students to engage in the meaningful use of technology and development of technology connected to the learning of science, engineering, or mathematics education.

A Vision for K-12 Engineering Education

The E in STEM represents engineering, often seen as the discipline most dependent and inextricably linked to the other three STEM disciplines (Bybee, 2011; Moore et al., 2014; NAS, 2020). Engineers use mathematics to determine constraints, describe and analyze data, and develop models (AAAS, 1990; Bybee, 2011; NCTM, 2000), use scientific concepts from the domains of physics, biology, and chemistry to understand and develop solutions to problems (Bybee, 2011; NAS et al., 2020), and utilize and develop new technologies purposefully (ITEA, 2007; NAS et al., 2000). While much may be known about the concepts, and skills utilized by practicing engineers, K-12 engineering education is still in its infancy when compared to disciplines like science and mathematics (Antink-Meyer & Brown, 2019). Much remains unknown or agreed upon pertaining to the engineering ideas, concepts, or skills students should be introduced to in K-12 education or the appropriate level of complexity of those concepts and skills for each grade-level (Bybee, 2011; Pleasants & Olson, 2019).

Common definitions or a philosophy for what constitutes quality learning experiences in K-12 engineering education are not agreed upon in the literature (Antink-Meyer & Brown, 2019; Pleasants & Olson, 2019). However, the National Academies of Science, Engineering and

Medicine attempted to define what constitutes engineering literacy in their 2020 consensus report, *Building Capacity for Teaching Engineering in K-12 Education*, stating that, “engineering literacy involves understanding concepts such as constraints, specifications, optimization, and trade-offs, and being able to apply the engineering design process” (p.55). Additionally, engineering literacy “involves recognizing the influence of engineering on society and how engineering is different from science in its application to personal, social, and cultural situations” (NAS et al., 2020, p.55). The AAAS called out the importance of engineering literacy in their report *Science for All Americans* but gave the enterprise limited attention and showcased it as a component of technology (AAAS, 1990). A few years later, AAAS published *Benchmarks for Science Literacy* with statements of what all students should know and be able to do in science, mathematics, and technology by the end of second, fifth, eighth, and twelfth grade (AAAS, 2014). Engineering learning goals for each grade band were associated with the nature of technology and advocated that students engage in planning, designing, making, evaluating, and modifying designed solutions to problems, be introduced to simple tools, a variety of materials, and consider constraints such as safety, time, cost, and available materials as part of a designed solution (AAAS, 1994). Since the publication of the *Benchmarks for Science Literacy*, there have been several calls for the development of a set of K-12 engineering education standards (Bybee, 2011; Chandler et al., 2011). However, numerous barriers exist in making this goal a reality including an already overburdened K-12 school curriculum and the lack of research on how students learn engineering and how that learning progresses over time (Bybee, 2011; Chandler et al., 2011; Svarovsky, 2011). The NRC consensus committee explored opportunities and barriers for K-12 engineering education in their consensus study in 2011 and proposed that rather than developing stand-alone engineering education standards, concepts and skills be infused in other disciplines like science, technology, and mathematics (Bybee, 2011). Although national mathematics standards minimally reference engineering as one of the many fields in which mathematics can be used (NCTM, 2000), *The Standards for Technological Literacy* (ITEA, 2007) and *The Framework for K-12 Science Education* (NRC, 2012) and subsequent *NGSS* (NGSS Lead States, 2013) do infuse aspects of engineering in their recommendations for standards.

Moore et al. (2014) attempted to provide a more comprehensive set of core ideas, concepts, skills, and dispositions that students should obtain through their K-12 educational experiences in *A Framework for Quality K-12 Engineering Education*. The framework outlined nine key indicators for quality learning:

1. Process of Design (POD)
    a. Problem and Background (POD-PB)
    b. Plan and Implement (POD - PI)
    c. Test and Evaluate (POD-TE)
1. Apply Science, Engineering and Mathematics (SEM)
2. Engineering Thinking (EThink)
3. Conceptions of Engineers and Engineering (CEE)
4. Engineering Tools (ETool)
5. Issues, Solutions, and Impacts (ISI)
6. Ethics
7. Teamwork (TEM)
8. Communication Related to Engineering (Comm-Engr)

The nine key indicators presented in the framework attempt to cast a vision for the *Process of Design*, often interpreted as tinkering in K-12 classrooms, through three sub-indicators: (1) problem and background, (2) plan and implement, (3) test and evaluate (Moore et al., 2014). Additionally, the framework includes *Apply Science, Engineering, and Mathematics* as an indicator clarifying that “engineering requires the application of science, mathematics, and engineering knowledge” and that “students should have the opportunity to apply developmentally appropriate mathematics or science in the context of solving engineering problems” (Moore et al., 2014, p. 5). Currently, the landscape of K-12 engineering curriculum does not fully encompass all nine key indicators. Curricular materials pay more attention to brainstorming and developing solutions and designing models and prototypes, with little wide-spread emphasis on testing prototypes (Chabalengula & Mumba, 2017; Peters-Burton & Johnson, 2018).

The call for K-12 engineering education to maintain as one of its goals the integration or incorporation of developmentally appropriate mathematics, science, and technology concepts and skills prevails because of the nature of engineering (NAS et al., 2020; Pleasants & Olson, 2019). It can be difficult to determine which mathematical or science concepts and skills should be associated with K-12 engineering education concepts and skills because engineering design challenges are diverse and require unique demands on the mathematics and science knowledge possessed by students. Some problems require “little or no application of ideas from these disciplines, while others may demand significant conceptual understanding as well as the ability to apply the concept” (NAS et al., 2020, p. 44). Grubbs, Strimel & Huffman (2018) suggested that disciplinary knowledge for P-12 engineering could include the knowledge capacities of specific fields of engineering (i.e., civil, mechanical, chemical, electrical/computer) coupled with the skills of engineering design, materials processing, quantitative analysis, ethical analysis, and societal application. Engineering uses the concepts and skills associated with disciplines like mathematics and science, but engineering has a knowledge base all its own that should be attended to in any learning goals for K-12 engineering education (Pleasants & Olson, 2019). The interconnected nature of engineering with other disciplines adds to the difficulty of defining K-12 learning goals or standards for the discipline. Therefore, creating a lack of common conceptions for what constitutes engineering in K-12 and STEM (Bybee, 2011).

Recently, the International Technology and Engineering Educators Association (ITEEA) and the Council on Technology and Engineering Teacher Education (CTETE) defined engineering as, “the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under given constraints” (ITEEA & CTETE, 2020, p.3). This definition continues to showcase the inextricable links between engineering and the other three disciplines of STEM and suggests that engineering as practice cannot occur without the use of the knowledge and skills of science, mathematics, and technology. Any vision for STEM education should be inclusive of the nature of engineering including engineering knowledge and skills and the interconnected nature of the discipline with other disciplines of STEM (Antink-Meyer & Brown, 2019; Grubbs et al., 2018; Moore et al., 2014). The explanatory model for STEM education proposed in this study will showcase the inextricable link between engineering and mathematics, science, and technology education.

A Vision for K-12 Mathematics Education

The M in STEM has had a long and sustained presence in K-12 education, with the first wide-spread publication concerned with how mathematics should be taught appearing in 1821 (Bidwell & Clason, 1970). Application of mathematics in other disciplines has been a long-standing national recommendation, appearing as early as 1894 with recommendations made by The Committee of Ten (NEA, 1894). Also highlighted was the importance of students expressing mathematical thinking verbally and through drawings and models, and that students should be engaged in reasoning and solving problems to learn mathematical concepts (NEA, 1894). The National Council of Teachers of Mathematics (NCTM) published a set of researched-based principles and standards for student learning and the teaching of mathematics in 1989. The recommendations were updated in 2000 and advocated that students learn mathematical concepts by engaging in a set of mathematical processes in order to be mathematically literate (NCTM, 2000). The mathematical processes emphasized problem solving, reasoning, communication, representation, and connection (NCTM, 2000).

The NCTM recommendations also included several guiding principles for school mathematics including: (1) *Teaching and Learning in Mathematics* to engage students in meaningful learning through individual and collaborative learning experiences that promote students making sense of mathematics and developing reasoning skills; (2) *Curriculum* designed to develop important mathematical concepts through coherent learning progressions from grade-to-grade in ways that develop connections among areas of mathematical study and between mathematics and the real world; and (3) The use of mathematical *Tools and Technology* as essential resources to help students learn and make sense of mathematics (Brahier et al., 2014; NCTM, 2000). Additionally, NCTM recommended teaching practices for mathematics that included implementing tasks that promote reasoning and problem solving, facilitating meaningful discourse, and supporting productive struggle in learning mathematics (Brahier et al., 2014; NCTM, 2000). Another important document further emphasized the importance of students engaging in mathematical practices that emphasized problem solving, critical thinking, communication, and application to the real-world (NRC, 2001). These documents were utilized throughout the 21st century to guide the development of individual state standards and curriculum and instruction. Leading up to these publications, mathematics instruction in the

United States predominantly focused on students memorizing discrete facts told to them by the teacher with opportunities to practice fluency through repetition (Hiebert et al., 1999; NRC, 2004).

In 2010, the *Common Core State Standards for Mathematics* (CCSSM) designed to bring more uniformity to mathematics standards across the nation (NGA, 2010). The CCSSM include content standards and process standards known as the *Standards for Mathematical Practices*. The Standards for Mathematical Practices emphasize students:

1. Making sense of problems and preserving to solve them
2. Reasoning abstractly
3. Constructing viable arguments and critiquing the reasoning of others
4. Modeling with mathematics
5. Using appropriate tools strategically
6. Attending to precision
7. Looking for and making use of structure
8. Looking for and expressing regularity in repeated reasoning

The long-standing and current recommendations for mathematics education as a standalone discipline supports the critical components of STEM education envisioned by advocates of STEM (Peters-Burton et al., 2014; Holmlund et al., 2018;) and the STEM skills necessary for STEM and non-STEM occupations (Carnevale et al., 2011). However, recent studies show that less than half the teachers of mathematics have curriculum aligned to these goals and best practices for teaching mathematics (Kaufman et al., 2021). Mathematics that students learn in K-12 education can support integrative approaches to STEM education, defined as approaches that explore teaching and learning between and among two or more disciplines

(Becker & Parker, 2011). However, studies of student achievement in mathematics through integrative STEM approaches were found to have minimal effect size (Becker & Parker, 2011), which coincides with other studies that found integrating mathematics with other subjects were less likely to produce productive learning experiences in mathematics (NRC, 2014). One reason for this observation could come from integrative approaches to mathematics disrupting the coherence of mathematical learning progressions deemed to be vital for mathematical knowledge and skill obtainment (Fitzallen, 2015; Schmid & Houang, 2015). While integrative STEM approaches to learning can support student interest and engagement in mathematics, Stohlmann and others advocate it only be used when there are natural connections between subjects (NRC, 2014; Stohlmann, 2018). Any efforts to establish goals for K-12 STEM education should be inclusive of the M in STEM and the research-based teaching and learning of mathematics, as they represent the knowledge and skills necessary for a STEM preparedness (ACT. I., 2019; Fitzallen, 2015; Maass et al., 2019; NCTM, 2018, STEM^4, 2018). Therefore, the explanatory model proposed in this study will leverage national, research-based recommendations for mathematics education that include both the content and practices of mathematics.

Frameworks for STEM Education and STEM Integration

Several frameworks for STEM education have been proposed in the last twenty years with the aim of providing clarity to the ambiguous nature of STEM (Roehrig et al., 2021). Some STEM frameworks focus on the relationships between the four disciplines of STEM and how instruction and curriculum can be designed to support STEM integration. Moore et al. (2014) defined STEM integration as, “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit or lesson that is based on connections between the subjects and real-world problems" (p.38). Kelley & Knowles (2016) defined STEM integration as "the approach to teaching the content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p.3). These definitions mirror the stance taken by the committee on *STEM Integration in K-12 Education* when they described STEM integration as a range of different experiences that involve some degree of connection among or across the disciplines of science, technology, engineering, and mathematics (NRC, 2014). Still others see a more narrow view of STEM integration as an effort to have students participate in engineering design and thinking to explore technology in a manner that requires application of mathematics and science (Johnson et al., 2015).

English (2016) contended that there are increasing levels of integration for STEM that can and should be implemented in K-12 education. Those levels included: (1) *disciplinary* whereby concepts and skills are learned separately in each discipline, (2) *multidisciplinary* whereby concepts and skills are learned separately in each discipline but within a common theme, (3) *interdisciplinary* whereby closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills, and (4) *transdisciplinary* whereby knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus helping to shape the learning experience. The levels of integration presented by English (2016) echoed the various perceptions of STEM education showcased by Bybee (2011) which included perspectives of STEM integration:

1. STEM equals science or math
2. STEM means both science and math
3. STEM means science incorporates technology, engineering or mathematics
4. STEM equals a quartet of separate disciplines
5. STEM means science and math are connected by one technology or engineering
6. STEM means coordination across disciplines (in reality, two or four disciplines

will likely be coordinated)

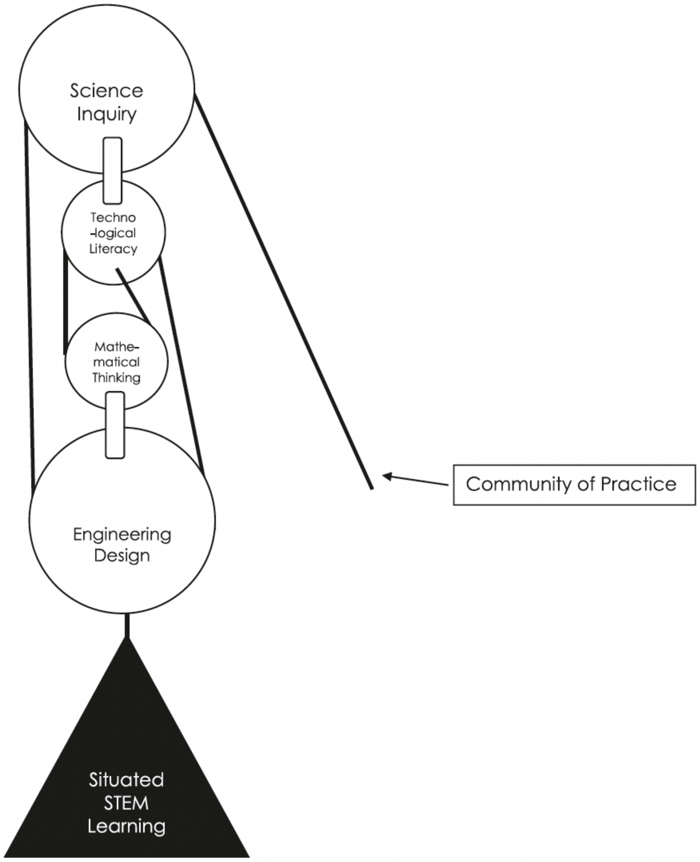
7. STEM means combining two or three disciplines
8. STEM means complementary overlapping across disciplines
9. STEM means a transdisciplinary course or program whereby the entire group of
10. STEM disciplines would be used to understand a major contemporary challenge.

Frameworks presented by both English (2016) and Bybee (2011) left room for conceptions of STEM education that honored the individual disciplines of STEM, while showcasing the relationships or connection that might exist if two or more subjects were the focus of a lesson, unit, or program. Other frameworks for STEM education and STEM integration attempt to provide guidance for learning or instructional models. One such framework expands on a well-known learning model for science education, the learning cycle, by adding engineering as an intentional phase (Yata et al., 2020).

Kelly & Knowles (2018) presented a STEM framework in 2018 that attempted to showcase how the practices within the four STEM disciplines could be connected (see Figure 1). The framework showcases engineering design as the STEM content integrator with students using mathematics and science inquiry to create and conduct experiments that will inform the function and performance of potential design solutions before a final prototype is created (Kelly & Knowles, 2018).

Figure 1

Graphic of Conceptual Framework for STEM Learning

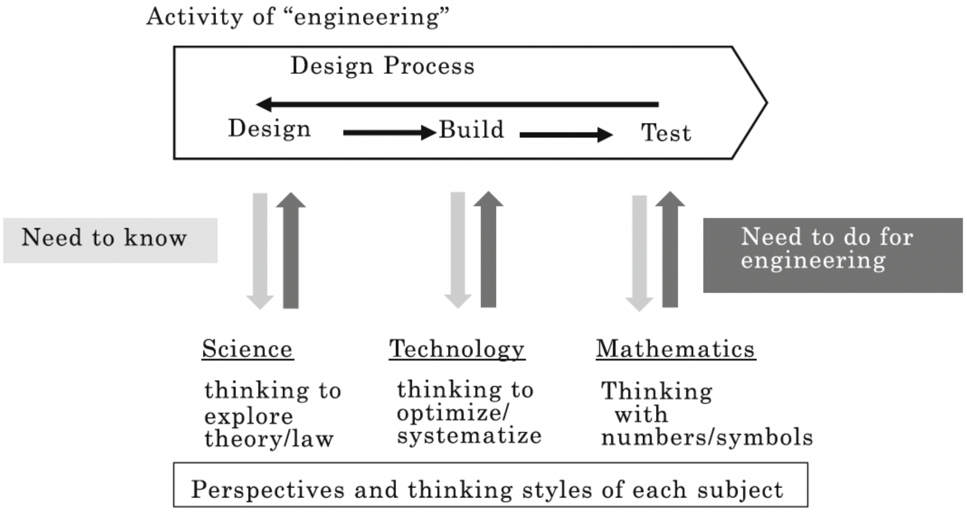


Note: Adapted from “A Conceptual Framework for Integrated STEM Education” by Kelley, T. R., & Knowles, J. G., (2018). *International Journal of STEM Education*, *3*(1), 1-11.

Yata et al. (2020) recently presented an alternative STEM framework that attempts to ensure the retention of the principles of science, technology, and mathematics in the activity of engineering (see Figure 2).

Figure 2

STEM Framework Reflecting the Relationships Between Engineering Design Processes, Science, Technology, and Mathematics

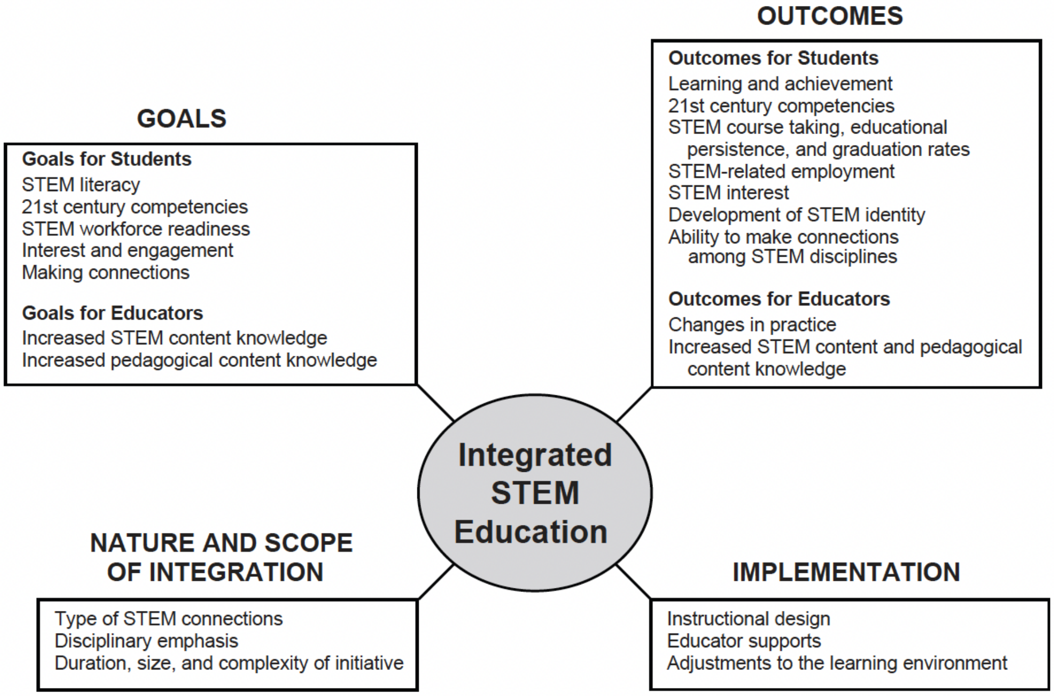


Note: Adapted from "Conceptual Framework of STEM Based on Japanese Subject Principles" by Yata, C., Ohtani, T., & Isobe, M. (2020). *International Journal of STEM Education*, *7*(1), 1-10.

In an attempt to further support educators, researchers, and policy makers, the *STEM Integration Framework* (see Figure 3) takes a comprehensive approach to identifying goals, outcomes for students, the nature and scope of the integration, including the type of STEM connections and disciplinary emphases that should be made and the way in which learning experiences should be implemented to achieve the goals and outcomes desired for students (NRC, 2014).

Figure 3

Descriptive Framework Showing General Features and Subcomponents of Integrated STEM Education



Note: Adapted from "*STEM Integration in K-12 Education: Status, Prospectus, and an Agenda for Research*" by the National Research Council. (2014). The National Academies Press.

The frameworks showcased in Figure 1 and Figure 2 aim to place engineering design at the center of STEM integration and lack any emphasis on disciplinary content use or learning. Figure 3, from the NRC findings on STEM integration, serves as a descriptive model showcasing different features and subcomponents of integrated STEM. The features and components emphasize the need for STEM integration that focuses on the disciplinary nature of the disciplines of STEM, including the content and practices associated with each discipline. This coincides with the committee for STEM Integration in K-12 Education's recommendation that attending to the learning goals and progressions of the individual STEM subjects should be prioritized in STEM education as to not inadvertently undermine student learning in those subjects (NRC, 2014). While the guidance, frameworks, and descriptive models showcased in this section of the literature review aim to provide STEM-education stakeholders with clarity on STEM and STEM integration, they further illustrate the diverse conceptions of STEM and STEM integration that exist in literature. While the Kelley and Knowles conceptual framework (2016) for STEM integration has been referenced in literature centered on advocacy for STEM integration (Dare et al., 2018; Estapa & Tank, 2017), little attention is given to utilizing the conceptual framework as a means for STEM-education stakeholders to achieve common conceptions of STEM. The Yato et al. (2020) framework is utilized to advocate for forms of STEM integration that place engineering design at the center (Roehrig et al., 2021; Sujarwanto et al., 2021) and to inform the development of other frameworks for STEM integration (Fallon et al., 2020). Similarly, explanatory attempts by English (2016) and Bybee (2013) seem to be utilized in literature to support claims that interpretations of STEM and STEM integration are vast and broad (Dare et al., 2018; Guzey et al., 2016; Li et al., 2020). However, an exhaustive literature review reveals that neither explanatory attempts (Bybee, 2013; English, 2016), conceptual frameworks for STEM integration (Kelley & Knowles, 2016; Yato et al., 2020) or descriptive frameworks (NRC, 2014) have been utilized with STEM-education stakeholders more broadly to craft a vision for STEM education or STEM integration.

Conclusion

The literature review highlights varied conceptions for STEM education that exist among STEM-education stakeholders and exhibits how those conceptions can lead to prioritization of instructional methods that center around problem-based learning and connections to real-world contexts indifferent to student acquisition of the concepts and skills associated with STEM disciplines like mathematics and science. As evidenced by the review of literature, such priorities conflict with workforce priorities and college and career readiness goals that emphasize the need for individuals to possess the knowledge and skills of mathematics and science for both STEM and non-STEM careers.

The literature review also showcases how long-standing recommendations for K-12 teaching and learning in the STEM disciplines attend to knowledge and skills needed for college, workforce, and citizenry readiness as well as STEM-education goals such as: student-centered approaches to learning, connections to real-world contexts, and obtainment of 21st century skills like teamwork and problem solving. In fact, the long-standing, research-based recommendations by professional organizations emphasize the importance of learning experiences that attend to the individual disciplines of STEM as well as integration across the STEM disciplines. Furthermore, technology and engineering education professional organizations assert that teaching and learning associated with these two disciplines is inextricably linked with and requires mathematics and science disciplinary knowledge and skills. The recommendations for K-12 teaching and learning for science, technology, engineering, and mathematics provided in the literature review serve to inform the elements present in the STEM explanatory model utilized in this study. The literature review also illuminates the lack of consensus that exists for teaching and learning in the fields of technology and engineering education, which may contribute to the lack of consensus for STEM education more broadly.

Several attempts have been made to bring clarity to K-12 technology and engineering education as well as STEM education and STEM integration by way of published frameworks and descriptive models. However, previously published frameworks have centered on providing clarity by emphasizing one STEM discipline over others or by emphasizing the STEM practices over content leading to an incomplete representation of the elements that comprise STEM disciplines. Still, other attempts have offered descriptive models showcasing varying levels of STEM integration that might exist in classroom activities or programs. While other descriptive models showcase how elements like assessments or teacher preparation relate to a broader system of support for STEM integration. Research indicates previous attempts to develop frameworks or descriptive models for STEM education and STEM integration have not been designed to assist diverse STEM-education stakeholders in crafting a coherent understanding of STEM education or STEM integration that includes a focus on the concepts and skills associated with the individual disciplines of STEM. This study aimed to fill a need in the field of research by examining the use of an explanatory model, that represents the nationally recommended content and skills for K-12 education of STEM disciplines, as a tool to assist STEM-education stakeholders in crafting coherent conceptions of STEM education and STEM integration.

Chapter 3: Methodology

While STEM education is recognized as a critical priority for national security, health, and economic prosperity, its various and often conflicting meanings, coupled with excessive use of the acronym as a super discipline, render it increasingly meaningless for many. Additionally, varied conceptions of STEM by STEM-education stakeholders can lead to prioritization of instructional methods and STEM-education programming absent the critical mathematics and science concepts needed for STEM careers and STEM-literacy. To determine if an explanatory model for STEM education and STEM integration will lead to greater coherence in understanding STEM and STEM integration among diverse STEM-education stakeholders, I utilized the following questions to guide this study:

1. How do STEM-education stakeholders describe their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model?
2. How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson before, during, and after the use of a STEM explanatory model?

Research Design

Understanding how conceptions of STEM and STEM integration remain constant or shift after being introduced to an explanatory model for STEM can inform conversations about effective approaches to STEM instruction for students, professional learning for educators, and STEM-education policy and programmatic decisions by various STEM-education stakeholders. As this study focused on understanding how conceptions of STEM and STEM integration among various STEM-education stakeholders shift when individuals are exposed to a STEM explanatory model, the theoretical framework of constructivism and social constructivism was used to guide the study. Constructivism is grounded in the philosophy that individuals do not find or discover knowledge, they construct or make it (Schwandt, 2015; Vygotsky, 1978). Constructivist worldviews believe that individuals develop subjective meanings of their experiences socially or historically and that those meanings are varied and complex (Creswell, 2014). Constructivism as a theoretical framework for the study fits well as the study aimed to analyze the effect of a STEM explanatory model on participants' abilities to construct new knowledge about STEM and STEM integration. Additionally, because participants of the study engaged in discussions to develop a consensus understanding of STEM or STEM integration using the STEM explanatory model, social constructivism also drove this study as the theory assumes that individuals gain understanding jointly with others through social and cultural interactions (Vygotsky, 1978). Constructivism and social constructivism have been the basis of my own personal worldview as a science educator and science education researcher for nearly twenty years, further influencing the study design.

I utilized a basic qualitative research design to develop and carry out the study. A qualitative research design aims to understand the meaning of human actions using qualitative methods including open-ended interviews and participant observations (Schwandt, 2015). Qualitative research involves studying things in their natural settings and attempting to make sense of individuals' interpretations of a phenomenon, problem, or situation (Creswell & Poth, 2018). Qualitative research methods include the use of "the voices of the participants, the reflexivity of the researcher, a complex interpretation of the problem, and its contribution to the literature or a call for change" (Creswell, 2013, p.44). This study was well suited for a qualitative research study because I aimed to understand how STEM-education stakeholders' complex interpretations of STEM and STEM integration shifted when introduced to a STEM explanatory model.

The study leveraged the voices of participants to understand their conceptions of STEM and STEM integration before, during, and after they were introduced to a STEM explanatory model. The study also examined how participant groups' (i.e., classroom teachers and informal educators) conceptions of STEM and STEM-integration shifted when introduced to the STEM explanatory model. Qualitative data (open-ended pre- and post-survey questions, recorded discussion, and researcher memos) were collected and analyzed to answer the study questions using emergent coding techniques fitting of qualitative methods (Saldaña, 2021). The study aimed to focus on a small subset (n = ~ 40) of STEM-education stakeholders from elementary and middle schools associated with a large school district.

Setting

The study took place in the context of several STEM-education programs offered by a regional STEM alliance center (SAC) in a large city in a midwestern state. The center was founded in 2012 and became a non-profit organization in 2017. It seeks to build broad, deep, and innovative pathways for all students to access high-impact careers. A partnership between the regional SAC and the large urban school district in the Midwest, referred to in this study as Northeastern Public School District (NPSD), has been in existence since the inception of the center in 2012 and continues today. NPSD serves approximately 33,000 PK-12 students each year and includes 56 elementary schools, 20 middle schools, and 13 high schools.

As part of the partnership, the regional SAC provides professional development programs in STEM areas for PK-12 educators and offers after school and summer STEM programs for students of NPSD. The study took place during a fall workshop facilitated by the regional SAC with STEM-education stakeholders associated with elementary and middle schools of NPSD. The workshop focused on helping STEM-education stakeholders craft a coherent understanding of STEM and STEM integration with the aim to assist them in setting goals to improve STEM learning experiences and opportunities for PK-12 students attending the school district.

Participants

Participants for the study were intended to be diverse STEM-education stakeholders associated with NPSD including PK-12 STEM teachers, administrators, curriculum coordinators, instructional coaches, informal STEM educators, business and community members, and representatives of philanthropic organizations associated with the school district.

Convenience sampling was utilized for this study, as the regional SAC provided access to study participants through an event they had already planned (Schwandt, 2015). Targeted schools, representing NPSD and surrounding suburban and rural school districts, as well as informal STEM educators and philanthropic organization representatives, were invited to participate in the workshop held by the regional SAC in the fall of 2022. Fifteen participants attended the workshop with two leaving early. The two participants that left early were removed from the study. The remaining thirteen participants included four elementary STEM teachers, three middle school STEM teachers, five informal STEM educators, and a representative of the state department of education who oversees STEM education. Two of the participants mentioned during the workshop that they had experience with the STEM explanatory model being studied.

The participants of the study were representative of STEM-education stakeholders in communities and states across the U.S. Individuals who did not speak English, who were not associated with NPSD or surrounding districts, and who were not engaged in STEM-education efforts with the school districts were not invited to participate in the study. Additionally, PK-12 students did not participate in the study.

- *Informal STEM Educators* – (N=5) Individuals who provide STEM instruction outside-of-school contexts or partner with PK-12 schools and classroom teachers and provide STEM instruction inside school contexts.
- *STEM Teachers* – (N=7) PK-12 classroom teachers responsible for providing instruction in STEM.
- *Governmental Employee* – (N=1) Individual who works at a state agency and supports education policy implementation by PK-12 schools.

Intervention

Participants participated in a two-hour professional development session that resided within a broader workshop designed to engage participants in setting goals for STEM education policies and programs to be offered to the invited district's PK-12 educators and students. During the two-hour professional development session, participants were asked to engage in a classroom activity aligned to middle school learning objectives associated with the Next Generation Science Standards (NGSS). The activity engaged participants in examining, discussing, and determining the distance a ball would travel along a ramp if it were to encounter a wall or not encounter a wall. The classroom activity engaged participants in modeling or drawing the expected and actual outcome of multiple trials testing a ball traveling down a ramp in instances where it hit a wall and did not hit a wall. Participants engaged in scientific practices (e.g., asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, and obtaining, evaluating, and communicating information) to gain an understanding of the disciplinary core ideas of force and motion, definitions of energy, and conservation of energy and energy transfer through the classroom activity. Some participants utilized technology to collect and analyze data but did not engage in designing technology. Participants utilized mathematics concepts and skills, but the activity was not designed to provide instruction in mathematics and did not include mathematics usage at a middle school grade-level. Participants did not engage in the process of engineering and the activity was not designed to engage participants in utilization of engineering concepts. Once participants completed the classroom activity, they were introduced to the study intervention, the STEM Explanatory Model (Table 5) and asked to use the explanatory model to come to consensus about the version of STEM or STEM integration the classroom activity represented. Participants were also provided with state academic standards for middle school science and math to reference with the STEM explanatory model as they analyzed the classroom activity to determine the version of STEM or STEM integration it represented.

STEM Explanatory Model

The STEM Explanatory Model was developed by myself and a colleague who now serves as the Executive Director of the regional SAC where the study was conducted. The explanatory model was developed after years of working with STEM-education stakeholders and attempting to explain STEM education and STEM integration. The explanatory model (Table 5) was developed using the descriptors for science, technology, engineering, and mathematics education from national recommendations for K-12 STEM education disciplines (NAS, 2020; NCTM, 2000; NRC, 2012; NRC, 2014; NSTC, 2018).

Table 5

Study Intervention: STEM Explanatory Model

S	T	E	M
Science content and practices are equally represented and on grade level.	Technology is both created and operated purposefully.	Engineering knowledge and design are present, and science and mathematics concepts are utilized.	Mathematics content and practices are equally present and on grade level.
s	**t**	**e**	**m**
Science content or practices are absent or science content and practices are not on grade level.	Technology is operated purposefully but not created.	Engineering knowledge or design are present but lack utilization of science and mathematics concepts.	Mathematics content or practices are absent or mathematics content and practices are not on grade level.
-	**-**	**-**	**-**
Science content and practices are absent.	Purposeful operation and creation of technology are absent.	Engineering knowledge and design are absent.	Mathematics content and practices are absent.

The STEM Explanatory Model provides three tiers of descriptions for levels of engagement with science, technology, engineering, and mathematics whereby the first set of descriptors correspond with capital letters for each of the STEM disciplines. The capital letter descriptions align with national recommendations for teaching and learning for the STEM disciplines. The second set of descriptors correspond with lower case letters for each of the STEM disciplines whereby disciplinary content or disciplinary practices may be absent or instruction in the discipline may not align with grade level recommendations. The last set of descriptors correspond with an absence of letters for the STEM disciplines and indicate that instruction related to the STEM discipline are absent. The explanatory model is designed to be used to analyze an activity, lesson, or program to determine the STEM disciplines that are present and whether instruction related to the discipline provides opportunities for learners to engage in on-grade-level instruction of the content knowledge and practices associated with the STEM disciplines. The explanatory model is not designed to indicate quality of instruction provided by an activity, lesson, or program, only whether the STEM disciplines are present and at what level they are present.

Data Collection

A chronological sequential design was utilized to collect data in a series of phases that involved tracking measurement before, during, and after participants were introduced to the intervention (Yin, 2014). I utilized multiple sources of data to serve as evidence for the study including open-ended pre- and post-survey questions serving as a form of interviews (Yin, 2014), recordings of participant discussions, and researcher memos. Triangulating data from multiple sources of evidence strengthens study confidence supporting more accurate interpretations of participants' conceptions about STEM and STEM integration throughout the study (Yin, 2014). Utilizing open-ended questions through pre- and post-surveys allowed for careful analysis of any shifts in understanding participants may have about STEM or STEM integration at various points in the study and allowed participants to share their conceptions expansively without restrictions (Creswell, 2014; Yin, 2014). This form of survey also fits within the theoretical framework for the study (constructivism) as it allows participants to showcase any new knowledge or meaning-making they experienced after exposure to the STEM Explanatory Model. The survey questions were informed by previous studies in the literature review (Brown et al., 2011; Holmlund et al., 2018; LaForce et al., 2016; Margot & Kettler, 2019).

At the start of the two-hour professional development session, participants were asked to respond in written format to three open-ended questions on pre-survey questions (see Table 6). After responding to Questions 1-3 on the pre-survey, participants had an opportunity to discuss their responses in small groups of three or four. The discussions were recorded, transcribed, and utilized to corroborate responses to the survey questions (Yin, 2014). After discussing their responses to Questions 1-3 from the pre-survey, participants engaged in the STEM classroom activity. Once participants completed the STEM classroom activity they were asked to respond in written format to pre-survey Questions 4-5 (see Table 6). Once participants finished responding to the pre-survey questions, they were introduced to the STEM Explanatory Model (Table 5). After being introduced to the STEM Explanatory Model, participants were asked to use the explanatory model to come to consensus about the version of STEM or STEM integration the classroom activity represents. The discussion was recorded and transcribed. After the discussion, participants were asked to respond in written format to five open-ended questions on a post-survey. The post-survey questions were the same five questions from the pre-survey (see Table 6).

Table 6

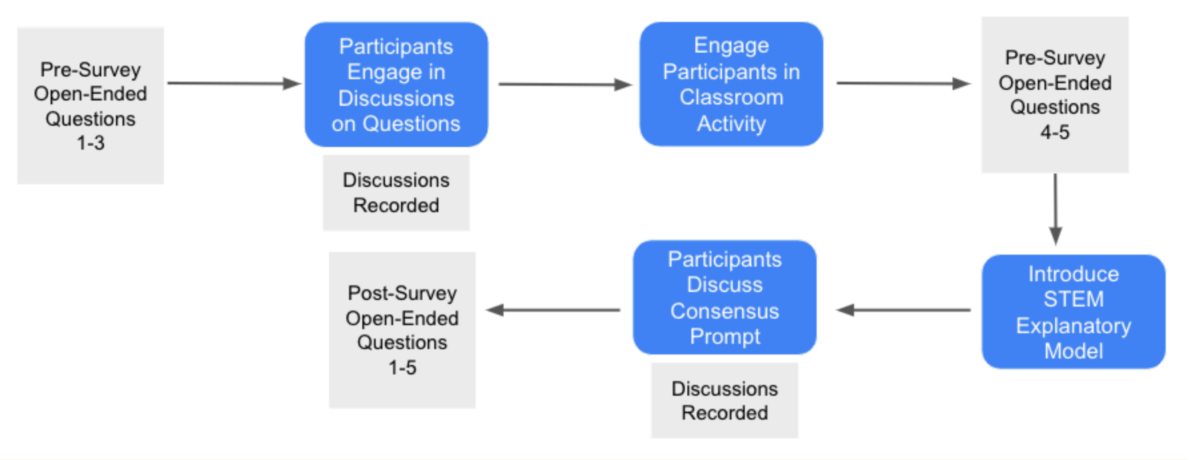
Pre- and Post-Survey Questions Utilized in the Study

PRE-SURVEY QUESTIONS	POST-SURVEY QUESTIONS
What is your understanding or conception of STEM education?	What is your understanding or conception of STEM education?
What do you see as the most important ideas, sub-ideas, or skills for STEM education?	What do you see as the most important ideas, sub-ideas, or skills for STEM education?
What experiences have influenced your understanding of STEM?	What experiences have influenced your understanding of STEM?
Does the activity represent a STEM activity? Explain your reasoning?	Does the activity represent a STEM activity? Explain your reasoning?
Describe what disciplines of STEM were addressed in the activity.	Describe what disciplines of STEM were addressed in the activity.

Figure 4 showcases the steps utilized to collect data from participants during the two-hour professional learning session where they were engaged in a STEM classroom activity, introduced to the STEM Explanatory Model, and used the explanatory model to come to consensus about the version of STEM or STEM integration the classroom activity represented.

Figure 4

Steps for Collecting Data in the Study



Researcher memos were maintained and used to supplement the pre- and post-surveys and recorded discussions (Croswell & Poth, 2018). To ensure the protection of study participants, I gained informed consent from the participants of the study prior to their participation. The consent form informed participants that their participation would remain confidential in the study. I assigned a unique identifying number to each participant to ensure their anonymity in the study. A formal approval for the study was sought and provided from the University of Oklahoma Institutional Review Board (IRB) prior to communicating with participants about the study (see Appendix A).

Data Analysis

Coding and theming techniques were utilized to analyze data from participant responses on pre- and post-surveys as well as transcribed recordings of participant discussions. In Vivo and descriptive coding methods were utilized for the first-cycle of coding and theming. In Vivo and descriptive coding splits data into individually coded segments and is particularly useful in this study as the goal was to use terms and concepts drawn from the words of the participants themselves to determine how their conceptions of STEM and STEM integration may have shifted after being introduced to the STEM Explanatory Model (Saldaña, 2021). I then employed focused-coding for the second-cycle of coding and theming. Focused coding searches for the most frequent or significant codes to develop categories (Saldaña, 2021). Researcher memos were utilized to supplement data analysis from pre- and post-surveys and transcribed participant discussions. Researcher memos were also utilized to provide contextual data (e.g., participant discussions not captured through audio recordings, relevant facilitator comments in the professional learning session, or any disruptions that might occur during the event). The analysis focused on any patterns that emerged related to how participants' conceptions of STEM and STEM integration shifted upon introduction to the STEM Explanatory Model and how they described the components of STEM believed to exist in the classroom activity before, during, and after the intervention. Analysis occurred within and across participant groups in the study. Since I, as the researcher, developed the STEM Explanatory Model being studied, I reported preliminary findings to two critical friends with a request that they offer alternative explanations and analysis of the data to reduce potential bias (Yin, 2014).

Conclusion

This study aimed to bring further clarity to STEM education and STEM integration by analyzing how the use of a STEM explanatory model assists STEM-education stakeholders’ in coming to consensus regarding their conceptions of STEM and STEM integration. A basic qualitative research design was utilized to carry out the study leveraging the voices of participants to understand their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model. The study took place during a workshop offered by a regional STEM alliance center in a large city in a midwestern state. Thirteen diverse STEM-education stakeholders participated in the study representing elementary and middle school

STEM teachers, informal STEM educators, and a government official. Data collected through a chronological sequence design with open-ended pre- and-post-survey questions, recorded discussions, and researcher memos were utilized as evidence for the study.

Chapter 4: Findings

The goal of this study was to determine how STEM-education stakeholders' use of a STEM explanatory model might shift their conceptions of STEM and STEM integration and assist them in crafting a more coherent understanding of STEM and STEM integration. A basic qualitative design was utilized to answer two questions central to the study: (1) how do STEM-education stakeholders describe their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model? (2) how do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson before, during, and after the use of a STEM explanatory model? To address these questions qualitative data from four STEM elementary teachers (EL), three middle school STEM teachers (MS), five informal STEM educators (IE), and one government employee (G) were collected during a workshop where participants were exposed to and utilized a STEM explanatory model. The findings and analysis are presented in this chapter. The first section discusses the qualitative data and analysis utilized to address Research Question 1 (RQ1). The second section discusses the qualitative data and analysis utilized to address Research Question 2 (RQ2).

Conceptions of STEM and STEM Integration

To answer RQ1, multiple data sources, including open-ended pre-and post-surveys, recorded participant discussions, and researcher memos, were combined and analyzed using opening coding analysis to generate emergent themes relevant to the research question (Merriam, 2009). Additionally, evidence from data sources were triangulated to better establish validity and confidence in the identified themes (Creswell & Poth, 2018; Schwandt, 2015). Table 7 showcases a roadmap of the sources of data utilized to address RQ1 and determine participants conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model.

Table 7

Roadmap for Analyzing Data to Address Research Question 1

DATA SOURCES	PARTS OF RESEARCH QUESTION 1		
	How do STEM-education stakeholders identify and describe their conceptions of STEM and STEM integration **before** the use of a STEM explanatory model?	How do STEM-education stakeholders identify and describe their conceptions of STEM and STEM integration **during** the use of a STEM explanatory model?	How do STEM-education stakeholders identify and describe their conceptions of STEM and STEM integration **after** the use of a STEM explanatory model?
Pre-Survey Questions	x		
Discussion 1	x		
Discussion 2		x	
Post-Survey Questions			x
Researcher Memos		x	

Each of the data sources were analyzed to identify themes related to participant conceptions of STEM and STEM integration before, during, and after the use of the STEM explanatory model. Through open coding and constant comparative methods (Creswell & Clark & Poth, 2018; Merriam, 2009), emergent themes that represent patterns or regular occurrences of participants' responses to questions regarding their conceptions of STEM and STEM integration before, during, and after use of the STEM explanatory model were identified and described. Themes were identified through an inductive first-cycle coding process (Saldaña, 2021). Phrases or words were coded directly from participant responses to open-ended survey questions and recordings of participant discussions, a process known as In Vivo coding (Saldaña, 2021). Descriptive coding was also utilized as a first-coding technique when analyzing the data to summarize the general topic of passages in a word or short phrase from survey responses and participant discussions (Saldaña, 2021). Focused coding was then utilized during second-cycle coding analysis to synthesize the codes and identify the themes (Saldaña, 2021). Additionally, evidence from audio recordings of participant discussions regarding their responses to pre-survey questions were triangulated with written responses to corroborate evidence and establish confidence in the themes identified (Creswell & Poth, 2018) as well as to better leverage the direct voices of participants for the study (Yin, 2011).

Conceptions of STEM and STEM Integration Before the Use of STEM Explanatory Model

Pre-coding techniques were utilized to highlight significant quotes that stood out in participant responses to pre-survey questions regarding their conceptions of STEM and STEM integration prior to the use of a STEM explanatory model (Saldaña, 2021). Preliminary jotting techniques were also utilized to record preliminary phrases or codes from pre-survey question responses and transcriptions of group discussions (Saldaña, 2021). Data from pre-survey questions were then broken into over 170 meaningful units through first-cycle In Vivo and descriptive coding techniques and entered into an Excel spreadsheet. Using focused coding, meaningful units or codes were then sorted and grouped based on commonalities seen across the units of data and assigned identifying theme names during a second-cycle coding process. Transcriptions of individual participant contributions in Discussion 1 were pre-coded then analyzed in first-cycle coding with In Vivo codes recorded on the Excel spreadsheet. In second-cycle coding, units of data were sorted and grouped through focused coding into themes identified from pre-survey data analysis. Table 8 showcases the seven identified themes and corresponding coding descriptions identified through first- and second-cycle coding processes representing participants' conceptions of STEM and STEM integration before they were introduced to the study intervention.

Table 8

Participant Conceptions of STEM and STEM Integration Before the Use of STEM Explanatory Model

THEMES	CODE DESCRIPTIONS
Involves STEM Disciplines	Participants mentioned one or more STEM disciplines in their responses or responded with statements about STEM disciplines.
Involves Integration of Disciplines	Participants mentioned integration or interdisciplinary or described instruction whereby disciplines were working together, multiple concepts taught simultaneously, or STEM disciplines were present in all lessons.
Leverages Inquiry-Based Learning	Participants made statements about instruction that engaged students in hands-on or project-based learning that engaged students in problem solving, critical or creative thinking, curiosity, or questioning.
Supports Development of Soft Skills	Participants made statements about students engaging in teamwork, collaboration, communicating with others, or persevering.
Connected to Real-World	Participants described learning that was able to be carried into real-life or have real-world application. Participants mentioned STEM as an avenue to careers exploration or obtainment.
Supports Social-Emotional Learning	Participants described learning that helps students gain social-emotional skills like empathizing with others, feeling accepted, empowered, or smart.
Drives Equity	Participants commented that STEM education makes STEM inclusive and accessible for all, accommodates multiple learning styles, and provides equal opportunity for students to high-quality lessons.

The findings associated with each of the seven themes is presented in more detail below using the meaningful units of data utilized to identify and describe each theme. The seven themes represent the array of conceptions of STEM and STEM integration participants held prior to their exposure and use of the STEM Explanatory Model. Codes from pre-survey Question 1 (PS1: What is your understanding or conception of STEM education?), pre-survey Question 2 (PS2: What do you see as the most important ideas, sub-ideas, or skills for STEM education? and Discussion 1 (D1) are presented in the results associated with each of the identified themes below.

Involves STEM Disciplines

Eight of the 13 participants explicitly mentioned science, technology, engineering, or mathematics in their descriptions of STEM, with one participant (EL4, PS1) listing only science, engineering, and mathematics. One participant referenced computer coding (IE5, PS1) in their description of STEM or components of STEM but later stated in discussions that “STEM is everything” (IE5, D1) with no reference to STEM disciplines. Five of the eight participants who mentioned science, technology, engineering, or mathematics in their understanding of STEM provided additional context in their survey responses or group discussions. One elementary STEM teacher recalled that they, “said basically what STEM stands for” (EL2, D1) and that STEM education “aims to teach students about science, tech, engineering, and math” (EL2, PS1). An informal STEM educator shared that they used “the acronym” (IE3, D1) to describe STEM and that STEM education incorporates “science, tech, engineering, and math principles into educational experiences so students can receive robust lessons” (IE3, PS1). The government official responded that at “its core, STEM = science, technology, engineering, mathematics” (G, PS1). This individual went on to state that “high-quality STEM should include strong foundations in science and mathematics, as well as application of those areas" (G, PS1). Two participants who explicitly referenced STEM disciplines in their responses did so in conjunction with references to integration, with a middle school STEM teacher sharing that in STEM education "students are exposed to science, tech, engineering, and math in almost all lessons" (MS1, PS1). Another middle school teacher stated that their understanding of STEM education centered on "engaging students in more abstract math concepts as they are integrated in S.T.E.M." (MS3, PS1). Two STEM educators and one informal STEM educator did not explicitly mention disciplines of STEM in their description of STEM prior to exposure to the STEM Explanatory Model.

Involves Integration of Disciplines

Seven of the 13 participants described STEM or STEM integration as an instructional approach that emphasizes integration or multidisciplinary approaches to learning with one participant describing STEM education as "the opportunity for students to learn about multiple concepts simultaneously" (EL3, PS1) and another stating it is "science, technology, engineering, and math working together" (EL4, PS1). This echoed another participant's response that STEM education is "learning how the subjects work together" (G, PS1). One informal STEM educator and one middle school STEM teacher shared conceptions of STEM that were limited to the integration of two or more disciplines which could include integration with the STEM disciplines or other disciplines like art. The informal STEM educator described STEM as "something from maybe math and incorporate into science or take something from maybe math and incorporate it into art" (IE4, D1). The middle school teacher emphasized that "math was the key" (MS3, D1) to integration in STEM. Another participant stated that STEM education was a "giant umbrella under which all concepts can be taught" (IE2, PS1) without any reference to the STEM disciplines. Another participant shared that their understanding of STEM was that “it is just incorporating all those, even if you’re just a math plan or a science plan, there’s a way to incorporate all the technology, engineering, art, and math” (IE3, D1).

Leverages Inquiry-Based Learning

Three participants who did not explicitly mention STEM disciplines in their conceptions of STEM education or as ideas, sub-ideas, or skills associated with STEM education, described it as hands-on, discovery, or inquiry-based learning that promotes problem solving and critical- and creative-thinking skills. One such participant stated that “discovery or inquiry-based learning” was an essential component of STEM education (IE2, D1) and STEM education is “an aim for more hands-on and project-based learning” (IE2, PS1). Another stated that the “most important ideas for them “were that learners are actively engaged in doing STEM rather than hearing about STEM or learning about the history of STEM or the people who use STEM in their careers” (IE1, D1). Another participant said that STEM education is “a hands-on, minds-on approach to learning” (IE5, D1). Some participants who explicitly mentioned STEM disciplines when describing their understanding of STEM also described STEM as an instructional approach using descriptors like hands-on, or inquiry-based. One participant clarified in the group discussion that STEM education goes “beyond traditional learning, sitting in a desk and answering test questions” and that “teachers of STEM should possess an ability to employ inquiry-based learning” (IE3, D1). This participant went on to share in later discussions that STEM education is “not just teaching at them but have them be the ones to ask the questions” because “if you’re asking questions then you’re understanding the subject enough to inquire” (IE3, D1). The same participant stated that STEM education is “just a way of learning or a way of presenting a topic” (IE3, D1). An elementary teacher shared that their understanding of STEM was that “there’s a move towards more hands-on, project-based learning focused on problem solving rather than you read a textbook and answer a test" clarifying that "we try to get kids more involved in the learning process" (EL2, D1) through STEM education.

Supports Development of Soft Skills

Several participants indicated that STEM and STEM integration included a focus on students gaining soft skills including effective communication, collaboration, perseverance, and creativity. Three participants mentioned communication or effective communication as an important skill students gain through STEM education (EL1, PS1; EL2, PS1; MS3, PS1). Four participants mentioned collaboration as an essential component of STEM education with one participant stating that they felt it was important for students to "understand other ideas" (MS1, PS1). One participant indicated that perseverance was a skill that students could gain through STEM education, "if you put it in a STEM activity, maybe it's less severe. It's not a test. It's not—maybe I can try it—less intimidating" (MS2, PS1). Another participant described STEM education as "a framework approach to life moving throughout the world with an open-mind, curiously questioning and finding meaning through science inquiry and the language of mathematics" (IE1, PS1) while another emphasized that the more people who understand computer code "the more creative" they can be (IE5, PS1).

Connected to Real-World

Eight of the 13 participants emphasized the role of real-world connections in STEM education, with one participant stating, "I believe STEM education is the integration of STEM and how it is used in the real-world application for solving future problems or making the world a better place to live" (MS3, PS1). The teacher went on to describe how valuable it is to bring "someone like and engineer or a cybersecurity expert" (MS3, PS1) into the classroom to get students interested in STEM. Another participant stated that STEM education involves students engaging in educational experiences that “are able to carry them into real-life situations” (IE3, PS1) and another participant indicated that STEM education is designed for students to learn “core things” that “drive everything in everyday life” (IE5, PS1). Three participants referenced career exploration or preparation in their responses to pre-survey questions with one participant stating that STEM education is designed to “prepare students now for the jobs and careers they will see in the future” (EL3, PS1) and another stating the STEM acronym “was part of an initiative to encourage students to choose STEM careers” (G, PS1). A middle school STEM teacher expressed a need to engage students in STEM education “so we can globally get where our country needs to be” (MS3, D1) and address “needs of having educated workers” (MS3, D1) locally.

Supports Social-Emotional Learning

Five participants discussed the role STEM education plays in students gaining social and emotional skills with statements about students learning compassion, empathy, and developing a STEM identity. One participant who did not mention STEM disciplines in their conceptions of STEM described an instructional approach they utilize for STEM instruction they called the “4 Cs of Problem Solving”, which focuses on “helping students empathize with the end user” of the solution to a problem and improving “the quality of life” (EL1, PS1) of others by putting “themselves in the shoes of the person who may benefit from a prosthetic or make a game where they can create a controller that allows differently-abled student to still participant” (EL1, D1). Another participant described STEM education as an instructional approach that helped students feel “accepted, powerful, and smart” (MS1, PS1) and allows students to understand “other peoples’ ideas, which goes with empathy” (MS1, D1). Another participant shared that STEM education should help students develop an “identity as a STEM person” (G, 14) and one informal STEM educator said STEM is “a framework for life” (IE1, PS1) as it helps students develop the soft skills needed to be successful.

Drives Equity

Six participants discussed how STEM education promotes equitable approaches to learning by making learning accessible to more or all students. One participant noted that STEM education makes “these concepts more easily understood and relatable” and results in exposure “to a more diverse audience than traditionally seen” with a focus on “more than masculine ideas or perceptions society has” (IE5, PS1). Three participants discussed how STEM education supports diverse learning styles, with one participant describing STEM education as an instructional approach that “accommodates multiple learning styles” (EL3, PS1). Another participant indicated that “STEM allows for all types of learners to be involved (IE3, PS1) and another stated that STEM supports “different styles of education due to so many ways of learning (IE4, PS1). One participant stated that STEM education aims “to make STEM more-and-more inclusive and accessible for all people (EL2, PS1) clarifying that its “been a major theme that we’ve been going towards” (EL2, D1). Another participant stated that “all students of all gender, background, and location receive an equal opportunity of access to high quality lessons” (MS1, PS1) through STEM education.

Influences of Perceptions of STEM and STEM Integration

To ascertain factors that might influence study participants’ conceptions of STEM, data from pre-survey Question 3 (PS3: What experiences have influenced your understanding of STEM? and (D1) data from participant responses were pre-coded and then broken into over 70 meaningful units through first-cycle In Vivo coding and descriptive coding and entered into an

Excel spreadsheet. Using focused coding, meaningful units of data or codes were then sorted according to defining attributes, grouped based on commonalities, and assigned identifying theme names during a second-cycle coding process. Table 9 showcases the four identified themes, corresponding coding descriptions, and codes identified through first- and second-cycle coding processes representing factors that have influenced participants' understanding of STEM.

Table 9

Experiences that Influenced Participants' Understanding of STEM

THEMES	CODE DESCRIPTIONS	IN VIVO CODES
Professional Development	Participants discussed how workshops, trainings, experiential learning opportunities, and educational resources and articles influence their understanding of STEM.	"Professional development" "Workshops" "Trainings" "Conferences" "STEM Framework"
Personal Experiences	Participants shared examples of personal experiences that included their own learning experiences as students and attending camps, museums, and science centers. Participants also shared examples of overcoming barriers or lack of opportunities to learn STEM.	Personal learning experiences "Experiential learning experiences" "hands-on experiences" "Overcoming insecurities" "STEM experiences" Overcoming barriers "Constructivist teachings" "College Courses"
Job or Position	Participants gave examples of current and previously held jobs including teaching positions.	"Classroom teacher" "STEM Smart Lab facilitator" "Teaching as science camp" "Working in a company" "Owning manufacturing business"
STEM or STEM-Education Stakeholders	Participants shared that other educators, national STEM organizations and industry leaders had shaped their understanding of STEM.	"Industry leaders" "Researchers and scientists" Other educators

Professional Development. Six participants shared that professional development including: workshops, trainings, and conferences influenced their conceptions of STEM. Two teachers referenced professional development they had experienced through the regional STEM alliance center where the study took place (EL1, PS3; MS1, PS3). The elementary teacher also referenced "scratch.org" (EL1, PS3) training and stated with scratch training "there's a lot of diversity and inclusion sessions that were really powerful" (EL1, D1) as something that had influenced their understanding of STEM. They also described how training she attended titled the "Heart of STEM" and the "Joy of STEM" which centered on "making it fun and the science behind how much more effective education is when kids are having fun" (EL1, D1). One participant referenced professional development experiences provided by experts in the field" (MS3, PS3) as a contributing factor while another mentioned attending professional development where they "heard from industry leaders" (MS2, PS3). Two participants mentioned workshops or conferences absent of details (EL3, PS3; EL4, PS3). The government employee stated they had "given professional development on this model [STEM explanatory model]" (G, D1) when discussing the role professional development had played in influencing their understanding of STEM.

Personal Experience. Participants described an array of personal experiences they felt had influenced their conceptions of STEM including their own personal learning experiences in PK-12 school and college. One participant said, "I always failed paper tests at school, but when there was a project-based lesson, I wrote, read, and worked harder than any other format" (MS1, PS3). Another described how the "constructivist teachings of Piaget, Dewey, Vygotsky" (IE1, PS3) had influenced them. One participant described several personal experiences that had influenced their understanding and love of STEM including "recognizing the relationship between fiber arts, and math, plus engineering”, taking a “science and cooking course and realizing they reacted to food differently based on how its cooked”, and taking “college courses” (IE5, D1). Another participant shared how “owning and operating a small manufacturing business” (MS3, PS3) had shaped their understanding and appreciation for STEM. Two participants discussed how overcoming barriers related to STEM learning had influenced how they now see STEM. One participant shared that when they were “younger, it wasn't encouraged for females or girls in that area” and that their counselor said, “I didn't belong in that class” (EL4, D1). She went on to say “yes, I was discouraged” and “I didn't realize how much I liked engineering and math until I was older” (EL4, D1). One participant conveyed that “opportunities to delve into my own insecurities and transform that into success through combination of time and opportunity” (IE2, PS3) shaped their view of STEM education.

Job or Position. Seven participants mentioned past or current jobs or positions as factors that influenced their understanding of STEM. Four participants described how their roles as educators has shaped how they understand STEM. One participant described working “at a Christian school” where they “talk about how Jesus was on the earth, he was meeting the needs of real people” (EL1, D1) and “He moved with compassion” (EL1, PS3) connecting these ideas to how they teach STEM. Another participant stated that “becoming a STEM/Smart Lab facilitator has greatly influenced my understanding of STEM education” (EL2, PS3). Later describing that their “students get to decide their project" then they, the teacher, are “just facilitating when they get stuck, when they need to work together as a team which happens a lot" (EL2, D1). One teacher described that “classroom experiences - students’ questions and concerns” (MS2, PS3) influenced how they viewed STEM. An informal STEM educator explained that “teaching at overnight science camp” (IE3, PS3) influenced their understanding of

STEM because “it was heavy on outdoor environmental education inquiry-based learning” (IE3, D1) where “STEM is organically incorporated using nature as our classroom” (IE3, PS3). Another informal STEM educator shared that “working and playing in museums and science centers” (IE1, PS3) had shaped their conception of STEM. While another mentioned that they “started working in a company, which was global engineering” (EL4, D1) that changed how they saw STEM. The government employee shared that “my current role” and “teaching math in a more project-based way” (G, PS3) had both influenced their understanding of STEM.

STEM or STEM-Education Stakeholders. Five participants described the role other STEM or STEM-education stakeholders had on their conceptions of STEM. A middle school STEM teacher commented on how “conversations on classroom ideas; brainstorming about projects and topics of study” (MS2, PS3) with other STEM educators had influenced how they thought about STEM. An informal educator shared how working with “researchers or scientists” (IE2, D1) had impacted their understanding of STEM and the role, “outstanding mentors modeling and sharing their journey” (IE2, PS3) added to their conceptions. One participant described how “collaboration with higher-level or targeted STEM education like USNA [United States Naval Academy], NASA [National Aeronautics and National Aeronautics and Space Administration], and Smithsonian, NASEM [National Academies of Science, Engineering and Medicine]” (MS3, PS3; RM) had influenced their conceptions. Two participants discussed how “hearing from industry leaders on needs for our future employees” (MS2, PS3) or just “talking to industry partners” (G, PS3) had influenced them.

Summary

Data from PS1, PS2, and D1 provided evidence of participant conceptions of STEM before the use of a STEM explanatory model. Analysis revealed that participants’ understanding of STEM and STEM integration encompass seven themes: *Involves STEM Disciplines*, *Involves Integration of Disciplines, Leverages Inquiry-Based Learning, Supports Development of Soft Skills, Connected to Real-World, Supports Social-Emotional Learning, Drives Equity*. Data from PS3 reveals that four themes contributed to participant understandings of STEM and STEM Integration including: *Professional Development, Personal Experiences, Jobs or Positions, and STEM or STEM-Education Stakeholders*. One participant did indicate that they had "not yet" (IE4, PS3) had any experiences that influenced their understanding of STEM.

Conceptions of STEM and STEM Integration During the Use of STEM Explanatory Model

To determine participant conceptions of STEM and STEM integration during the use of a STEM explanatory model, qualitative data derived from recordings of participant conversations during Discussion 2 (D2) were used. During D2 participants were prompted to use the STEM explanatory model to come to consensus about the version of STEM or STEM integration the classroom activity they experienced represented. Additionally, researcher memos (RM) were utilized to capture relevant data that were reflected in conversations when the conversations were not being recorded and to document the table groups participants were at when D2 occurred. Participants were in four table groups during this discussion (see Table 10).

Table 10

Participants by Table Group During Discussion 2

GROUP 1	GROUP 2	GROUP 3	GROUP 4
EL1	IE1	MS2	EL4
EL2	IE2	G	IE5
MS1	IE3	EL3	
	IE4	MS3	

Pre-coding techniques including highlighting and circling significant conversations, preliminary jotting of phrases for codes exhibited in the conversations, and macro-coding

(Saldaña, 2021) large chunks of conversations were implored before first-cycle In Vivo and descriptive coding techniques were utilized to identify units of data representing participants' conceptions of STEM and STEM integration during the application of the STEM explanatory model. As units of data were identified through conversations among participants, segments of both individual participant statements and back-and-forth conversations among participants within a table group were leveraged as evidence of participants' conceptions of STEM and STEM integration. Codes identified through this process were grouped and sorted through focused coding and common themes were identified. Table 11 exhibits the three themes and corresponding code descriptions that emerged from participants' discussions during the use of a STEM explanatory that showcase their conceptions of STEM and STEM integration at the time.

Table 11

Themes and Descriptions Representing Participant Discussion During the Use of STEM Explanatory Model

THEMES	CODE DESCRIPTIONS
Levels of STEM Disciplines Exist	Participants discussed how STEM disciplines incorporated into the activity were capable of being "turned up" or "turned down" and how there were lower-levels of disciplines.
Grade-Level Evaluation is Confusing and Difficult	Participants commented on the difficulty of evaluating on-grade level science and mathematics and questioned why grade level technology and engineering were not being considered.
STEM Disciplines are Not Well-Understood	Participants made comments indicating a lack of understanding of STEM disciplines and distinguishing between math and engineering and the scientific method and engineering design.

Levels of STEM Disciplines Exist

Several participants described how levels of STEM disciplines were present in the classroom activity or in STEM activities in general. Additionally, participants indicated cognizance that STEM disciplines could be turned up. Two participants discussed this concept extensively, both of whom shared they had been introduced to the STEM explanatory model previously (MS3, D2; G, D2). One participant stated, "I think sometimes STEM activities are strong in different areas at different times. I always stress to my students if we do a science experiment, that it's STEM-science" (MS3, D2). The same participant stated that "a lot of times when we are teaching STEM lessons in class, they're going to vary on the different areas of what we're hitting on or the strength of those areas in an activity" (MS3, D2). The same participant shared that they loved "the aspiration of having everything being turned up in an ideal world, like we could have every single lesson every single day, but it's unfortunately not the reality always" and "that's why we have the different levels so that we're keeping in mind" (MS3, D2). The participant later shared that if today they did a very science heavy STEM activity, they would "need to bring in some of the mathematics and get kids engaged with that. Then maybe next week I have all turned up and it's an application of what we were doing" (MS3, D2). The other participant in the same group indicated the activity they were asked to evaluate "was a version of STEM, similar to what you [MS3] were talking about with the idea of different levels" (G, D2) and later stated that "that not every lesson is going to be all up on the ladder on the STEM grading scale or whatever they are calling that" (G, D2).

Additionally, participants across table groups provided examples of how the classroom activity they participated in could be turned up. Below is an excerpt from a conversation among participants in Group 2 where they discussed how engineering could be turned up in the activity.

EL2 – “Engineering be little e maybe. I think it was definitely there, but maybe not fully developed.”

EL1 – “I think there’s potential.”

EL2 – “If we took a step further and say, okay, design your own ramp.”

EL1 – “Yes.”

EL2 – “Something like that.”

EL1 – “If you changed your variables and changed your slope and did more, there’s potential to cover engineering.”

EL2 – “We would almost have to build a solid ramp that you could move and actually measure versus just having someone hold it and changing your up and down and left and right.”

Participants of Group 2 also discussed how math could be turned up in the activity with one participant sharing that “there could be more questions asked” (IE3, D2) and another participant responding in the affirmative and saying they thought “it had potential” (IE2, D2). A participant in Group 3 contended that “if we wanted to turn [math] all the way up, we could take a look at graphing” (G, D2) in the activity. Finally, one participant suggested “you could science the crap out of this too” (IE1, D2) to turn science up further.

All four table groups discussed how levels of technology were present in the activity or they discussed how technology could be turned up (see Table 12).

Table 12

Table Group Discussions of Technology Levels Present in the Classroom Activity

GROUP 1
EL2 – “Technology is pretty low if not absent because --- Here [reference to explanatory model] it says it’s both created and operated. I don’t think we created or operated.” MS1 – “Well if we used the phone to record slow motion, that would be technology.” EL2 – “Pretty small T operated, but not created.” MS1 – “Correct.” EL2 – “Very small t, I would say. Yes, you are right, we did use the phone.”
GROUP 2
IE1 – “Almost nonexistent T.” IE3 – “Other than the use of the phone.” IE3 – “If I didn’t use the phone, it would be underscore.” IE1 – “I thought it was the touching of technology.” IE3 – “If we didn’t use the phone, yes.”
GROUP 3
G – “I do feel like it would be very easy to add the technology, like you were saying, and it give a strong [unintelligible] to the baseline. G – “If students did use like the slow-motion camera to capture, or the parabola generator app or something like that, then maybe it would have a lowercase t, but since we didn’t use it, it was probably absent. EL3 – “Technology, if you were to use data collecting device that has different sensors on it.
GROUP 4
IE5 – “I think it was pretty low tech because you didn’t use – materials we used were average everyday materials.” IE5 – “I would say underscore on technology.” EL4 – “We did use our phones.” EL4 – “To take the picture. It wouldn’t be an underscore. I’d say a lower t.”

Grade-Level Evaluation is Confusing and Difficult

As participants utilized the STEM explanatory model, they discussed whether the classroom activity represented on-grade level science or math revealing evidence that grade-level analysis was difficult or confusing. Group 2, comprised entirely of informal STEM educators, exhibited such evidence in their dialogue below.

IE1 – “But I think we should think really closely about where we say on grade-level because you don’t say it in technology, you don’t say it in engineering, but you say it in math, and you say it in science.”

IE1 – “I don’t know why we bother to say, on grade-level. Everybody’s going to bring themselves to this, and so if it’s really engaging, you’re on grade-level.”

IE1- “But you could go beyond grade-level.”

IE2 –“But when it said on grade-level, what I heard was a standard.”

IE3 – “Standard, I think that’s what we are doing.”

IE1 – “There are engineering standards and there’s technology standards.”

IE1 – “In the description up there, it only listed on grade-level for science and math, not engineering and technology.”

IE1 – “Is that a mistake? Because if you’re saying on grade-level, it really depends on what the learner’s bringing to this, because you could math the crap out of this and you’d be on grade-level.”

IE2 – “If she were to take out that mathematical side of it and they were just measuring angles, all of a sudden, it’s not necessarily an eighth-grade and middle school lesson.”

The same table group grappled with grade-level understanding of math (see excerpt below).

IE1 – “Pretty, I guess low grade-level math, so l lowercase. Is that lowercase?

IE3 – “Yes”

IE1 – “I don't know. Maybe capital

IE3 – “I guess for eighth-grade”

The government employee provided evidence of grade-level understanding of both math and science during their table group discussion with statements like “the math, not so much. That’s a third-grade standard to measure” and “I did think it was on grade-level science standard” (G, D2). Participants in Groups 2 and 4 made comments once the audio recordings were turned off that they had not referenced the standards for mathematics and science provided to them to assist with the evaluation of the activity using the STEM explanatory model (RM). Other participants in all four table groups expressed a lack of experience teaching the grade-level math or science targeted in the lesson (RM).

STEM Disciplines are Not Well-Understood

Participants across all four table groups showed evidence that STEM disciplines were not well-understood. Confusion about what constituted engineering and whether the activity represented mathematics, science, or engineering came up in several conversations. The excerpt below comes from participant discussions in Group 1.

> EL1 – “There are applications for engineering, none that are inherent in the activity. You could add that on to your discussion in your application, the engineering components, but not in what we just did.”
>
> MS1 – “Could it be a small e because they had to use their knowledge of angle or would that be more mathematical they needed to decide the distance from the wall and the angle to get their results?”
>
> EL1 – “I think that is math.”
>
> EL2 – “I don’t know. I would say it falls into engineering. I feel liked applied math, where you’re taking math and you’re adding force and experimentation.”
>
> MS1 – “Would the change of doing different balls be classified as part of engineering to switch out the balls or would that be more science?”
>
> EL2 – “Well, I was kind of split between because the science method versus the engineering design process, pretty similar. It’s like an iterative process where you try and fail until you find your data, I guess.”
>
> EL2 – “I feel like with engineering it’s more of you creating something. We didn’t really create much. We didn’t design the system. We didn’t change anything other than running the test. We weren’t trying to create and end goal by engineering something. We were just testing existing objects.”

One participant from Group 3 stated that “science and math integration for engineering is definitely a different definition of engineering than what I was using” (MS3, D2) with another participant responding:

> I felt like the, we did do the applying scientific principles to design an object tool processor system and utilize that engineering practice. I thought it could fit and work in the actual design of the ramp and what we were doing with that could qualify potentially as engineering (G, D2).

While participants in table group 4 grappled with what constituted engineering (see excerpt below from Group 4).

L4 – “I’m on the fence with the capital and lower e. I would do it closer to a capital E”.

IE5 – “I think that engineering is the one I’m still not a 100% on”.

IE5 – “Both a body of knowledge about design and the creation of human-made products. That would include the ball and ramp, I suppose”.

EL4 – “We had to put it [the ramp]at an angle”

In a discussion regarding how science was represented, one participant in Group 4 didn’t seem to recognize that physics or physical science concepts were connected to science (see excerpt below).

EL4 – “I would say higher E and an M, a lower T, and science since it was like a ..

IE5 – “Physics.”

EL4 – “Where do you see physics, under science?”

IE5 – “It comes under - Well physics falls under science.”

EL4 – “Oh, okay.”

Summary

Data from D2 and RM gave evidence of participant conceptions of STEM during the use of a STEM explanatory model. Analysis revealed that participants' understanding of STEM and STEM integration encompass three themes during the use of the explanatory model: *Levels of STEM, Grade-Level Evaluation is Confusing and Difficult, and Understanding of STEM Disciplines is Not Well-Understood.*

Conceptions of STEM and STEM Integration After the Use of STEM Explanatory Model

To understand study participants' understanding of STEM and STEM integration after the use of a STEM explanatory model, data from post-survey questions were broken into nearly 80 meaningful units through first-cycle In Vivo and descriptive coding and entered into an Excel spreadsheet. Using focused coding, meaningful units or codes were then sorted and grouped based on commonalities seen across the units of data and assigned identifying theme names during a second-cycle coding process. Table 13 showcases five identified themes, two sub-themes and corresponding coding descriptions identified through first- and second-cycle coding processes representing participants' conceptions of STEM and STEM integration after participants were introduced to the study intervention.

Table 13

Participant Conceptions of STEM and STEM Integration After the Use of STEM Explanatory Model

THEMES		CODE DESCRIPTIONS
Involves Teaching and Learning the Disciplines of STEM		Participants mentioned one or more STEM disciplines in their responses or responded with statements about STEM disciplines. Participants described purposeful learning of the content and skills of STEM disciplines supporting strong foundational knowledge of science, technology, engineering, and mathematics.
Levels of STEM Disciplines Exist		Participants indicated that STEM education lessons or activities can include levels of STEM disciplines.
Multiple Disciplines are Involved		Participants made statements about STEM education being multidisciplinary with two or more disciplines being taught simultaneously.
Leverages Specific Instructional Approaches	Inquiry-Based Learning	Participants made statements about instruction that provided opportunities for students to engage in hands-on or discovery learning that provide students with multiple experiences to engage in problem solving, critical thinking, curiosity, questioning, and sharing their ideas with others.
	Integration and Application of STEM Disciplines	Participants described instruction that included the integration of the STEM disciplines with an understanding of how the disciplines worked together. Additionally, participants made statements about instruction that focused on students applying their learning to real-world situations.
Builds STEM Interest and Identity		Participants described STEM education as a way to spark passion and interested in STEM subjects, empower STEM thinkers and doers, and help students develop STEM identities.

The findings associated with each of the five themes and two sub-themes is presented in more detail below using the meaningful units of data utilized to identify and describe each theme. The five themes and two sub-themes represent the array of conceptions of STEM and

STEM integration participants held after their exposure and use of the STEM Explanatory Model. Codes from post-survey Question 1 (POS1: What is your understanding or conception of STEM education?) and post-survey Question 2 (POS2: What do you see as the most important ideas, sub-ideas, or skills for STEM education?) are presented in the results associated with each of the identified themes and sub-themes below.

Involves Teaching and Learning the Disciplines of STEM

Ten of the 13 participants described STEM education as involving the teaching and learning of the STEM disciplines when asked about their understanding of STEM education. One participant shared that "STEM education features the individual STEM subject-areas" (G, POS1). While another said it gives students the opportunity to experience all four subject areas which they described as "S.cience, T.echnology, E.engineering, and M.math" (EL1, POS1). One participant asserted that STEM education is "the purposeful learning, operation, and creating of science, technology, engineering, and math" (EL2, POS1). While another shared that it "allows the participants to experience STEM content and concepts" (IE2, POS1). A middle school STEM educator described STEM education as broad "with intentions of strengthening content knowledge" (MS2, POS1) in STEM.

Levels of STEM Disciplines Exist

Six of the participants' responses included phrases indicating that they believed levels of STEM could exist in STEM education. One participant stated that STEM education "allows the participants to experience STEM content and concepts at a variety of grade-levels" (IE2, POS2). Another described a STEM activity as "an activity that utilizes components of STEM at some level" (IE5, POS2). While another participant shared that "STEM isn't measured by equal components of science, tech, engineering and math" and "some subjects will be heavier than others" (EL3, POS1). Two participants shared how the STEM explanatory model helped them understand that STEM education might include levels of STEM. One participant stated that "the STEM explanatory model provides more clear, cohesive understanding of how STEM is used in education and "it provides a soundboard vision of meeting standards" (EL4, POS1). Another participant said they "really like the 'soundboard' description of utilizing all letters of STEM to adjust the levels at which each topic is utilized" (IE3, POS1).

Multiple Disciplines are Involved in STEM Education

Six study participants included descriptions of STEM education in post-survey responses indicating that STEM involves multiple disciplines. One participant stated that "STEM education is a multidisciplinary endeavor" (IE2, POS1). Another said, "that STEM gives students the chance to learn using multiple disciplines simultaneously" (EL3, POS1). An informal STEM educator shared that "STEM is an incorporative way to teach multi-faceted lessons" (IE3, POS1). While another described STEM education as a way "that they [STEM disciplines] all can be put together" (IE4, POS1). A middle school STEM teacher suggested that "STEM education should strive to incorporate as many areas of S-T-E-M" (MS3, POS1) as possible. One participant claimed that "a great lesson will have what is needed for that lesson, so two of the four or three of the four [STEM disciplines]" (MS1, POS1).

Leverages Specific Instructional Approaches

Participant responses to post-survey Questions 1 and 2 exhibited units of data corresponding with a theme that STEM education *Leverages Specific Instructional Approaches.* Two sub-themes emerged from the data associated with this theme, *Inquiry-Based Learning* and *Integration and Application of STEM.* The results associated with both sub-themes are presented below.

Inquiry-Based Learning. Eight participants included descriptions associated with inquiry-based learning in their responses to post-survey questions. One participant stated that STEM education “allows the participants to experience STEM content and concepts” (IE2, POS1) and listed sub-ideas that included students engaging in “collaboration, interaction, experience, experiential learning, sharing, reasoning, observation, and re-examining of notions or ideas” (IE2, POS2). Another participant echoed these sentiments by suggesting that the most important ideas, sub-ideas, or skills for STEM are “opportunities to learn S-T-E-M in a hands-on, intentional way” that include “learning from peers”, “collaboration”, and “opportunities to problem-solve” (MS3, POS2). An informal STEM educator stated that the most important ideas were “inquiry-based learning” and “scientific discovery of different topics” (IE3, POS2). Another study participant stated that their understanding of STEM education included “giving hands-on opportunity for students to explore the world and experience” (EL1, POS1) science, technology, engineering, and mathematics. This participant also listed several terms and phrases often associated with inquiry-based instruction as the most important skills for STEM including “curiosity”, “critical-thinking”, “innovation”, “communication”, and “collaboration” (EL1, POS2).

Integration and Application of STEM Disciplines. Four participants described features of STEM education that included integration and/or application of the STEM disciplines. One participant said that “STEM education features the individual STEM subject-areas, integration of these subject areas, and application of those subject areas” (G, POS1). The participant went on to describe the importance of students engaging in instruction focused on integration of STEM disciplines by stating that students learn “how science, tech, engineering and math work together” (G, POS2). A middle school STEM teacher described how important it is that STEM instruction include “problem-solving continuing with the lesson applying what you know with what you have learned” (MS1, POS2). Another middle school STEM educator shared that “STEM education should strive to incorporate as many areas of S-T-E-M as possible in multiple experiences for students” with “integration and connections to real-world experiences” (MS3, POS1) as key. One participant suggested that “multi-faceted lessons” for STEM are used as a way “that they all [STEM disciplines] can be put together to help everyone learn from different points of view or understanding” (IE4, POS1).

Builds STEM Interest and Identity

Three participants described STEM education as a mechanism to build student interest in STEM and/or as way to support student identity in STEM. One participant who focused on STEM education as a means to builds interest in STEM suggested STEM education should be taught “with intentions of strengthening content knowledge, sparking passion in STEM fields” and “creating and building tomorrow's leaders” (MS2, POS1) further elaborating that STEM education should support students in “understanding future STEM careers” (MS2, POS2). Two participants focused on STEM education as a way to develop student identity in STEM with one stating that STEM education is an endeavor that empowers “STEM thinkers and doers” (IE2, POS1). While another stated that a central idea of STEM education is to develop “students’ identity as STEM people” (G, POS2).

Influences of Perceptions of STEM and STEM Integration

The post-survey provided participants with an opportunity to reflect, for a second time during the workshop, on factors that might have influenced their conceptions of STEM. Data from post-survey Question 3 (POS3: What experiences have influenced your understanding of STEM?) were analyzed through first-cycle In Vivo coding and focused second-cycle coding.

Patterns of data revealed the *STEM Explanatory Model* to be an emergent theme suggesting it influenced study participant perceptions of STEM and STEM integration. This theme did not appear as a significant pattern or theme in pre-survey Question 3. One participant said they did also learn about STEM from “the STEM explanatory model from this PD” (EL2, POS3). While another participant said their understanding of STEM had been shaped by “great PD [professional development] presented by [the regional STEM center] like the STEM Soundboard” (MS1, POS3). Another participant said that “taking this class has given me a better understanding of STEM” (IE4, POS3) and another stated that “workshop made the STEM clarification” (EL4, POS3). The government employee said that “the STEM framework and teaching experience have influenced me the most” (G, POS3). While one participant shared that “the STEM explanatory model reframed my perception from STEM consisting of any one component to including components, although not at equal levels” (IE5, POS3).

Summary

Data from POS1, POS2, and POS3 gave evidence of participant conceptions of STEM after the use of a STEM explanatory model. Analysis revealed that participants’ understanding of STEM and STEM integration encompass five themes and two sub-themes after the use of the explanatory model: *Involves Teaching and Learning the Disciplines of STEM*, *Levels of STEM Exist*, *Multiple Disciplines are Involved*, *Builds STEM Interests and Identity*, and *Leverages Specific Instructional Approaches* which include two sub-themes: *Inquiry-Based Learning and Integration and Application of STEM Disciplines.* Additionally, analysis of post-survey data revealed participants viewed the *STEM Explanatory Model* as influential to their understanding of STEM.

Components of STEM and Forms of STEM Integration

To answer RQ2 data sources (open-ended pre- and post-surveys, participant discussions, and researcher memos) were combined and analyzed using opening coding (Merriam, 2009) to generate emergent themes (Merriam, 2009) relevant to the research question. Additionally, data sources were triangulated to better establish validity and confidence in the identified themes (Creswell & Poth, 2018; Schwandt, 2015). Table 14 showcases a roadmap of data sources utilized to address RQ2 and determine STEM education stakeholders' ability to identify STEM components and forms of STEM integration in a lesson or classroom activity before, during, and after the use of a STEM explanatory model.

Table 14

Roadmap for Analyzing Data for Research Question 2

DATA SOURCES	PARTS OF RESEARCH QUESTION 2		
	How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson **before** the use of a STEM explanatory model?	How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson **during** the use of a STEM explanatory model?	How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson **after** the use of a STEM explanatory model?
Pre-Survey Questions	x		
Discussion 2		x	x
Post-Survey Questions			x
Researcher Memos	x	x	

Each of the data sources were analyzed to identify themes related to participant abilities to identify components of STEM and various forms of integration represented in a lesson or classroom activity before, during, and after the use of a STEM explanatory model. Through open-coding and constant comparative methods (Creswell & Poth, 2018; Merriam, 2009) emergent themes that represent patterns or regular occurrences of participants' responses to questions regarding their ability to identify components of STEM and forms of STEM integration within a lesson or classroom activity before, during, and after use of the STEM Explanatory Model were identified and described. Themes were identified through an inductive first-cycle coding process (Saldaña, 2021). Phrases or words were coded directly from participant responses to open-ended survey questions and recordings of participant discussions through In Vivo coding or descriptive coding techniques (Saldaña, 2021). Second-cycle coding analysis was then utilized to synthesize the codes and identify emergent themes from data sources (Saldaña, 2021). Additionally, evidence from audio recordings of participant discussions regarding their responses to survey questions were triangulated with written responses to corroborate evidence and establish confidence in the themes identified (Creswell & Poth, 2018) as well as to better leverage the direct voices of participants for the study (Yin, 2011).

Components of STEM and Forms of STEM Integration Before the Use of STEM Explanatory Model

Data from pre-survey questions were broken into over 80 meaningful units through first-cycle In Vivo and descriptive coding and entered into an Excel spreadsheet to showcase participants' conceptions of STEM and STEM integration before the use of a STEM explanatory model. Using focused coding, meaningful units or codes were then sorted and grouped based on commonalities seen across the units of data and assigned identifying theme names during a second-cycle coding process. Table 15 showcases the three identified themes, two sub-themes, corresponding coding descriptions, and some of the codes representing participants'abilities to identify components of STEM and various forms of integration in a classroom activity before the use of the STEM Explanatory Model.

Table 15

Participant Identification of Components of STEM and Integration Before the Use of STEM Explanatory Model

THEMES		CODE DESCRIPTIONS	CODES
STEM Disciplines, Topics, Processes		Participants listed STEM disciplines, topics, and processes.	"Science" "Technology" "Engineering" "Math" "Physics" "Newton's Law" "Measurement" "Velocity" "Mass" "Problem-solving" "Reasoning" "Critical-thinking"
Experimentation, Design, and Application		Participants made statements about the classroom activity involving an experiment and/or including engineering design and/or application.	"Application" "Experimentation" "Iterative development" "Collect our evidence" "Design of experiment" "Real-world application"
Levels of STEM	Full or Incomplete STEM	Participants described the classroom activity as fully, mostly, or not fully STEM.	"Full STEM" "Not full STEM" "Most of a STEM"
	Levels of STEM Disciplines	Participants made statements about STEM disciplines in terms of levels of presence.	"Heavy on science" "Some math" "Lacking strong" [specific STEM discipline]

The findings associated with each of the three themes and two sub-themes are presented in more detail below using the meaningful units of data utilized to identify and describe each theme. The three themes and two sub-themes represent the array of conceptions of STEM components and forms of STEM integration participants held after engaging in a classroom activity and before their exposure and use of the STEM Explanatory Model. Codes from pre-survey Question 4 (PS4: Does the activity represent a STEM activity? Explain your reasoning) and pre-survey Question 5 (PS5: Describe what disciplines of STEM were addressed in the activity) are presented in the results associated with each of the identified themes and sub-themes below.

STEM Disciplines, Topics, and Processes

One pattern that emerged in study participant responses to PS4 and PS5 reflecting their understanding of the components of STEM or forms of STEM integration present in a classroom activity was *STEM Disciplines, Topics, and Processes*. Ten of the study participants indicated that the classroom activity they experienced represented a STEM activity. The remaining three participants shared that the activity represented a version of STEM that was “not strong” or “not fully turned up”. Table 16 showcases the codes utilized by participants to justify their claims about the classroom activity and the disciplines of STEM believed to be addressed through the activity and used to identify the theme *STEM Disciplines, Topics, and Processes.*

Table 16

Participant Descriptions of the Classroom Activity Prior to Exposure to a STEM Explanatory Model

PARTICIPANT	STEM ACTIVITY Yes/No	STEM DISCIPLINES IDENTIFIED	STEM TOPICS AND PROCESSES IDENTIFIED
EL1	Yes	Science Tech [if device used] Engineering Math	Physics
EL2	Yes	Science Engineering Math	Newton's Theories Experimentation Iterative development process and problem-solving Find best method to collect data
MS1	Yes	Science Engineering Math	Gravity and Newton's Laws Timing and measurement
IE1	Yes	Engineering Technology	Physics Investigation Measurement and mathematical collection or results
IE2	Yes	Science Technology Engineering Math	Newton's Laws History of Science Observation Link to current tech Design of experiment Reasoning Measurement
IE3	Yes	Science Technology [as a tool]	

		Math Art	
IE4	Yes	Science Technology Engineering Math Art	
MS2	No to strong activity	Science Math S_em	Forces and motion Experiment Measurement Reasoning
G	It is STEM, but not fully turned up	S_Em	
EL3	Most of a STEM activity but not all	Science Math[some]	
MS3	Yes	None Identified	Design experiment Data collection Reasoning Problem-Solving
EL4	Yes	Science Technology Engineering Math	Newton's Law Measure
IE5	Yes	Science Math	Physics Mass Friction

Experimentation, Design, and Application

Eight participants described some aspect of experimentation, design, or application as justification for claiming the classroom activity represented a STEM activity or some version of a STEM activity. One participant suggested it represented a STEM activity "because it is allowing students to explore a question that is being posed and they are allowed to design their own test to gather data for their reasoning" (MS3, PS4). While another suggested "it allows for an investigation of Physics, some engineering, and a mathematical collection of results" (IE1, PS4) corresponding with another participant's justification that "the experiment involved science, Newton's Law" (EL4, PS4). Another participant simply stated, "multiple tests are needed" (MS1, PS4) as a reason for their claim. One informal STEM educator suggested that the "application of scientific understanding to observation" and "engineering the design of the experiment and translating understanding and reasoning" (IE2, PS4) were both reasons to classify the activity as a STEM activity.

Levels of STEM

Participant responses to pre-survey Questions 4 and 5 exhibited units of data corresponding with the theme that *Levels of STEM* exist within the classroom activity. From this theme two sub-themes emerged: *Full, Weak, or Incomplete STEM* and *Levels of STEM Disciplines.* The results associated with both sub-themes are presented below.

Full, Weak, or Incomplete STEM. One participant said, "Yes. It covers STEM strongly with a weak area in tech, unless videos were used, making it a full STEM" (MS1, PS4). Another participant indicated it was possibly a STEM activity, but "no to a strong STEM activity" (MS2, PS4). One participant stated, "it is STEM, but not fully 'turned up' STEM" (G, PS4). While another said, "this activity represents most of a STEM activity, but not all" (EL3, PS4).

Levels of STEM Disciplines. Three participants suggested that levels of STEM disciplines were present in the activity. One participant suggested the classroom activity was "heavy on science and some math" (EL3, PS5) while another said it was "lacking strong technology, math, and engineering concepts" (MS2, PS4). Two participants who had been exposed to the STEM explanatory model (RM) in previous settings described the classroom activity using capital and lower-case letters to indicate that levels of disciplines were present. A middle school teachers described the activity as “S_em” (MS2, PS4) and the government official described it as “S_Em” (G, PS4).

Summary

Data from PS4 and PS5 provided evidence of participant conceptions of STEM components and forms of integration present in a classroom activity prior to exposure to a STEM explanatory model. Analysis revealed that participants’ understanding of STEM components and forms of integration present in the classroom activity include three themes: *STEM Disciplines, Topics and Processes; Experimentation, Design, and Application;* and *Levels of STEM* with two sub-themes: *Full or Incomplete STEM* and *Levels of STEM Disciplines.*

Components of STEM and Forms of STEM Integration During the Use of STEM Explanatory Model

To determine participant conceptions of the components that comprise STEM and forms of STEM integration during the use of a STEM explanatory model, qualitative data from participant conversation during D2 were utilized and broken into over 20 meaningful units through first-cycle In Vivo coding and descriptive coding. Identified codes were entered into an Excel spreadsheet. Using focused coding, meaningful units or codes were then sorted and grouped based on commonalities seen across the units of data and assigned identifying theme names during a second-cycle coding process (see Table 17). The themes and codes represent participants’conceptions of components of STEM and various forms of integration present in the classroom activity during the use of the STEM explanatory model.

Table 17

Participant Identification of Components of STEM and Forms of STEM Integration During the Use of STEM Explanatory Model

THEMES	CODE DESCRIPTIONS
Strong Science Includes Science Content, Experimentation, and Grade-Level Emphasis	Participants listed content topics like “Newton’s Law”, “Forces and Motion”, and “Physics” in responses in addition to codes associated with scientific experimentation. Participants also described their evaluation of the lesson in terms of grade-level science.
Use of Technology Represents Lowercase Technology	Participants described technology as representing “lowercase t” or slightly incorporated if it was “only used” or “operated”.
Engineering Includes Design and Connections to Science or Math	Participants described engineering in terms of activity engagement in the “design process”. Additionally, participants made comments about the activity including connections to science or math as descriptors for engineering.
Math Evaluation is Based on Grade-Level Emphasis	Participants utilized the phrase “grade-level” in their evaluation of the activity and whether it represented lowercase, uppercase, or the absence of mathematics.
Integration of STEM Disciplines Vary in Lessons	Participants described STEM activities as “varying” in the levels of STEM disciplines that might be present.

The findings associated with each of the five themes are presented in more detail below using the meaningful units of data utilized to identify and describe each theme. The five themes represent conceptions of the STEM components and forms of STEM integration participants held during (D2) the use of the STEM Explanatory Model to reach consensus about the version of STEM or STEM integration the classroom activity they experienced represented. Codes from D2 are presented in the results associated with each of the identified themes and sub-themes below.

Strong Science Includes Science Content, Experimentation, and Grade-Level Emphasis

When describing science as a component of STEM identified in the classroom activity, participants described the significance of science content, experimentation, and grade-level priority. One participant said, “I think it’s high [in reference to science] because we covered Newton’s Laws and physics” (MS1, D2). Another participant in the same table group followed with the statement that “we definitely did the scientific method and hypothesis” (EL2, D2). One participant didn’t feel science was represented in a strong way claiming they “did think it wasn’t on grade-level science standard” (G, D2). Another participant disagreed stating “I believe the science standards were being met and it did provide the opportunity for students to create their own experiment” (MS3, D2). In both cases grade-level emphasis was mentioned.

Use of Technology Represents Lowercase Technology

As study participants discussed how technology might be represented in the activity, they consistently expressed the theme of *Use of Technology Represents Lower Technology*. One participant shared that “technology is pretty low if not absent [in the activity] – I don’t think we created or operated” and went on to clarify that it was a “pretty small t, operated, but not created” (EL2, D2). These sentiments were echoed by another participant who suggested the activity represented “almost nonexistent T” (IE1, D2). A fellow participant sitting at the same table said, “other than the use of the phone” and “if we didn’t use the phone, it would be underscore” (IE3, D2). Another participant at a different table suggested “since we didn’t use it [technology] it was probably absent” (G, D2). While another participant also suggested that “we did use our phones to take the picture” so “it would be an underscore or I’d say a lower t” (EL4, D2).

Engineering Includes Design and Connections to Science or Math

Discussions surrounding engineering as a component of STEM suggested participant believed *Engineering Includes Design and Connections to Science or Math*. One participant explained that “for me it was a capital E because engineering knowledge and design are present, and science and mathematics concepts are utilized” clarifying that “we had to use our knowledge of how to design it, and then also the actual design of it” (IE2, D2). Another participant said, “I feel like we did do the applying scientific principles to design an object, tool, processor system and utilize the engineering practice” but suggested “if we wanted to turn it up, we could maybe look at graphing” (G, D2) proposing a pathway for connecting engineering with math in the activity. Another participant attempted to describe how they felt engineering, math, and science should be connected by sharing “I would say it falls into engineering like applied math, where you’re taking math and you’re adding force and experimentation” (EL2, D2). One participant claimed that engineering was present as a component of STEM in the activity because engineering is “both a body of knowledge about design and creating human-made products” (IE5, D2) indicating they felt the activity encompassed this definition. One participant suggested the activity did not meet their standards for engineering because it did not include design as a process stating “I feel like with engineering it’s more of you creating something. We didn’t really create much. We didn’t design the system” (EL2, D2).

Math Evaluation is Based on Grade-Level Emphasis

Participants focused on grade-level math as part of their evaluation of the activity and whether math was a component of STEM present in the activity. One participant questioned the grade-level mathematics represented and its connection to a capital or lowercase letter associated with the STEM Explanatory Model stating, “I guess [the activity is] low grade-math, so lowercase [m] is the that lowercase?" (IE1, D2). Another stated "I feel like mathematics is lowercase m because I didn't feel like it meant all of that [in reference to] mathematics content and practices are equally present and on grade-level" (IE2, D2). Another participant at the same table chimed in sharing that the activity "should be looking more at some of those other concepts [in reference to grade-level standards for mathematics]" and pointing out that "there wasn't the geometry usage or any of those things [associated with grade-level standards], so most certainly we'll be using a practicing skill" (IE2, D2) from a lower grade-level. Another participant in a different table group suggested that "the math, [was] not so much [present]" and that the lesson represented "a third-grade standard do to measure" (G, D2). The same participant indicated that the grade-level focus could be higher because "there's scatter plots in eighth grade, we could incorporate scatter plots" (G, D2). A participant at another table suggested the activity might represent a higher-level math because "they had to do the measuring" (EL4, D2). Another participant at the table responded, "it would be low count [in reference to lowercase m]" (IE5, D2).

Integration of STEM Disciplines Vary in Lessons

As study participants described forms of STEM integration in then evaluation of the classroom activity utilizing the STEM Explanatory Model, they indicated that lessons could vary in their composition of the STEM disciplines and reflect varying levels of the STEM disciplines. One discussion among participants in Group 3 reflected this theme (see excerpt below).

> MS3 - "I think sometimes STEM activities are strong in different areas at different times. I always stress to my students if we do a science experiment, that it's STEM science".

MS3 - “I think a lot of times when we are teaching STEM lessons in class, they’re going to vary on the different areas we areas of what we’re hitting on or the strength of those areas and activities.

G - “I did say it was a version of STEM [in reference to the activity], similar to what you were talking about with the idea of different levels”.

G - “It’s also a very strong lesson. I agree with you that not every lesson is going to be all up on the ladder on the STEM grading scale or whatever they are calling that.”

MS3 - “I love the aspiration of having everything being turned up in an ideal world, like we could have every single lesson every single day, but it’s unfortunately not the reality always. That’s why we have the different levels so that we’re keeping in mind.”

MS3 - “Oh, yes. Today I did a very science heavy STEM activity, so I need to bring in some of the mathematics and get kids engaged with that. Then maybe next week I have all turned up and it’s an application of what we were doing”.

IE1 - “You could science the crap out of this too, and that’s where I got really excited”.

Group 3 went on to discuss how the activity they participated in during the workshop reflected the idea that a STEM activity can have varying STEM disciplines and levels of those disciplines (see excerpt below).

MS2 - “I put that it could be a possible STEM activity, but it was not strong STEM activity. It was lacking strong technology, math, and engineering concepts.”

EL3 - “I think it does not represent and actual STEM activity.”

EL3 – “It did include science and it did have some math, but it did not include the technology or the engineering.”

MS3 – “I think it did represent a STEM activity because even though it wasn't strong in engineering piece, I believe the science standards were being met and it did provide the opportunity for students to create their own experiment and using the math trials and collecting the data and analyzing the data to come up with their claims and reasoning.”

Summary

Data from D2 provided evidence of participant conceptions of STEM components and forms of integration present in a classroom activity as they utilized the STEM Explanatory Model. Analysis revealed that participants’ understanding of STEM components and forms of STEM integration present in the classroom activity include five themes: *Strong Science Includes Science Content, Experimentation, and Grade-Level Emphasis; Use of Technology Represents Lowercase Technology; Engineering Includes Design, and Connections to Math and Science; Math Evaluation is Based on Grade-Level Emphasis; and Integration of STEM Disciplines Vary in Lessons.*

Components of STEM and Forms of STEM Integration After the Use of STEM Explanatory Model

To determine participant conceptions of components of STEM and forms of STEM integration after the use of a STEM explanatory model, data from post-survey questions were broken into over 60 meaningful units through first-cycle In Vivo coding and descriptive coding. Identified codes were entered into an Excel spreadsheet. Using focused coding, meaningful units or codes were then sorted and grouped based on commonalities seen across the units of data and assigned identifying theme names during a second-cycle coding process. Table 18 showcases the identified themes, corresponding coding descriptions, and some of the codes identified through first- and second-cycle coding processes. The themes and codes represent participants'conceptions of components of STEM and various forms of integration present in the classroom activity and after the use of the STEM Explanatory Model.

Table 18

Participant Identification of Components of STEM and Forms of STEM Integration After the Use of STEM Explanatory Model

THEMES	CODE DESCRIPTIONS
STEM Disciplines, Topics, Processes	Participants listed individual STEM disciplines, topics, and processes when describing components of STEM and forms of STEM integration.
Involves Integration of Disciplines	Participants made statements about the activity "requiring several STEM areas" or the "use of each letter" in STEM when describing components of STEM or forms of STEM integration.
Grade-Level Emphasis	Participants referenced the phrases "grade-level" and "elementary" when describing the components of STEM or forms of STEM integration present in the classroom activity.
Levels of STEM Disciplines	Participants made statements about STEM disciplines in terms of levels of presence in the classroom activity with the potential for some disciplines to be "turned up".

The findings associated with each of the themes are presented in more detail below using the meaningful units of data utilized to identify and describe each theme. The four themes represent the array of conceptions of STEM components and forms of STEM integration participants held after engaging in a classroom activity and after their exposure and use of a STEM explanatory model. Codes from post-survey question 4 (POS4: Does the activity represent a STEM activity? Explain your reasoning), post-survey question 5 (POS5: Describe what disciplines of STEM were addressed in the activity) and D2 are presented in the results associated with each of the identified themes below.

Table 19 showcases participant conceptions of the components of STEM and forms of STEM integration present in the classroom activity after exposure to the STEM explanatory model and if they believed the activity represented a STEM activity. Twelve of the 13 study participants believed the activity represented a STEM activity with two participants indicating it was a “version of STEM” (MS2, POS4) or “not a strong” (G, PSO4) representation of STEM. One participant stated the activity would represent STEM “only if the phone was used” (IE5, PSO4) to collect data during the investigation.

Table 19

Participant Descriptions of the Classroom Activity After Exposure to a STEM Explanatory Model

PARTICIPANT	STEM ACTIVITY Yes/No	STEM DISCIPLINES IDENTIFIED	STEM TOPICS AND PROCESSES
EL1	Yes	Stem	S- doing science t- little use" e- not inherent m- lower level
EL2	Yes	Stem	S- scientific method t- not used much e- slightly used" m- not high level
MS1	Yes	S_em	S- heavy _ - not vital e- small amounts m- small amounts
IE1	Yes	Stem	
IE2	Yes	Science Technology Engineering Math	Newton's Laws Use of phone Design experiment Measuring
IE3	Yes	Science Technology Engineering Math	Newton's Law, Experimental process Use of phone Experimental design Illustrations Measurement/graphs
IE4	Yes	Science Engineering Math	
MS2	Yes [not strong]	S_em	Forces and motion Creating/designing experiment

			Measurement
G	Yes [version]	S_em	S-on grade-level e- engineering knowledge m-elementary math measurement
EL3	Yes	Science Engineering Math	
MS3	Yes	Science Engineering Math	
EL4	Yes	S_eM	S- content and practices equally grade-level _-created and operated e-knowledge design math and science utilized
IE5	[only if phone used]	Science Technology Engineering Math	Physics Phone and slow-mo Creating varying models Distance, velocity, speed

STEM Disciplines, Topics, and Processes

Participant responses to PS4 and PS5 showcased regular attributes regarding their understanding of the components of STEM or forms of STEM integration present in the classroom activity. These attributes were consistent with the theme of *STEM Disciplines, Topics, and Processes*. All 13 participants conveyed in their responses that the STEM disciplines of science, engineering, and mathematics were presented in the activity. Six of the participants indicated that the discipline of technology was absent with one stating technology was present “only if phone used” (IE5, POS4). Four participants called out specific topics associated with STEM disciplines they felt were present in the classroom activity with two stating the activity included a focus on “Newton’s Law” (IE2, POS5; IE3, POS5) and one referenced the concepts of “forces and motion” (MS2, POS5) as part of their explanation for the disciplines of STEM addressed in the activity. One participant responded that the activity included “physics” and stated that “distance, velocity, speed” (IE5, POS5) were also addressed. Two participants stated that the math concept of “measurement” was involved (IE3, POS5; MS2, POS5). Six participants included STEM processes or practices as part of their responses to POS4 and POS5. One participant said students were “doing science” (EL1, POS5). While others shared that because “multiple tests are needed” (MS1, POS4), the activity included the “scientific method” (EL2, POS5), or because participants were engaged in “designing an experiment” (IE2, POS5; MS2, POS5), the activity represented a STEM activity. One of these participants stated engaging in process of “illustration” and “graphs” (IE2, POS5) reflected that the activity was indeed a STEM activity. Another participant said that the act of “creating varying models” (IE5, POS5) as a process represented STEM. One participant justified that the classroom activity represented a STEM activity because it included STEM topics or processes associated with each of the STEM disciplines:

> Science - Physics
> Tech -Phone and slow-mo
> Engineering - creating varying models to drop ball from
> Math -- distance, velocity, speed (IE5, POS5).

Involves Integration of Disciplines

Participants also indicated, with some form of regularity in their responses to POS4 and POS5, that STEM involves the integration of disciplines. One participant shared that “Yes” the classroom activity they experienced was a STEM activity because “it requires several STEM areas” (EL2, POS4). Another participant justified that the activity was a STEM activity because “we were able to use each letter in STEM” (IE3, POS4) corresponding with another participant’s claim that it was a STEM activity “because it hits almost all of the components of STEM” (MS3, POS4). One participant claimed it was “approaching complete integration but generating an appreciation for sure” (G, POS4). While another participant indicated that they “could see areas to apply technology” (MS3, POS5) in order to include all four disciplines of STEM in the activity. One participant claimed that the activity included engineering because “science and math [were] utilized” alongside “knowledge design” (EL4, POS5).

Grade-Level Emphasis

Several participants referenced grade-level attributes of STEM disciplines, explicitly or inexplicitly, when describing whether the activity was a STEM activity or not. One participant suggested that “while the science content was age-appropriate, the math was not” (MS2, POS4). This statement corresponded with three other participants who shared that the activity was “not high-level math” (EL3, POS4) or that the activity represented “on-grade level science” and “elementary math” (G, POS5). Another participant stated that the activity contained both math “content/practices” but “not on grade level” (IE2, POS4). The government employee went on to explain that “for fully ‘tuned up' version of STEM, on grade-level math and purposeful computer science should be included” (G, POS4). One participant justified their claim that the classroom activity represented STEM by stating that it included “content or practices and equally grade-level” (EL4, POS5).

Levels of STEM Disciplines

Study participants utilized descriptions and phrases indicating they believed STEM disciplines were present in varying degrees or levels in the classroom activity. Some participants reflected on each of the STEM disciplines in terms of how much or little the disciplines were present in the activity. Participant EL1 described each discipline as follows in response to post-survey question 4:

> S- kids are doing science, not just reading about it
>
> t - little use of tech
>
> e - opportunity for deeper experiences with engineering but not inherently built in
>
> m - lower level unless more depth encouraged, more trials and changing variables (POS4).

Participant EL3 shared that the activity represented “heavy science content” (POS4) explaining that “science and scientific method were used heavily” and that “we tested, experimented, and reevaluated several times” (POS5) throughout the activity. In describing technology, participant EL3 shared that there was “no technology (according to my definition of technology)” (POS4) later stating that “tech was not used much” because “we did use cell phone to record” (POS5). For engineering the participant stated that “some engineering [was] used” (POS4) clarifying that it was “slightly used but wasn’t the focus” (POS5). When describing the presence of math in the activity participant EL3 explained that it was “low math” (POS4) and that “math was used and needed to verify our theory, but not high-level math” (POS5). Another participant suggested that “some groups used the phone for tech, but it was not a vital part of the lesson” (MS1, POS5). However, the participant said the activity was “heavy on science” with “small amounts of eng[ineering] and math” (MS1, POS5). A middle school educator indicated that “the engineering and technology integration needed to be intentional, direct” (MS2, POS4) suggesting that there were levels of representation of the two disciplines in the activity. Two participants referenced the word “levels” explicitly when describing if the activity represented a

STEM activity and the STEM disciplines that were addressed. One of the participants said that the activity "allows for opportunity to increase learning levels in each area [STEM discipline] (MS3, POS4). Another stated that STEM "topics were made to be adjustable for grade-level audiences" (IE3, POS4).

Each of the participants in the study described the activity in terms of capital, lower-case, or the absence of letters in the STEM discipline (see Table 15) in reference to the level of science, technology, engineering, or mathematics present in the activity. Some participants utilized direct language from the STEM Explanatory Model in post-survey responses and D2. One example came from participant IE2's response to post-survey Question 4:

- The science and content practices equally represented
- Technology was used but not represented
- Engineering knowledge/design present
- Math-while content /practices- on grade-level

Another participant utilized direct language from the STEM Explanatory Model sharing: that the activity represented science "content and practices and equally grade-level"; that technology was both" created and operated with purpose"; and engineering was present because "knowledge design, science and math [were] utilized" (EL4, POS5). One participant described the lesson in terms of STEM disciplinary levels by sharing that the activity was "S.t.e.m. with lots of potential" (IE1, POS5).

Summary

Data from POS4, POS5, and D2 provided evidence of participant conceptions of STEM components and forms of STEM integration present in a classroom activity after exposure to a STEM explanatory model. Analysis revealed that participants' understanding of STEM components and integration present in the classroom activity included four themes: *STEM Disciplines, Topics and Processes; Involves Integration of Disciplines, Grade-Level Emphasis,* and *Levels of STEM Disciplines.*

Conclusion

This chapter provided an analysis of the results of responses to pre-and post-survey questions and two small group discussions designed to answer RQ1) How do STEM-education stakeholders describe their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model? and RQ2) How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration before, during, and after the use of a STEM explanatory model? To answer RQ1, pre-and post-survey Questions 1 and 2 and Discussion 1 were designed to elicit participants' conceptions of STEM and STEM integration before, during, and after the use of the study intervention. Seven emergent themes representing participants conceptions of STEM and STEM integration were identified before they were exposed to the STEM Explanatory Model, three emergent themes were identified while participants utilized the STEM Explanatory Model, and five emergent themes, and two sub-themes were identified after participants were exposed to the explanatory model.

Additionally, this chapter provided an analysis of pre-and post-survey Questions 4 and 5 and Discussion 2 designed to elicit participants' understanding of components of STEM and forms of STEM integration before, during, and after the use of the study intervention to answer RQ2. Three emergent themes and two sub-themes were identified representing participant understanding of STEM components and forms of integration before participants were exposed to the STEM Explanatory Model, five emergent themes were identified during use of the explanatory model, and four emergent themes were identified after participants were exposed to the STEM Explanatory Model.

The study also aimed to understand participant background experiences that may have influenced their conceptions of STEM and STEM integration through pre-and post-survey Question 3 and D2. The emergent themes identified before participants were exposed to the STEM explanatory model included: *Professional Development, Personal Experiences, Job or Position, and STEM or STEM-education Stockholders*. After participants were exposed to the STEM Explanatory Model, the explanatory model emerged as a theme that influenced their conceptions of STEM and STEM integration.

The next chapter discusses researcher interpretations of the data presented in this chapter and resulting implications. Limitations and strengths of the study are also discussed as well as possible avenues for future research and proposed modifications to the explanatory model based on the results of this study. Final conclusions regarding the role of a STEM explanatory model as a tool for school leaders, instructional coaches, professional development providers, teachers, informal STEM educators, and community members to achieve a common vision for STEM education are explored.

Chapter 5: Discussion, Implications, and Conclusion

This study aimed to determine if STEM-education stakeholders' conceptions of STEM and STEM integration shifted after the use of a STEM explanatory model. The findings of the study show that STEM-education stakeholders did experience shifts in their conceptions of STEM and STEM integration after the use of a STEM explanatory model. Findings also indicated that STEM-education stakeholders hold on to some conceptions possessed prior to exposure to an explanatory model and that stakeholders' comprehension of the STEM disciplines, the knowledge and skills associated with them, and grade-level expectations were not well-understood.

This chapter will include a summary of the methods and data collection approaches utilized in the study, followed by an overview of the major findings. There will be a discussion of the interpretations of the data as compared to the literature review from Chapters 1 and 2 and research questions. Conclusions will be drawn that relate directly to the research questions, significance of the study, and their implications for STEM education. Study limitations will be addressed and recommendations for future research and practice will be presented.

Methods and Procedures

The study employed qualitative methods to analyze study participant responses to pre- and post- survey questions and corresponding discussions designed to elicit their understandings of STEM, STEM integration, components of STEM, and forms of STEM integration before, during, and after the use of an explanatory model for STEM. The participants for the study included STEM elementary and middle school teachers, informal STEM educators, and a government official. The study took place in a large urban center in a midwestern state. In Vivo and descriptive coding were utilized in first-cycle coding and grouped based on commonalities through focused coding to determine emergent themes associated with the data collected in the study. The following research questions guided the study:

1. How do STEM-education stakeholders describe their conceptions of STEM and STEM integration before, during, and after the use of a STEM explanatory model?
2. How do STEM-education stakeholders identify and describe components of STEM and forms of STEM integration in a lesson before, during, and after the use of a STEM explanatory model?

Major Findings

This study produced four major findings associated with RQ1 and two associated with RQ2. Interpretation of data will be explored in relation to each of the major findings and pertinent aspects of the literature reviewed in Chapters 1 and 2.

Conceptions of STEM and STEM Integration Before, During, and After the Use of a STEM Explanatory Model

RQ1 was addressed through the triangulation of data collected from pre- and post-survey questions and recorded discussions designed to elicit participants' understanding of STEM, STEM integration, and the most important ideas, sub-ideas, or skills for STEM before and after exposure to a STEM explanatory model. Recorded discussions while participants utilized the STEM explanatory also contributed data to address RQ1. In Vivo and descriptive codes were identified, grouped, and narrowed down to the themes reflected in Table 20. The comparison table showcases the emergent themes representing conceptions of STEM and STEM integration held by participants before, during, and after the use of a STEM explanatory model.

Table 20

Emergent Themes of STEM-Education Stakeholders' Conceptions of STEM and STEM Integration Before, During, and After Use of a STEM Explanatory Model

BEFORE	DURING	AFTER	
Involves STEM Disciplines	Levels of STEM Exist	Involves Teaching and Learning the Disciplines of STEM	
Involves Integration of Disciplines	Grade-Level Evaluations are Confusing and Difficult	Levels of STEM Disciplines Exist	
Leverages Inquiry-Based Learning	STEM Disciplines are Not Well-Understood	Multiple Disciplines are Involved	
Supports Development of Soft Skills		Leverages Specific Instructional Approaches	Inquiry-Based Learning
Connected to Real-World			Integration and Application of STEM Disciplines
Supports Social-Emotional Learning		Builds STEM Interest and Identity	
Drives Equity			

Comparisons of the themes representing participant conceptions of STEM and STEM integration before, during, and after the use of the STEM explanatory along with analysis of corresponding data associated with themes, expose four central findings germane to RQ1 and enduring and shifting conceptions of STEM and STEM integration exhibited by participants after the use of a STEM explanatory model: (1) inquiry-based learning is a central feature; (2) narrowing emphasis on STEM disciplines emerge; (3) levels of STEM disciplines exist and vary in classroom activities; and (4) engineering and technology were not well-understood.

Inquiry-Based Learning is a Central Feature

Inquiry-based learning as an approach to instruction appeared as emergent themes both before and after participants were exposed to the STEM Explanatory Model and appeared to be central to their understandings of STEM and STEM integration. In many cases, participants viewed STEM education as an alternative approach to traditional forms of instruction that allowed students to engage in hands-on learning promoting problem solving and critical thinking. This was exhibited in multiple participant responses to questions about their conceptions of STEM and STEM integration. Participants conveyed that STEM education is more than passive desk-work and answering test questions and instead is active and intentional. Prior studies also found that STEM-education stakeholders had conceptions of STEM that emphasize teaching methodologies centered on critical thinking, problem solving, and hands-on learning (Breiner et al., 2013; Holmlund et al., 2018; Tan, 2018). With the exception of one participant, conceptions of inquiry-based learning did not appear to encompass principles of constructivism. In Vivo and descriptive codes did not include references to students constructing knowledge from inquiry-based learning experiences which is a central tenant of constructivism (Dewey, 1997). This implies that participants' conceptions of inquiry-based learning were limited to notions that hands-on learning equated to students actively doing something as part of classroom learning experiences. However, hands-on learning does not always include a critical thinking component designed to engage students in purposeful observation and data collection leading to knowledge construction and therefore does not guarantee inquiry (Barnes & Foley, 1999). Therefore, if participant conceptions of inquiry-based learning associated with STEM education are absent of constructivist principles, STEM learning experiences will likely be devoid of opportunities to make sense of STEM disciplinary concepts or gain STEM skills needed for post-secondary success. Insights from the study, indicate that participants' conceptions of inquiry-based learning have been influenced by professional development they have attended, their background experiences, and their roles as formal or informal STEM educators. The professional learning experiences that have influenced their perceptions of STEM and STEM education centered on making learning fun as an alternative to traditional forms of teaching or hearing from industry experts about the STEM skills needed for careers. Their personal experiences in STEM courses in high school or college appeared to be traditional in nature, causing them to desire alternative approaches to learning for students centered on active forms of learning. Additionally, their interactions with other STEM educators appeared to reinforce notions of STEM or STEM education equating to fun or active approaches to learning. However, participant background experiences and professional development opportunities appear to be void of constructivist theories that underpin effective approaches to inquiry-based learning.

Narrowing Emphasis on STEM Disciplines

While many participants explicitly mentioned STEM disciplines in their conceptions of STEM and STEM integration prior to exposure to the STEM Explanatory Model, study results showed that participant understandings of STEM and STEM integration contained a stronger focus on the STEM disciplines, the content and practices associated with the disciplines, and teaching and learning of the disciplines after exposure to the model. This was evident from shifts in the themes identified before and after participants were exposed to the STEM Explanatory Model. Seven themes were identified prior to exposure to the explanatory model and five were identified after, indicating a narrowing of conceptions of STEM and STEM integration occurred (see Table 17). Additionally, content associated with the themes focused more centrally on the disciplines of STEM after participants were exposed to the explanatory model. Before exposure to the STEM Explanatory Model, participant conceptions were broad and not well-connected to STEM disciplines. Emergent themes prior to exposure to the STEM Explanatory Model included: development of soft skills, social-emotional learning, career exploration, and a mechanism for driving equity in addition to some notion that STEM disciplines, integration, and inquiry-based learning represented STEM and STEM integration. In some cases, participant conceptions of STEM were not connected to STEM disciplines prior to exposure to the STEM Explanatory Model. These findings correspond with previous findings and literature that suggest STEM has come to represent more than the STEM disciplines and sometimes little to no connection to science, technology, engineering, or mathematics (Angier, 2010; Brown et al., 2011; Holmlund et al., 2018; Seikman, 2016). After exposure to the STEM explanatory model, findings indicated that conceptions of STEM and STEM integration were not divorced from STEM disciplines, concepts and practices, or the teaching and learning of STEM disciplines with participants suggesting that STEM education emphasized the purposeful learning of the STEM disciplines (see Table 20). Further indication that there was a narrowing emphasis on STEM disciplines after participants were exposed to the STEM Explanatory Model comes from the realization that only eight participants explicitly mentioned science, technology, engineering, or mathematics in their descriptions of STEM in pre-survey data and recorded discussions while all participants included references to STEM disciplines in their conceptions of STEM and STEM integration after exposure to the explanatory model.

Findings indicate that when STEM-education stakeholders are provided with an explanatory model that focuses on the individual STEM disciplines and their associated content and practices, conceptions of STEM reflect a greater emphasis on the STEM disciplines and the teaching and learning of related concepts and skills. This is a promising result considering insights from the literature call for an emphasis on STEM disciplines in any effort to craft coherence around conceptions of STEM or STEM education (Bybee, 2013; NRC, 2014; Siekman, 2016).

Levels of STEM Disciplines Exist and Vary in Classroom Activities

An anticipated result from the data was that participants would assimilate, as part of their conceptions of STEM and STEM integration, that levels of STEM disciplines can exist within a classroom activity and may vary across classroom activities. The constructivist and social constructivist theoretical framework guiding the study (Vygotsky, 1978) likely contributed to the observed shifts in participant conceptions. Participants engaged in social interactions utilizing the STEM Explanatory Model, designed to showcase the different levels of STEM disciplines that could exist in a STEM lesson, activity, or program, and constructed meanings of STEM and STEM integration with the explanatory model through both individual reflections and small group discussions. The notion that levels of STEM exist in a classroom activity began to emerge as a theme during D2 when participants were utilizing the explanatory model to evaluate the classroom activity. Two participants who were introduced to the explanatory model prior to the study discussed this concept extensively suggesting that STEM lessons can have varying levels of STEM disciplines present and students should experience lessons with varying levels of STEM disciplines over the course of a school year. Additionally, participants began to suggest that various STEM disciplines could be “turned up” in the activity, suggesting that levels of STEM disciplines existed in the classroom activity and could be changed with modifications to the activity that incorporated stronger aspects of science, technology, engineering, or mathematics. Later in this chapter, this finding is discussed further in relation to RQ2.

Engineering and Technology Were Not Well-Understood

Results indicated that engineering and technology were not well-understood. Some participants acknowledged that their conceptions of engineering did not include the integration of science and mathematics, while others indicated that engineering equated to applied mathematics. Some participants struggled with distinguishing between science and engineering, suggesting the scientific method and engineering design were the same processes. Other participants seemed to suggest that if something was not created within a classroom activity, engineering was not involved. Participant understandings of the concepts and practices for engineering were not reflective of recommendations for K-12 engineering from the field (ITEA, 2007; Moore et al., 2014; NRC, 2012) or workforce priorities (Carnevale et al., 2011).

Understanding of the concepts and skills associated with the discipline of technology were also found to be ill-understood by participants of the study. Participant discussions related to the presence of technology in the classroom activity centered on whether participants utilized their phones to make video recording or not. One participant claimed that technology was pretty low because the materials utilized in the activity were everyday materials, indicating that if more complex technology were incorporated there would be a stronger presence of technology in the activity. Many participants believed that technology was present in the activity at a low-level if a phone was utilized to conduct video recordings. However, there were no discussions pertaining to any skills or concepts of technology represented in the activity as was discussed with other STEM disciplines. One interpretation of this finding is that participants may not have possessed an understanding of the discipline of technology as presented in contemporary standards for technology (ITEA, 2007). These findings add support to the notion that technology and engineering in K-12 education are the least understood and researched of the STEM disciplines (Antink-Meyer & Brown, 2019; Ellis et al., 2020; Wang et al., 2010).

Components of STEM and Forms of STEM Integration in a Lesson Before, During, and After the Use of a STEM Explanatory Model

RQ2 was answered through triangulation of data collected from pre- and post-survey questions asking participants to determine and explain if a classroom activity represented a STEM activity and corresponding recorded discussions of responses to pre-survey questions. Recorded discussions collected while participants utilized the STEM explanatory also contributed data to address RQ2. In Vivo and descriptive codes were identified, grouped, and narrowed down to the themes reflected in Table 21. The comparison table showcases the emergent themes for how participants identified and described components of STEM and forms of STEM integration before, during, and after the use of a STEM explanatory model.

Table 21

Emergent Themes of STEM-Education Stakeholders' Identification and Description of STEM Components and Forms of STEM Integration Before, During, and After Use of a STEM Explanatory Model

BEFORE		DURING	AFTER
STEM Disciplines, Topics, Processes		Strong Science Includes Content, Experimentation, and Grade-Level Emphasis	STEM Disciplines, Topics, Processes
Experimentation, Design, and Application		Use of Technology Represents Lowercase Technology	Involves Integration of Disciplines
Levels of STEM	Full or Incomplete	Engineering Includes Design and Connections to Science or Math	Grade-Level Emphasis

	Levels of STEM Disciplines	Math Evaluation is Based on Grade-Level Emphasis	Levels of STEM Disciplines Exist
		Integration of STEM Disciplines Vary in Lessons	

A comparison of the emergent themes before, during, and after the use of the STEM explanatory model demonstrate two central findings pertinent to RQ2 and after the use of the STEM Explanatory Model: (1) terminology associated with the STEM explanatory model was adopted by participants; and (2) there was greater coherence in descriptions of components of STEM represented in the classroom activity.

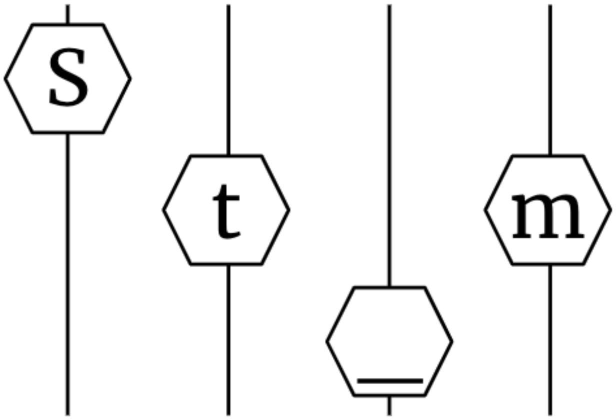
Terminology Associated with the STEM Explanatory Model was Adopted by Participants

A central finding from the study was that participants adopted the terminology associated with the STEM Explanatory Model as part of their explanations for the components of STEM or forms of STEM that existed in the classroom activity they experienced during the workshop. Prior to exposure to the STEM Explanatory Model participants described components of STEM present in the classroom activity as including science, technology, engineering, or mathematics. One participant indicated that the classroom activity was heavy on science with some level of mathematics while others simply listed the STEM disciplines they perceived to be present in the activity without indications of how heavy or light the discipline may have been present. Additionally, statements about integration of the STEM disciplines focused on subjects working together or multiple disciplines being present. However, participants who had been exposed to the explanatory model previously described the classroom activity using upper and lowercase letters corresponding to the criterion in the STEM Explanatory Model. After exposure to the STEM Explanatory Model more participants began to utilize terminology from the explanatory model to describe the components of STEM and forms of STEM they perceived in the classroom activity, including the frequent use of capital and lowercase letters to explain the version of STEM the classroom activity represented. Two participants utilized capital and lowercase letters to describe components of STEM in the classroom activity in pre-survey data and seven utilized capital and lowercase letters in post-survey data (see Table 16). Additionally, participants utilized criterion statements from the STEM Explanatory Model as evidence for claims of the presence and/or level of STEM disciplines present in the activity.

Another interesting finding related to how participants perceived the components of STEM and forms of STEM in the classroom activity after exposure to the explanatory model was the number of references by participants that the activity could be “turned up” in some way related to a STEM discipline to achieve a capital letter. While the phrases “turned up” or “turn up” do not appear in the criterion of the explanatory model, a visual representation of the model was provided to participants during the workshop via the presentation slide deck utilized (Appendix B). The visual image characterized a soundboard or sound mixing board commonly utilized in music to turn volume, base, or other components of music up or down (see Figure 5). The visual image for the STEM Explanatory Model utilized in the study showcases how STEM disciplines might be turned up (capital letter), turned down (lowercase letter), or turned off (underscore).

Figure 5

Visual Representation of STEM Explanatory Model as a Soundboard or Sound Mixing Board



Here to, the results indicated that the theoretical framework of the study likely contributed to participants constructing meaning and new knowledge as they engaged with the STEM Explanatory Model and interacted with peers to make sense of how the explanatory model could be utilized to identify component of STEM or forms of STEM (Schwandt, 2015; Vygotsky, 1978). The fact that a relatively small number of STEM-education stakeholders adopted terminology from a STEM explanatory model swiftly after utilizing it, indicates that an explanatory model is relevant to STEM-education stakeholders. Additionally, findings suggest an explanatory model might serve to address facets of disequilibrium held by stakeholders regarding STEM and STEM integration and provide utility in assimilating and accommodating new constructs for STEM and STEM integration.

Greater Coherence in Components and Forms of STEM Represented in Classroom Activity

The results from the study also showed that participants exhibited greater coherence in the components of STEM or forms of STEM they identified before and after utilization of the STEM Explanatory Model (see Table 22). This finding was particularly salient among participants who sat together at the same table during the workshop.

Table 22

Participant Table Group Identification of Components of STEM and Forms of STEM Before and After Utilization of a STEM Explanatory Model

PARTICIPANT	**GROUP 1** BEFORE	**GROUP 1** AFTER	PARTICIPANT	**GROUP 2** BEFORE	**GROUP 2** AFTER
EL1	Science Tech Engineering Math	Stem	IE1	Engineering Technology	Stem
EL2	Science Engineering Math	Stem	IE2	Science Technology Engineering Math	Science Technology Engineering Math
MS1	Science Engineering Math	S_em	IE3	Science Technology Math Art	Science Engineering Math

PARTICIPANT	**GROUP 3** BEFORE	**GROUP 3** AFTER	PARTICIPANT	**GROUP 4** BEFORE	**GROUP 4** AFTER
MS2	S_em	S_em	EL4	Science Technology Engineering Math	S_eM
G	S_Em	S_em	IE5	Science Math	Science Technology Engineering Math
EL3	Science Math	Science Engineering Math			
MS3	None Identified	Science Engineering Math			

Prior to exposure to the STEM Explanatory Model, participants in Group 1 made no reference to the classroom activity representing lower levels of math. After using the explanatory model all three participants stated the activity represented lower levels of math. Additionally, only one participant in Group 1 identified technology as a component of the activity before exposure to the explanatory model. After, two participants claimed the activity represented lowercase t and one participant identified it with an underscore indicating no technology was present. One participants in Group 2 identified art as a component of the classroom activity prior to use of the explanatory model. This was not surprising as the discipline of art has a history of being incorporated into the STEM acronym as STEAM. Advocates for the inclusion of the arts in STEM argue that the content and practices of math can be utilized in the context of artistic design or that correlations exist between artistic design and engineering or technology design (Daugherty, 2013; Gess, 2017). However, STEAM is plagued by many of the same challenges as STEM with studies indicating that there are a myriad of definitions for STEAM and a variety of interpretations of how the "A" in STEAM should be integrated with science, technology, engineering, or mathematics (Perignat & Katz-Buonincontro, 2019). After exposure to the STEM Explanatory Model, which did not include references to the arts, no participants identified art as a component of the activity.

Group 3 also showcased stronger coherence in their identification of STEM disciplines in the classroom activity after use of the STEM explanatory model. Two participants identified the presence of engineering in the classroom activity prior to exposure to the STEM Explanatory Model. After, all four participants identified engineering as a component. Prior to use of the explanatory model one participant in the group did not identify any STEM disciplines in the activity. After, all four participants showcased complete coherence with the components of

STEM they identified for the classroom activity indicating that science, engineering, and math were present, but not technology. Additionally, the two participants who had been exposed to the STEM Explanatory Model prior to the workshop exhibited stronger coherence in their analysis of the classroom activity with one participant indicating the activity represented S_em and the other stating it represented S_Em in pre-survey data. After utilizing the explanatory model and discussing as a group, both participants came to consensus and indicated the lesson represented S_em. Group 4 exhibited greater coherence in their perceptions of how engineering was represented in the activity with only one participant including engineering as a discipline believed to be present before exposure to the explanatory model and both participants identifying engineering after. However, the two participants of Group 4 did not come to consensus on the presence of technology in the classroom activity with one participant indicating it was present and the other indicating it was not.

One reason that study participants may have exhibited greater coherence in their conceptions of the components of STEM represented in classroom activity, especially among members of the same table group during the workshop, comes from literature that suggests when stakeholders have opportunities to engage in conversations aimed at shared understanding, coherence can be achieved (Fullan & Quinn, 2016; Honig & Hatch, 2004; Newmann et al., 2011). Additionally, Siekmann (2016) suggested a pathway towards coherence for STEM might be best achieved through the identification of distinct components within STEM in order to provide a high degree of shared understanding of STEM. The study findings support Siekmann's (2016) claim.

Implications and Recommendations

There are several implications of this study that can be made regarding the utility of the STEM Explanatory Model to assist diverse STEM-education stakeholders in crafting a coherent understanding of STEM and STEM integration. As described in Chapter 2, the lack of a clear, consistent vision for STEM education among STEM-education stakeholders can lead to uncoordinated efforts and less rigorous STEM educational experiences for students (NCTM, 2018; NRC, 2014) that may be absent of the disciplines of STEM altogether (LaForce et al., 2016). Additionally, lack of solidifying perceptions of STEM threatens over the long-term to destroy support for STEM education efforts or movements (Herschback, 2011). The findings from this study can have relevant implications for policy makers, professional development providers, philanthropic organizations, business and industry, school administrators, pre-service, in-service, and informal educators. This study found that supporting diverse STEM-education stakeholders in understanding what the STEM acronym means can support greater conceptual understanding and coherence of the components that comprise STEM and the various forms of STEM integration that might be present in a classroom activity. The participants of this study exhibited shifts in their conceptions of STEM and STEM integration after exposure to a STEM explanatory model and they showed greater coherence in their understandings of STEM and STEM integration when compared to others they interacted with while utilizing the explanatory model to evaluate a classroom activity. However, participants showcased a lack of understanding of the STEM disciplines, concepts, and practices, particularly outlined in grade-level standards or recommendations, that ensure students graduate STEM-literate or prepared for post-secondary experiences in STEM fields. Additionally, the background experiences participants reported as influential to their understanding of STEM and STEM integration appear to be devoid of these components. Explicit preparation of STEM educators in the STEM disciplines and the concepts and practices associated with K-12 STEM education have been called for in previous studies (Nadelson et al., 2013; Rink et al., 2016). STEM-education stakeholders can take study findings into consideration when planning professional development, engaging in strategic planning, or providing instruction aimed at improving K-12 STEM education.

The use of a STEM explanatory model proved beneficial in this study as a tool assisting STEM-education stakeholders in crafting more coherent understandings of STEM and STEM integration and identifying the components of STEM or form of STEM integration represented in a classroom activity. However, this study indicates that modifications to the STEM Explanatory Model would be beneficial. Such modifications should include more elaborative descriptions of engineering and technology with connections to grade-level mathematics or science prioritized. A STEM explanatory model grounded in the content and practices associated with the STEM disciplines could assist advocates for STEM education and the education community to move beyond a slogan for STEM that has led to disjointed efforts to more closely aligned efforts that prepare K-12 students for the STEM-literacies needed to be an informed and engaged citizenry and for the knowledge and skills needed to pursue STEM careers and post-secondary efforts (ACT I., 2017; Bybee, 2010; Siekmann, 2016).

Limitations

There were several limitations to this study, which included the nature of qualitative methods design, the limited sample size, participant selection and representation, and the role of the researcher as a co-developer of the intervention tool in the study. One limitation that came from using a qualitative method design was the highly subjective nature from which meaning was constructed and interpreted by me as the researcher. To reduce this bias, I conducted a check against the interpretations drawn from the data with two colleagues. Another limitation related to qualitative method design is the inability to generalize findings in a statistical sense (Merriam, 2009; Stake, 1995). As such, those using the findings from this study need to be aware that the information learned can only directly represent the group of individuals and the project from which these findings emerged.

The research was also limited by sample size, participant selection, and representation represented another set of limitations in the study. The 13 participants in the study cannot and should not represent the conceptions of all STEM-education stakeholders. However, their voices in the study can add to an understanding of how STEM-education stakeholders' conceptions of STEM may shift after being introduced to a STEM explanatory model. The research is limited by participant selection. Participants were selected through convenience sampling and choose to take part in the workshop offered by a regional STEM alliance center (SAC) they had previous connections to and relationships with. This could mean that the participants were more willing to shift their conceptions of STEM and STEM integration than STEM-education stakeholders that did not choose to attend the workshop or who do not have connections to or relationships with the SAC. Another limitation of the study was the representation of STEM-education stakeholders. Most study participants represented elementary and middle school STEM teachers and informal STEM educators. School administrators, business and industry representatives, philanthropic organizations, or teachers who identify as math or science teachers may hold different conceptions of STEM and STEM integration than the participants of this study and may not hold similar conceptions of STEM and STEM integration after the use of the STEM Explanatory Model. Additionally, the participants in the study came from urban and suburban school districts and communities limiting the results. Future studies should include a more diverse group of STEM-education stakeholders from urban, suburban, and rural school districts and communities to address research limitations related to representation.

Another limitation centers on me, the researcher. In this study, I developed the STEM Explanatory Model with a colleague who facilitated the workshop and introduced the STEM Explanatory Model to participants. The closeness I have with the STEM Explanatory Model and the relationship I have with the individual who introduced participants to the tool could have influenced how I interpreted the data. To help alleviate influence I as the researcher may have had in the study, I relied on other research professionals and colleagues to review the data and interpretations. I also utilized a variety of data sources including pre- and post-surveys, participant discussions, and researcher memos. The varied sources of data and efforts to triangulate data whenever possible strengthened the validity of the interpretations and findings found within this study.

Areas for Future Research

A STEM explanatory model that focuses on the content and practices associated with the STEM disciplines could be a valuable tool to support diverse STEM-education stakeholders in crafting coherent conceptions of STEM and STEM integration and setting goals for STEM education efforts. Future research could explore how the STEM Explanatory Model could be utilized to craft coherent conceptions of STEM among STEM-education stakeholders seeking to design or implement STEM programs and how conceptions correlate to goal setting or implementation efforts (Brown et al., 2011; Peters-Burton et al., 2014). The STEM Explanatory Model could also inform conversations about effective approaches to STEM instruction for students, professional learning for educators, and STEM-education policy and programmatic decisions by various STEM-education stakeholders. Researchers could utilize the explanatory model and measure how science and mathematics teachers' conceptions of STEM shift or remain the same when exposed to it or how they might utilize the explanatory model to evaluate curriculum (Margot & Kettler, 2019). This could lead to more science and math teachers viewing themselves as STEM teachers or recognizing that the disciplines they teach are a central part of STEM education. Researchers could also conduct studies with pre-service teachers to determine how the STEM Explanatory Model might impact their understanding of STEM education and the disciplines that comprise STEM (Akerson et al., 2018; Ring et al., 2018). Lastly, future research could analyze how the STEM Explanatory Model might assist policy makers and community members in understanding STEM and STEM education so that funding and policy decisions are based on common definitions rather than fragmented conceptions that lead to less focused and coherent efforts (Oleson et al., 2014).

Conclusion

This study examined the impact a STEM explanatory model grounded in STEM discipline content and practices might have on diverse STEM-education stakeholders' conceptions of STEM and STEM integration. Participants in the study showed a narrowing of their understanding of STEM and STEM integration that was more centered on STEM disciplines, stronger coherence among participants in their identification of the STEM components that comprised a classroom activity, and a lack of deep understanding of disciplines that comprise the STEM acronym. Through this study participants adopted terminology associated with the STEM explanatory model introduced as an intervention in the study. Recorded conversations among participants during the use of the explanatory model indicated that participants constructed new meanings of STEM and STEM integration not possessed prior to exposer to the explanatory model. As a result, participants exhibited shifts in their understanding of STEM and STEM integration by the end of the study. The findings from this study are significant and relevant and could prove useful to the fields of science, technology, engineering, and mathematics education as well as STEM education. The study of and discussion of conceptual coherence of STEM and STEM integration among diverse STEM-education stakeholders must continue if efforts for STEM education are to fulfill the hopes and dreams of the nation.

References

Abt Associates I. (2012). *Mathematics and science partnership program highlights*. https://www.education.ne.gov/wp-content/uploads/2017/07/MSP_Policy_Brief_Final.pdf

ACT, I. (2017). *STEM education in the U.S.: Where we are and what we can do.* ACT, Inc. https://www.act.org/content/act/en/research/reports/act-publications/stem-education-in-the-us-2017.html

ACT, I. (2018). *The Condition of College Career Readiness.* ACT, Inc. https://www.act.org/content/dam/act/unsecured/documents/National-CCCR-2019.pdf

ACT., I. (2019) *The condition of college & career readiness*. ACT, Inc. https://www.act.org/content/dam/act/unsecured/documents/National-CCCR-2019.pdf

Akerson, V. L., Burgess, A., Gerber, A., Guo, M., Khan, T. A., & Newman, S. (2018). Disentangling the meaning of STEM: Implications for science education and science teacher education. *Journal of Science Teacher Education*, *29*(1), 1-8.

America, E. (2007). *Rising above the gathering storm.* Washington, DC: The National Academies Press.

American Association for the Advancement of Science. (1990). *Science for all Americans*.

American Association for the Advancement of Science. (1994). *Benchmarks for science literacy*.

Angier, N. (2010, October 4). STEM education has little to do with flowers. *The New York Times.* https://www.nytimes.com/2010/10/05/science/05angier.html

Antink-Meyer, A., & Brown, R. A. (2019). Nature of engineering knowledge: An articulation for science learners with nature of science understandings. *Science & Education, 28*(3–5), 539–559.

Ay Emanet, E., & Kezer, F. (2021). The effects of student-centered teaching methods used in mathematics courses on mathematics achievement, attitude, and anxiety: A meta-analysis study. P*articipatory Educational Research*, *8*(2), 240–259.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., Hayes, M. L., & Horizon Research, I. (2018). Report of the 2018 NSSME+. Horizon Research, Inc. http://horizon-research.com/NSSME/2018-nssme/research-products/reports/technical-report

Barnes, B.B., & Foley, R.M. (1999). Approaches to hands-on learning in elementary and secondary science methods courses. *Electronic Journal of Science Education*, 4(12), 1-7.

Becker, K. H., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5–6), 23–37.

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education, 99*(1), 98–120.

Bidwell, J. K., & Clason, R. G. (1970). *Readings in the history of mathematics education.* U.S. Department of Health, Education and Welfare. Office of Education.

Brahier, D., Leinwand, S., & Huniker, D. (2014). Principles to actions: Mathematics programs as the core for student learning. *Mathematics Teacher, 107*(9), 656–658.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11.

Brown, R., Brown, J., Reardon, K., and Merril, C. (2011) Understanding STEM: Current perceptions. *Technology and Engineering Teacher. 70*(6), 5-9.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30-35.

Bybee, R. W. (2011). K-12 engineering education standards: Opportunities and barriers. *Technology and Engineering Teacher*, *70*(5), 21–29.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities.* National Science Teachers Association.

Carnevale, A. P., Smith, N., & Melton, M. (2011). *STEM: Science, Technology, Engineering and Mathematics.* Georgetown University Center on Education and the Workforce.

Chabalengula, V. M., & Mumba, F. (2017). Engineering design skills coverage in K-12 engineering program curriculum materials in the USA. *International Journal of Science Education*, *39*(16), 2209–2225.

Chandler, J., Fontenot, A. D., & Tate, D. (2011). Problems associated with a lack of cohesive policy in K-12 pre-college engineering. *Journal of Pre-College Engineering Education Research*, *1*(1), 40–48.

Christenson, J. (2011, November 13). Ramaley coined STEM term now used nationwide. *Winona Daily News.* http://www.winonadailynews.com/news/local/article_457afe3e-0db3-11e1-abe0-001cc4c03286.html

Creswell, J. W. (2013). *Qualitative Inquiry & Research Design: Choosing among Five Approaches* (3rd ed.). Sage Publication Inc.

Creswell, J.W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage Publication Inc.

Creswell, J.W. & Poth, C.N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage Publication Inc.

Dare, E.A., Ellis, J.A., & Roehrig, G.H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education, 5*(4), 1-19.

Daugherty, M. K. (2013). The Prospect of an" A" in STEM Education. *Journal of STEM Education: Innovations and Research*, *14*(2).

Dewey, J. (1997). Experience And Education (Reprint.). New York, NY: Touchstone. (Original work published in 1938).

Doan, S., & Lucero, A. (2021). *Changing the subject: K-12 teachers' use of and access to science-specific instructional materials, feedback, and professional learning.* Data Note: Insights from the American Educator Panels. Research Report. RR-A134-7. RAND Corporation.

Ellis, J., Wieselmann, J., Sivaraj, R., Roehrig, G., Dare, E., & Ring-Whalen, E. (2020). Toward a productive definition of technology in science and STEM education. *Contemporary Issues in Technology and Teacher Education*, *20*(3), 472-496.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*(1), 1-8.

Epstein, D., & Miller, R. T. (2011). *Slow off the mark: Elementary school teachers and the crisis in science, technology, engineering, and math education.* Center for American Progress.

Estapa, A.T., & Tank, K.M. (2017). Supporting integrated STEM in the elementary classroom: a professional development approach centered on an engineering design challenge. *International Journal of STEM Education, 4*(6), 1-16.

Executive Office of the President. (2011). *The federal science, technology, engineering, and mathematics (STEM) education portfolio*. A Report from the Federal Inventory of STEM Education Fast-Track Action Committee on STEM Education National Science and Technology Council. https://files.eric.ed.gov/fulltext/ED542910.pdf

Executive Office of the President. (2018). *Charting a course for success: America's strategy for STEM education.* A Report by the Committee on STEM Education of the National Science & Technology Council.

https://www.energy.gov/sites/default/files/2019/05/f62/STEM-Education-Strategic-Plan-2018.pdf

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology, 29*(3), 369-385.

Fitzallen, N. (2015). *STEM education: What does mathematics have to offer?*. Mathematics Education Research Group of Australasia.

Fullan M., & Quinn J. (2016). Coherence making: How leaders cultivate the pathway for school and system change with a shared process. *School Administrator, 30*(1): 30–34.

Gardner, D. P. (1983). *A nation at risk: The imperative for educational reform. An open letter to the American people.* A Report to the Nation and the Secretary of Education.

Gess, A. H. (2017). Steam education: Separating fact from fiction. *Technology and Engineering Teacher*, *77*(3), 39-41.

Gnagey, J., & Lavertu, S. (2015). The impact of inclusive STEM high schools on student achievement. AERA Open. doi:10.1177/2332858416650870

Gonzalez, H., & Kuenzi, J. (2012). Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer. Congressional Research Service. https://sgp.fas.org/crs/misc/R42642.pdf

Grubbs, M. E., Strimel, G. J., & Huffman, T. (2018). Engineering education: A clear content base for standards. *Technology and Engineering Teacher, 77*(7), 32–38.

Guzey, S.S., Moore, T.J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research, 6*(1), 11-29.

Haag, S., & Megowan, C. (2015). Next generation science standards: A national mixed-methods study on teacher readiness. *School Science and Mathematics*, *115*(8), 416-426

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. *Journal of STEM Teacher Education*, *48*(1), 96-122.

Hiebert, J., Stigler, J. W., & Manaster, A. B. (1999). Mathematical features of lessons in the TIMSS Video Study. *ZDM*, *31*(6), 196-201.

Hoeg, D. G., & Bencze, J. L. (2017). Values underpinning STEM education in the USA: An analysis of the next generation science standards. *Science Education*, *101*(2), 278–301.

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of STEM Education*, *5*(32), 1-18.

Honig, M. I., & Hatch, T. C. (2004). Crafting coherence: How schools strategically manage multiple, external demands. *Educational Researcher*, *33*(8), 16–30.

International Technology Education Association (ITEA) (2007). *Standards for technological Literacy: Content for the study of technology*.

International Technology and Engineering Education Association (ITEEA) & Council on Technology and Engineering Teacher Education (2020). *Pre-publication standards for technological and engineering literacy: Defining the role of technology and engineering in STEM education*.

Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (Eds.). (2015). *STEM road map: A framework for integrated STEM education*. Routledge.

Kaufman, J. H., Doan, S., & Fernandez, M. P. (2021). *The rise of standards-aligned instructional materials for US K-12 mathematics and English language arts instruction.* Findings from the 2021 American instructional resources survey. Data Note: Insights from the American Educator Panels. Research Report. RR-A134-11. RAND Corporation.

Kelley, T. (2010). Staking the claim for the "T" in STEM. *Journal of Technology Studies*, *36*(1), 2–11.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 1-11.

Kloser, M. (2014). Identifying a core set of science teaching practices: A delphi expert panel approach. *Journal of Research in Science Teaching, 51*(9), 1185–1217.

LaForce, M., Noble, E., King, H., Century, J., Blackwell, C., Holt, S., Ibrahim, A., & Loo, S. (2016). The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education*, *3*(1), 1-11.

Li, Y., Wang, K., Xiao, Y., & Freud, J.E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education, 7*(11), 1-16.

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The role of mathematics in interdisciplinary STEM education. *ZDM*, *51*(6), 869-884.

Margot, K. C., & Kettler, T. (2019). Teachers' Perception of STEM Integration and Education: A Systematic Literature Review. *International Journal of STEM Education*, *6*.

McGarr, O., & Lynch, R. (2017). Monopolising the STEM agenda in second-level schools: Exploring power relations and subject subcultures. *International Journal of Technology and Design Education*, *27*(1), 51–62.

Mackenzie, J.C. (1894). The report of the committee of ten. *The School Review*, *2*(3), 146-155.

Mattern, K., Radunzel, J., Westrick, P., & ACT, I. (2015). *Development of STEM readiness benchmarks to assist educational and career decision making.* ACT Research Report Series, 2015 (3). ACT, Inc.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. Jossey-Bass.

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research*, *4*(1), 1–13.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

National Academies of Science, Engineering and Medication. (2021). *Call to action for science education: Building opportunity for the future.* The National Academies Press.

National Academies, N. A. of S., National Academies, N. A. of E., & National Academies, N. A. of M. (2020). *Building capacity for teaching engineering in K-12 education*. Consensus Study Report. National Academies Press.

National Assessment Governing Board. (2018). *Technology and engineering literacy framework for the 2018 national assessment of educational progress.* U.S. Department of Education.

National Center for Education Statistics. (2018). *Highlights of U.S. PISA 2018 Results Web Report (NCES 2020-166 and NCES 2020-072).* Institute of Education Science, U.S. Department of Education. U.S. Government Printing Office.

National Center for Education Statistics. (2018). *TIMSS 2019 U.S. highlights* (NCES 2017-002). Institute of Education Science, U.S. Department of Education. https://nces.ed.gov/timss/results19/index.asp

National Center for Educational Statistics (2019). *NAEP highlights of 2017 mathematics and science assessment.* https://www.nationsreportcard.gov/

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*.

National Council of Teachers of Mathematics. (2018) *Building STEM education on a sound mathematical foundation* [Position Paper]. Retrieved from https://www.nctm.org/uploadedFiles/Standards_and_Positions/Position_Statement

National Education Association of the United States. Committee on Secondary School Studies. (1894). *Report of the committee of ten on secondary school studies:* With the reports of the conferences arranged by the committee. National Education Association.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). Common Core State Standards.

National Research Council. (1996). *National science education standards*. The National Academies Press.

National Research Council. (2001). *Adding it up: Helping children learn mathematics*. The National Academies Press.

National Research Council. (2004). *How students learn: History, mathematics, and science in the classroom*. The National Academies Press.

National Research Council. (2005). A*merica's lab report: Investigations in high school science* (Vol. 3). S. R. Singer, M. L. Hilton, & H. A. Schweingruber (Eds.). The National Academies Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. The National Academies Press.

National Research Council. (2013). *Monitoring progress toward successful K-12 STEM education; a nation advancing?* The National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* The National Academies Press.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospectus, and an agenda for research.* The National Academies Press.

National Science & Technology Council (2013). *Federal science, technology, engineering, and mathematics (STEM) education.* https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

National Science & Technology Council (2018). *Charting a course for success: America's strategy for STEM education.* https://www.energy.gov/sites/default/files/2019/05/f62/STEM-Education-Strategic-Plan-2018.pdf

Newmann, F. M., Smith, B., Allensworth, E., & Bryk, A. S. (2001). Instructional program coherence: What it is and why it should guide school improvement policy. *Educational evaluation and policy analysis*, *23*(4), 297–321.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* The National Academies Press.

Noble, E., Ferris, K. A., LaForce, M., & Zuo, H. (2020). A mixed-methods approach to understanding PBL experiences in inclusive STEM high schools. *European Journal of STEM Education*, *5*(1), 2.

Oklahoma State Department of Education (OSDE), 2019. *The Oklahoma Academic Standards for Science.* https://sde.ok.gov/sites/default/files/Oklahoma%20Academic%20Standards%20for%20Science%20Final%2006.29.21%20with%20Grammatical%20Edits.pdf

Oleson, A., Hora, M., & Benbow, R. (2014). *STEM: How a poorly defined acronym is shaping education and workforce development policy in the United States* (Vol. 2). WCER Working Paper No. 2014-2. University of Wisconsin-Madison.

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking skills and creativity*, *31*, 31-43.

Penuel, W. R., Shaw, S., Bell, P., Hopkins, M., Neill, T., & Farrell, C. C. (2018). Building a networked improvement community to promote equitable, coherent systems of science education: How a state-level team can support district-level change efforts. *AASA Journal of Scholarship & Practice*, *15*(1), 30–38.

Peters-Burton, E. E., Lynch, S. J., Behrend, T. S., & Means, B. B. (2014). Inclusive STEM high school design: 10 critical components. *Theory Into Practice*, *53*(1), 64–71.

Peters-Burton, E. E., & Johnson, T. (2018). Cross-case analysis of engineering education experiences in inclusive STEM-focused high schools in the United States. I*nternational Journal of Education in Mathematics, Science and Technology*, *6*(4), 320–342.

Pleasants, J., & Olson, J. K. (2019). What Is engineering? Elaborating the nature of engineering for K-12 Education. *Science Education*, *103*(1), 145–166.

Rakich, S. S., & Tran, V. (2016). A balanced approach to building STEM college and career readiness in high school: combining STEM intervention and enrichment programs. *European Journal of STEM Education*, *1*(3), 59.

Reiser, B. J., Novak, M., McGill, T. A. W., & Penuel, W. R. (2021). Storyline Units: An Instructional Model to Support Coherence from the Students’ Perspective. *Journal of Science Teacher Education*, *32*(7), 805–829.

Rinke, C. R., Gladstone-Brown, W., Kinlaw, C. R., & Cappiello, J. (2016). Characterizing STEM teacher education: Affordances and constraints of explicit STEM preparation for elementary teachers. *School Science and Mathematics*, *116*(6), 300-309.

Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, *28*(5), 444-467.

Roberts, A. (2013). STEM Is Here. Now What? *Technology and Engineering Teacher*, *73*(1), 22–27.

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: a detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, 3(1), 1-18.

Schmidt, W. H., & Houang, R. T. (2007). *Lack of focus in the mathematics curriculum: A symptom or a cause?* In T. Loveless (Ed.), Lessons learned: What international assessments tell us about math achievement. Brookings Institution Press.

Schwandt, T.A. (2015). *The sage dictionary of qualitative inquire* (4th ed.). Sage Publication Inc.

Sgro, C. M., Bobowski, T., & Oliveira, A. W. (2020). *Current praxis and conceptualization of STEM education: A call for greater clarity in integrated curriculum development.* In Critical questions in STEM education (pp. 185-210). Springer, Cham.

Siekmann, G. (2016). *What is STEM? The need for unpacking its definitions and applications.* National Center for Vocational Education Research (NCVER). https://files.eric.ed.gov/fulltext/ED570651.pdf

Siekmann, G., & Korbel, P. (2016). *Defining" STEM" skills: Review and synthesis of literature.* Support Document 1. National Center for Vocational Education Research (NCVER). https://files.eric.ed.gov/fulltext/ED570655.pdf

STEM^4. (2018). STEM^4: *The power of collaboration for change*. Reston, VA: Advance CTE, Association of State Supervisors of Math (ASSM), Council of State Science Supervisors (CSSS), and International Technology and Engineering Educators Association (ITEEA). Retrieved from https://www.iteea.org/File.aspx?id=137271&v=cb3f06a2

Saldaña, J. (2021). *The coding manual for qualitative researchers* (4th ed.). Sage Publication Inc.

Stohlmann, M. (2018). A vision for future work to focus on the “M” in Integrated STEM. *School Science and Mathematics*, *118*(7), 310–319.

Sujarwanto, E., & Sanjaya, I. G. M. (2021). A conceptual framework of STEM education based on the Indonesian Curriculum. *Journal of Physics, 1760*(1) p. 012022.

Svarovsky, G. N. (2011). Exploring complex engineering learning over time with epistemic network analysis. *Journal of Pre-College Engineering Education Research*, *1*(2), 19–30.

Tan, M. (2018). Why STEM? Why now? Educating for technologies, or technologies for education? *Learning: Research and Practice*, *4*(2), 203–209.

Trygstad, P. J., Smith, P. S., Banilower, E. R., Nelson, M. M., & Horizon Research, I. (2013). *The status of elementary science education: Are we ready for the next generation science standards?* Horizon Research, Inc.

Trygstad, P. J., Malzahn, K. A., Banilower, E. R., Plumley, C. L., Bruce, A. D., & Horizon Research, I. (2020). Are All Students Getting Equal Access to High-Quality Science Education? Data from the 2018 NSSME+. Horizon Research, Inc.

Tyler, B., Britton, T., Nguyen, K., Estrella, D., Arnett, E., Iveland, A., Nilsen, K., & WestEd. (2020). *Six years of scaling up: Districtwide implementations of the next generation science standards.* Evaluation Report #12. In WestEd. WestEd.

Vygotsky, L. S. (1978). *Mind in society: The development of higher mental process.* Harvard University Press.

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), 1–13.

Westrick, P. (2015b). *Profiles of successful STEM majors: ACT college readiness assessment scores*, ACT Interest Inventory scores for quantitative science, biological\biomedical science, and non-STEM majors. ACT Inc.

World Economic Forum (2015). *New vision for education: unlocking the potential of technology.* World Economic Forum.

Yata, C., Ohtani, T., & Isobe, M. (2020). Conceptual framework of STEM based on Japanese subject principles. *International Journal of STEM Education*, *7*(1), 1-10.

Yin, R.K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage Publication Inc.

Appendix A: IRB Letter of Approval

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Initial Submission – Exempt from IRB Review – AP01

Date: August 03, 2022 **IRB#:** 14809

Principal Investigator: Mrs Tiffany N Neill, BA

Approval Date: 08/03/2022

Exempt Category: 2

Study Title: Understanding the Impact of a STEM Explanatory Model on STEM-Education Stakeholders' Conceptions of STEM Education

On behalf of the Institutional Review Board (IRB), I have reviewed the above-referenced research study and determined that it meets the criteria for exemption from IRB review. To view the documents approved
for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Request approval from the IRB prior to implementing any/all modifications as changes could affect the exempt status determination.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor. Notify the IRB at the completion of the project.

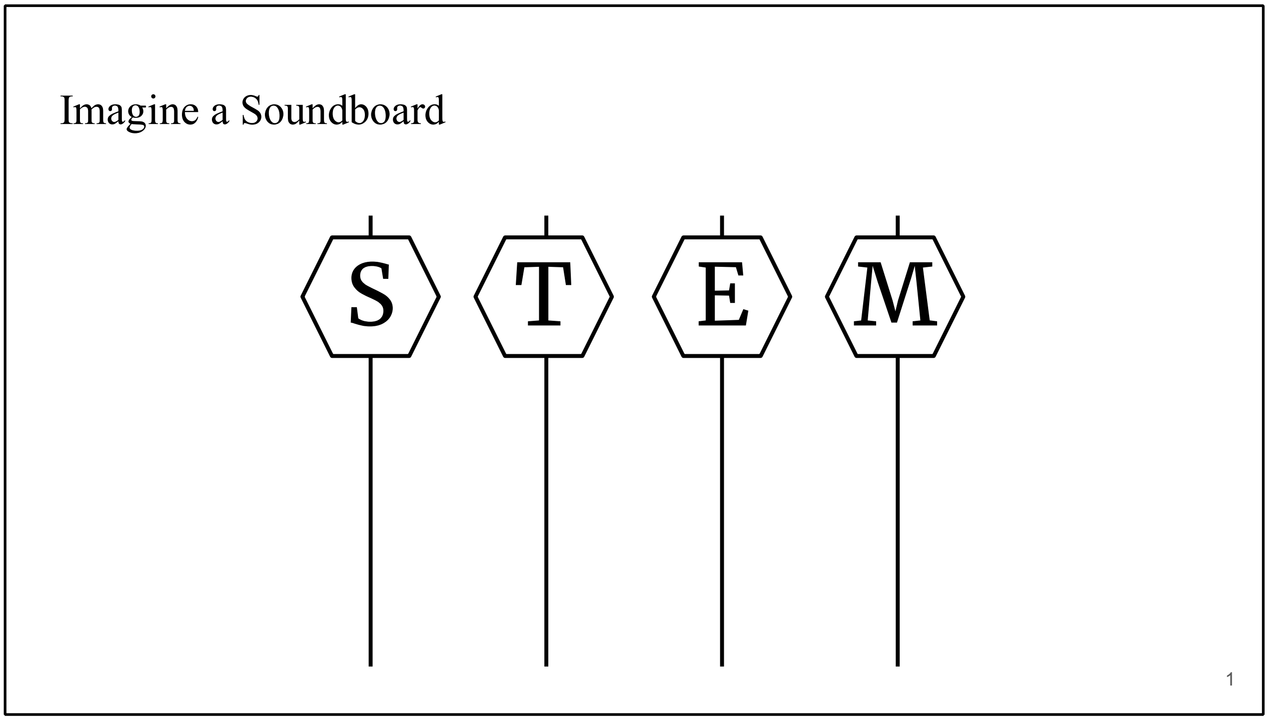
If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Aimee Franklin

Aimee Franklin, Ph.D.
Chair, Institutional Review Board

Appendix B: Workshop Slide Deck


Imagine a Soundboard

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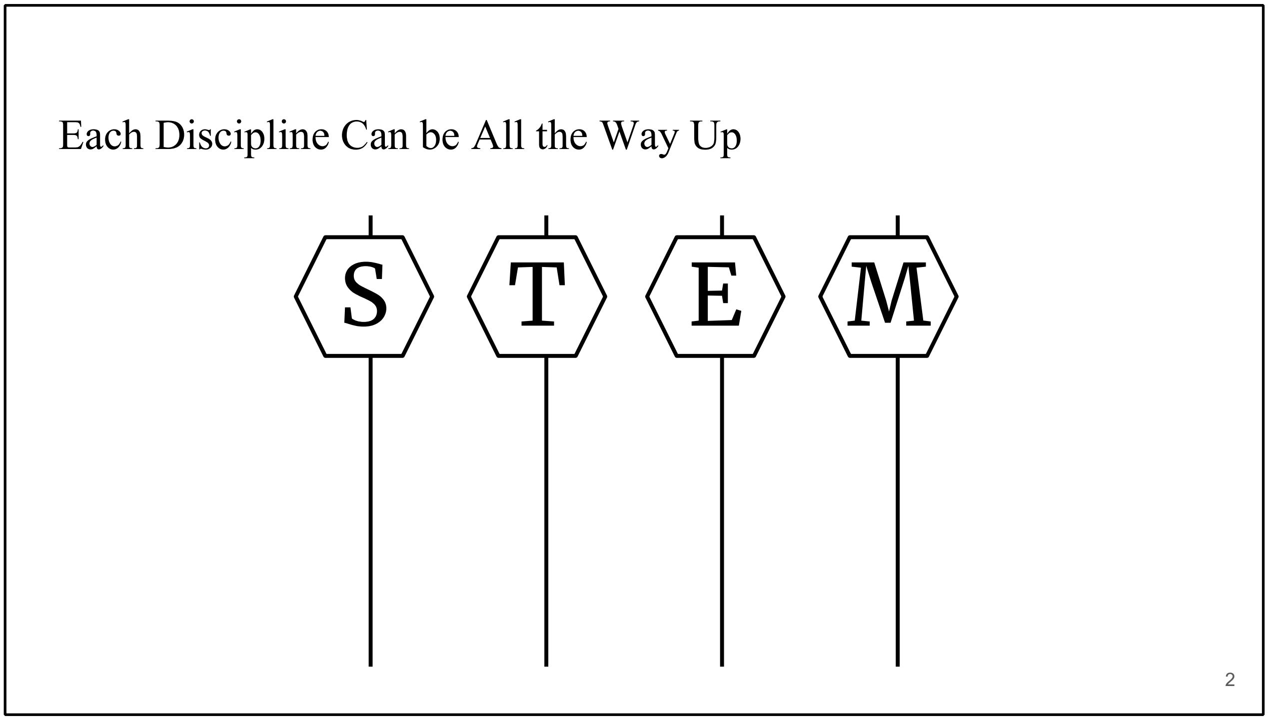
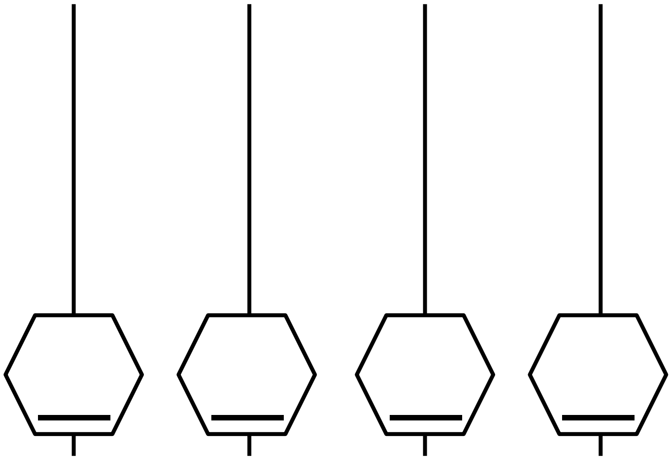
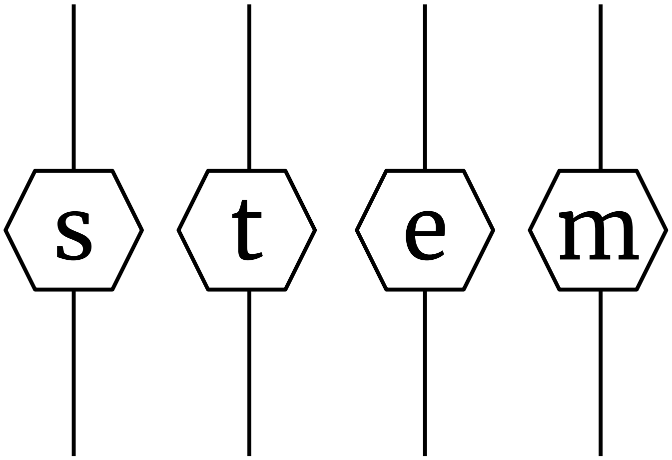

Each Discipline Can be All the Way Up

2

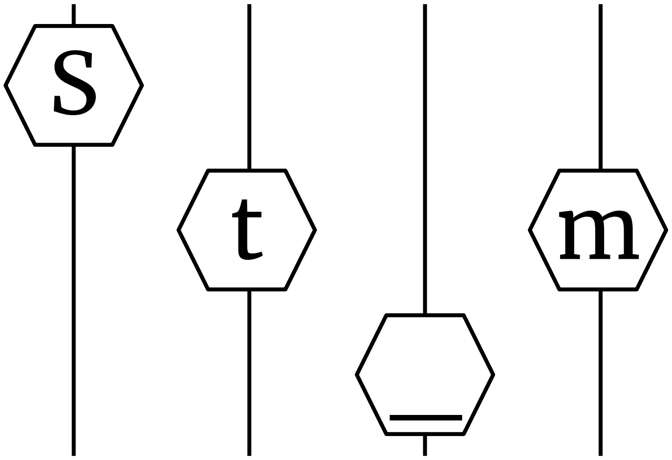
Each Discipline Can be All the Way Down



Or, Somewhere In the Middle



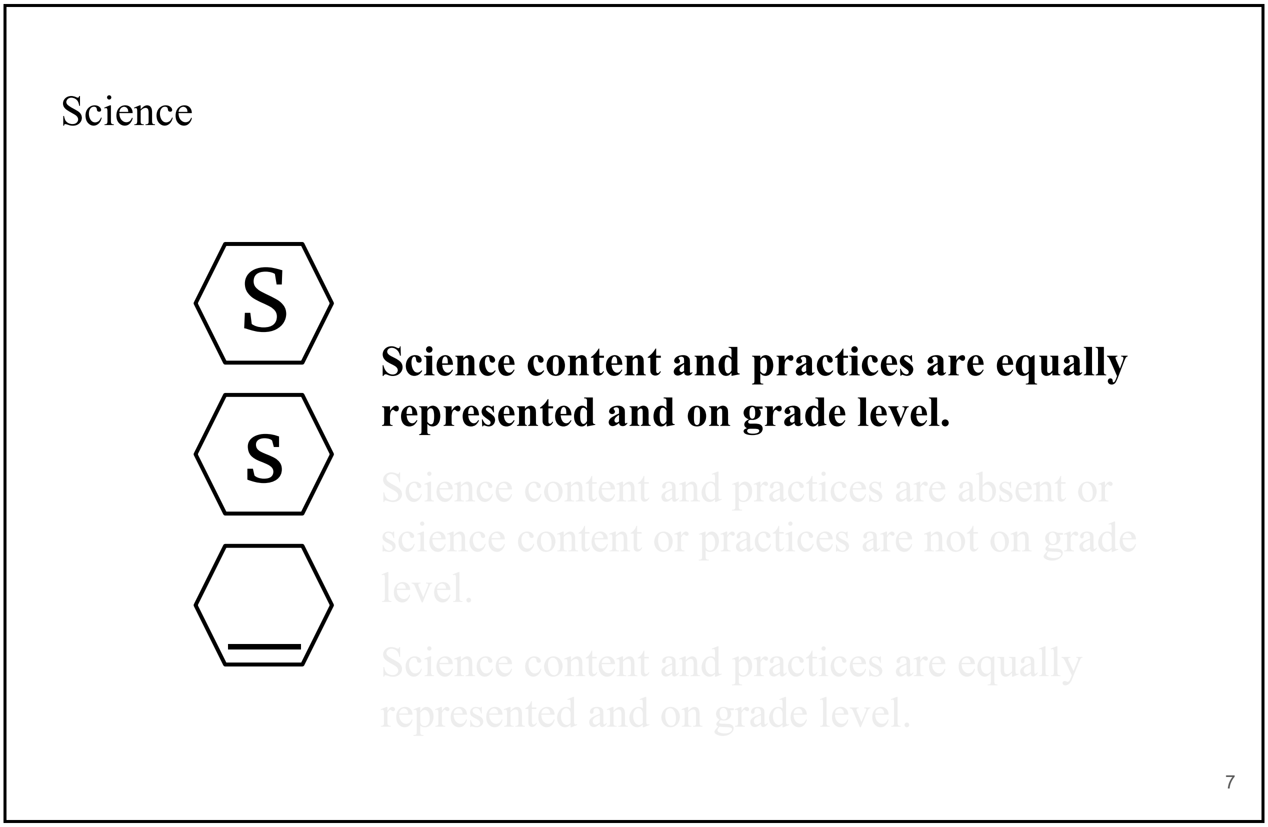
They Can Move Independently



Science

- Study of the natural world, including laws of nature.
- Both a body of knowledge and a process – scientific inquiry

STEM Disciplines (adapted from NRC 2014)


Science

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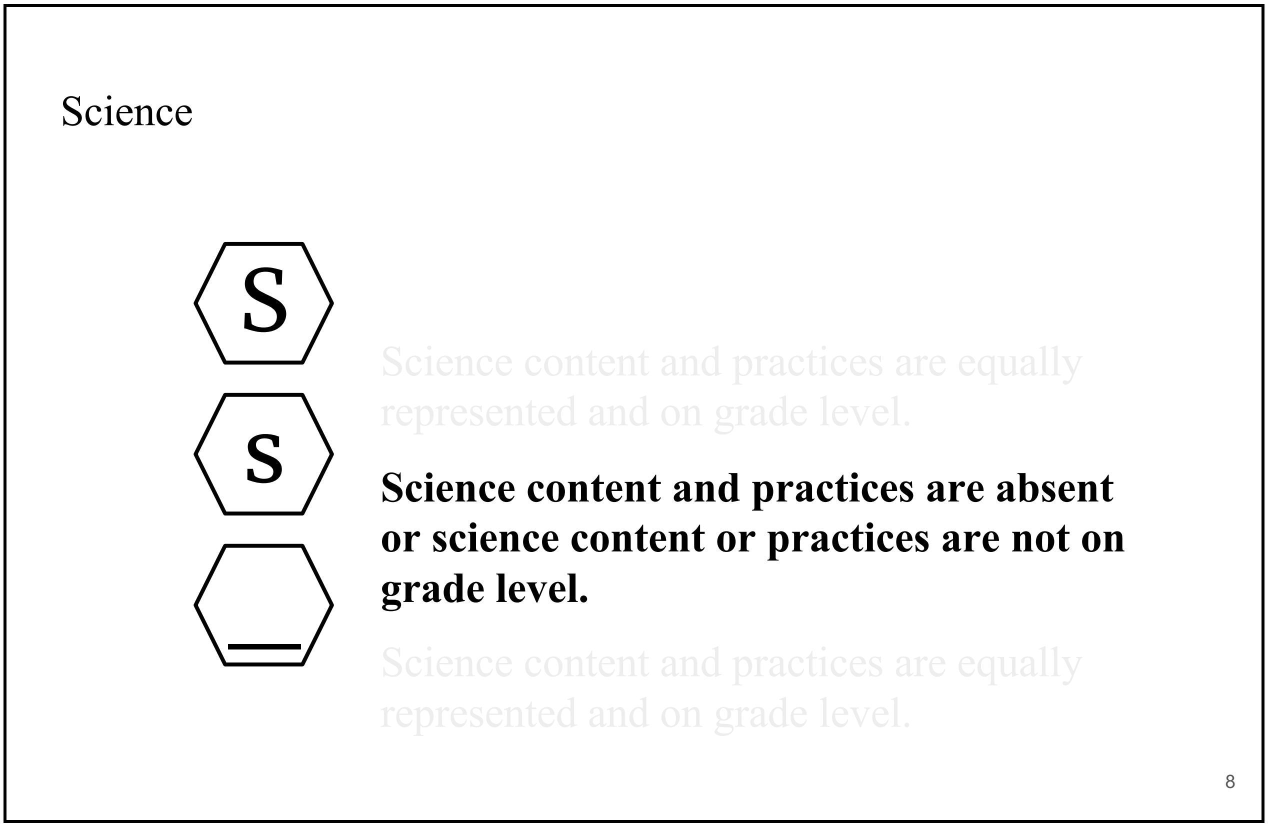
Science content and practices are equally represented and on grade level.

Science content and practices are absent or science content or practices are not on grade level.

Science content and practices are equally represented and on grade level.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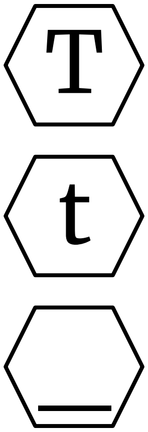
Science content and practices are equally represented and on grade level.

Technology

- People, organizations, knowledge, processes, and devices that go into creating and operating technological artifacts.
- Much of modern technology is a product of science and engineering, and technological tools are used in both fields.

STEM Disciplines (adapted from NRC 2014)

Technology

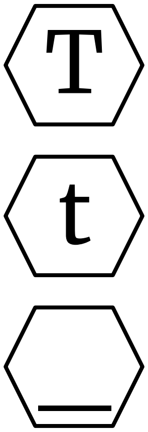


Technology is both created and operated purposefully.

Technology is operated purposefully but not created.

Purposeful operation and creation of technology are absent.

Technology



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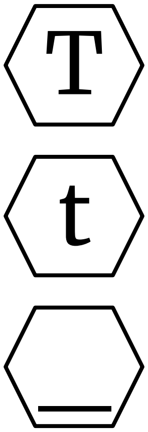


Technology is both created and operated purposefully.

Technology is operated purposefully but not created.

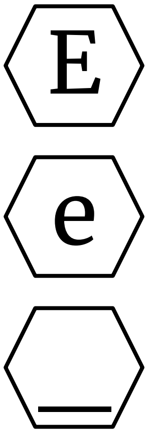
Purposeful operation and creation of technology are absent.

Engineering

- Both a body of knowledge – about the design and creation of human-made products – and a process for solving problems.
- Utilizes concepts in science and mathematics as well as technological tools.

STEM Disciplines (adapted from NRC 2014)

Engineering

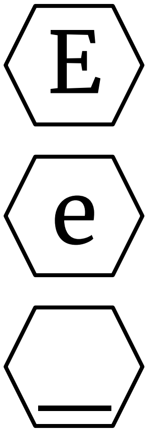


Engineering knowledge and design are present, and science and mathematics concepts are utilized.

Engineering knowledge or design are present but lacks utilization of science and mathematics concepts.

Engineering knowledge and design are absent.

Engineering



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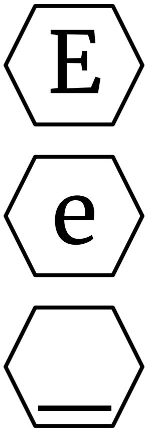
Engineering



Engineering knowledge and design are present, and science and mathematics concepts are utilized.

Engineering knowledge or design are present but lacks utilization of science and mathematics concepts.

Engineering knowledge and design are absent.

Mathematics

- Study of patterns and relationships among quantities, numbers, and space.
- Logical arguments themselves are part of mathematics as along with the claims.

STEM Disciplines (adapted from NRC 2014)

Mathematics

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Mathematics content and practices are equally represented and on grade level.

Mathematics content and practices are absent or mathematics content or practices are not on grade level.

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