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A Phenomenographic Study of K-8 Mathematics Teachers' Conceptualizations and Their Accounts of Enacting Integrated STEM Education

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

A PHENOMENOGRAPHIC STUDY OF K-8 MATHEMATICS TEACHERS' CONCEPTUALIZATIONS AND THEIR ACCOUNTS OF ENACTING INTEGRATED STEM EDUCATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of
DOCTOR OF PHILOSOPHY
in
TEACHING AND LEARNING
by
Elizabeth Natasha Forde
2022

To: Dean Michael Heithaus
College of Arts, Sciences and Education

This dissertation, written by Elizabeth Natasha Forde, and entitled A Phenomenographic Study of K-8 Mathematics Teachers' Conceptualizations and Their Accounts of Enacting Integrated STEM Education, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

Maria L. Fernandez

Enrique Villamor

Emily A. Dare, Co-Major Professor

Barbara King, Co-Major Professor

Date of Defense: June 21, 2022

The dissertation of Elizabeth Natasha Forde is approved.

Dean Michael Heithaus
College of Arts, Sciences and Education

Andrés G. Gil
Vice President for Research and Economic Development
and Dean of the University Graduate School

Florida International University, 2022

DEDICATION

This dissertation is dedicated to the loving memory of my mother, Josephine Forde, my first mathematics teacher. Despite not having the opportunity to complete secondary or tertiary education, you always instilled in your children the importance of acquiring a proper education. You did everything within your means to make provision for us to achieve our fullest potential. You have been my number one cheerleader, motivator, inspiration, and pillar of support throughout my life. You continued to encourage me and believed in my ability even when I doubted myself. You were indeed the "wind beneath my wings."

I also dedicate this accomplishment to my siblings, Brian and Dianne, and niece, Jemila. My dear Jemila, I truly hope that this serves as an inspiration for you and allow you to learn from my journey. May it help you to remember that despite the challenges that may come your way, you should remain focused on your goals and believe that you can accomplish whatever you set your mind on.

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ABSTRACT OF THE DISSERTATION

A PHENOMENOGRAPHIC STUDY OF K-8 MATHEMATICS TEACHERS' CONCEPTUALIZATIONS AND THEIR ACCOUNTS OF ENACTING INTEGRATED STEM EDUCATION

by

Elizabeth Natasha Forde

Florida International University, 2022

Miami, Florida

Professor Barbara King, Co-Major Professor

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Students' mathematics performance in the United States and internationally continues to cause concern among educators, researchers, and policymakers. This concern coupled with a re-energized interest in science, technology, engineering, and mathematics (STEM) has resulted in calls to revisit the approaches used in teaching mathematics. A promising pathway for improving students' problem-solving skills and mathematical understanding is through integrated approaches (Burghardt et al., 2010; Chiappetta, 2009) as is currently being practiced in STEM education. One of the major stakeholders and catalysts in implementing this transformative possibility is mathematics teachers. Teachers' conceptualizations and approaches to instruction affect student learning outcomes (Srikoom et al., 2017).

This phenomenographic study sought to investigate how 16 K-8 mathematics teachers in South Florida conceptualize integrated STEM education as well as their accounts of enacting this phenomenon in their classroom teaching. The study also explored the factors these mathematics teachers identified as influencing their enactment of integrated STEM education. Semi-structured interviews were utilized to capture the variations in conceptualizations and enactment practices. The data analysis resulted in four Categories of Conceptualization representing the qualitatively different ways that mathematics teachers conceptualized integrated STEM education: Mathematics and Science Integrators, Mathematics, Science, and Technology Integrators, Science, Technology, Engineering, and Mathematics Integrators, and Science, Technology, Engineering, Arts, and Mathematics Integrators. Teachers' accounts showed an array of enactment practices of this phenomenon, the accounts with similar themes were grouped in the following way: Contextualizing the Learning, Teacher as Facilitator, Cooperative Learning, and Formative Assessment. Factors influencing teachers' enactment of integrated STEM education were also categorized based on similar theme patterns, resulting in four main themes: Personal Factors, School-Related Factors, Professional Factors, and External Factors.

The findings of this study revealed that teachers' conceptualizations and accounts of enactment of integrated STEM education in their mathematics teaching are multidimensional and that conceptions do not always inform enactment. Recommendations for transformative change, limitations, and implications for future research are presented.

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CHAPTER ONE

Introduction

This phenomenographic study examined K-8 mathematics teachers' conceptualizations and accounts of enacting integrated STEM education as well as factors they identified as influencing their enactment of this phenomenon. Chapter one firstly provides a Background of the Study, followed by a Statement of the Problem, and the Purpose of the Study. The Research Questions that drove the study and Statement of Significance are then presented. Finally, the Assumptions and Delimitations of the study are stated.

Background of the Study

Traditional mathematics teaching and learning have most often reflected a procedural approach, wherein students are usually shown the steps to solve a problem and then engage in repeated practice following the steps shown to them by the teacher. This traditional practice can be seen through all levels of education from the early years to the tertiary level. It is characterized by a predominantly teacher-centered, teaching and learning model. This approach places the teacher as the focal point where they establish lesson objectives, develop, and deliver the content and skills in a predetermined manner (Guzzetti, 2002; Slavin, 2012). In such a model, students are tasked with passively acquiring this teacher-determined knowledge and skills (Arends, 2012). Freire (2008) coined this transmissive style of instruction as the *banking concept,* in which he explained that knowledge is deposited upon individuals, who are considered to know nothing, from those who consider themselves more knowledgeable. Similarly, conceptualizations of mathematics teaching purport the subject to be a content-focused set of static plans targeted at performing mathematical tasks using step-by-step procedures, as imparted by the teacher, with an emphasis on mastery of the discipline’s rules and procedures (Kuhs & Ball, 1986; Skemp, 1978). Notably, these models or approaches have not significantly enhanced students' skills at problem-solving in mathematics, but they may in fact inhibit students' critical, analytical, and creative thinking (Firdaus et al., 2015; Qolfathiriyus, 2019).

Fritz et al. (2019) admitted that mathematics, in general, is typically perceived as a difficult subject. Notwithstanding is the notion that this discipline plays a fundamental role in many professions, particularly science, technology, and engineering (Li & Schoenfeld, 2019). Unfortunately, mathematics performance in classrooms in the United States as well as on the international stage has been concerning. The acting commissioner for the National Center for Education Statistics (NCES), Peggy Carr, underscored that the results from the 2015 Program for International Student Assessment (PISA) indicated that U.S. students across the board, whether they were bottom, middle, or top performers were doing worse in mathematics compared to previous years (Barshay, as cited in The Hechinger Report, 2016). Despite this noted poor performance in mathematics, research has highlighted the importance of mathematics learning in students' overall academic success as well as its influence on students pursuing STEM-related fields. For example, Adelman (2006) pointed out that middle schoolers’ success in algebra is undoubtedly pivotal in their future academic success. More specifically, it functions as a critical gatekeeper that inevitably serves as a constraint to students’ decisions in pursuing further opportunities in science, technology, engineering, and mathematics (STEM) fields (Star et al., 2014).

In addition to concerns about test scores, there has been a re-energized interest in STEM with respect to the U.S.'s ability to develop future scientists, technologists, engineers, and mathematicians to continue being competitive in the global economy (Wang et al., 2011). Moreover, the Institute of Medicine (2007) recommended that the onus for laying "the foundation for developing a workforce that is literate in mathematics and science, among other subjects" (p. 112) is on the U.S. system of public education. The Institute of Medicine (2007) further stated that "it is the creative intellectual energy of our workforce that will drive successful innovation and create jobs for all citizens" (p. 112). One of the consequences of these concerns and recommendations is that the U.S.'s approach to mathematics education has been brought into question. One consideration to help enhance students' mathematical understanding and competency is to change the approach and integrate mathematics with other academic subjects (Burghardt et al., 2010; Chiappetta, 2009). Wang et al. (2011) further suggested that the problems being faced in our constantly changing, increasing global society are, in essence, multidisciplinary by nature and thus mandate the integration of multiple STEM concepts to generate possible solutions. Additionally, Burghardt et al. (2010) proposed that there needs to be more research that focuses on the beneficial effects of integrating STEM curricula into student learning, for example, connecting mathematics to engineering/technology education.

At present, there is no legislative stipulation that mandates integrated STEM education be adopted by schools. There are, however, national documents indicating a thrust towards the integration of disciplines. These efforts are more geared towards science classrooms. For example, The Next Generation Science Standards (NGSS) have incorporated engineering and technology within the science standards. Also, noting that within recent years, there have been projects and investments in resources aimed at teacher training, research incentives, and the provision of other opportunities to promote an integrated approach to STEM education (Li et al., 2020). Li et al. (2020), however, suggested these efforts were still considered limited in number and went on to hope additional projects encourage scholarship in which mathematics inclusion is factored in. Evidence of interdisciplinary approaches as reflected in curricular documents and other initiatives show the need to develop students' mathematical knowledge in real-world scenarios, as well as facilitate comprehension of problem-solving strategies and the effective application of these strategies (Florida Benchmarks for Excellent Student Thinking [B.E.S.T.] Standards for Mathematics, 2020; National Council of Teacher of Mathematics [NCTM], 2021; Singapore Science, Technology, Engineering, and Mathematics Applied Learning Programme, 2014). These initiatives show intentional efforts by policymakers for teachers and schools to adopt integrative techniques using two or more of the STEM disciplines, whether it is via the use of problem-based and project-based learning (PBL) or design challenges for addressing real-world situations. This thrust, augmented by the need for an increase in STEM literacy[1] among our students, offers increasing support for providing studies that attempt to give voice to teachers and strive to accentuate their conceptualizations, perspectives, and beliefs about integrated STEM education.

Throughout the literature, however, there is also a need for more research that reflects an intentional attempt to highlight an integrated STEM approach in mathematics

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[1] "STEM literacy includes the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues. It involves the integration of STEM disciplines and four interrelated and complementary components" (Bybee, 2013, p.31).

classrooms, as well as reiterate the critical role mathematical concepts play in integrated STEM education. Research in both these areas is relevant and beneficial for advancing education. Adopting an integrated STEM approach within mathematics teaching can help students appreciate the importance and applicability of mathematical concepts, as well as how this subject is interconnected with the other disciplines of science, technology, and engineering. An initial step in this direction should seek to elicit from teachers their conceptualizations of this phenomenon, particularly more so teachers in grades K-8. These primary grades from K-8 are foundational for student learning and ultimately student success. More specifically, Nadelson et al. (2013) suggested that elementary education forms the foundation of knowledge for science, technology, engineering, and mathematics. At this early level, the basis for children's cognitive, and by extension, their holistic development is established. Likewise, Woolley et al. (2010) noted that skills in the STEM areas acquired by middle school students are foundational for successful careers in STEM.

The paucity in research specifically addressing mathematics teachers' conceptualizations and enactment of integrated STEM education could result from several factors. One factor is the ambiguity that still surrounds the varied interpretations of this phenomenon. Another factor may stem from the fact that most of the integrated STEM research has been conducted in science spaces. For instance, Bybee (2010) and Martín-Páez et al. (2019), among others, have noted that there are multiple interpretations of what STEM education is, and ironically, these interpretations may or may not always involve an integration of the four disciplines. These nuances in regard to conceptualizing STEM education inevitably influence how it is effectively implemented in the classroom

(Breiner et al., 2012). Breiner et al. (2012) further explained that throughout the last decades, the primary focus was improving science and mathematics as isolated disciplines. Despite this observation that the understanding of STEM education has appeared to be disjointed in many spheres, Bybee (2010) recommended that it is still quite possible for an integrated curricular approach to be encouraged and applied to solve global challenges and contemporary concerns regarding energy, health, and the environment. English (2016) made a similar call and suggested a greater focus on STEM integration, with a more equitable representation of the four disciplines in studies, which will advance learning.

Integrated STEM knowledge and its applicability are being highlighted at many educational levels. Policymakers and other stakeholders have also attempted to facilitate an integrated stance to STEM education (NGSS Lead States, 2013; NCTM Principles and Standards for School Mathematics; Common Core Standards for Mathematical Practices). Noting NGSS Lead States (2013) has incorporated engineering design standards, and the NCTM Principles and Standards for School Mathematics has technology as one of its Six Principles for School Mathematics. More specifically, within the state of Florida, The Florida Department of Education (FLDoE, 2021) has defined STEM education as:

> … the intentional integration of science, technology, engineering, and mathematics, and their associated practices to create a student-centered learning environment in which students investigate and engineer solutions to problems, and construct evidence-based explanations of real-world phenomena with a focus on a student’s social, emotional, physical, and academic needs through shared contributions of schools, families, and community partners.
>
> http://www.fldoe.org/

As noted from this perspective, in addition to its interdisciplinary aspect, the FLDoE's concept has also infused an aspect of STEM education that highlights its functionality. The above definition suggests a collaboration of the disciplines in an effort to "investigate and engineer solutions to problems" as well as its application to the real world. As proposed by El Nagdi et al. (2018), real-world problems can be complex and inherently draw from multiple disciplines. El Nagdi et al. (2018) further advised that solving these problems goes beyond just having the ability to use design thinking and inquiry, it also requires proficiency to select the most appropriate "approach or combination of approaches that capitalize on the strengths of each way of thinking" (p. 2). Balka (2011) also pointed out a similar notion, where the conceptualization of STEM education was described as "the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems" (p. 7).

For the successful implementation of an integrated STEM approach in the mathematics classroom, one of the key stakeholders is the teachers. Their conceptualizations, perceptions, and beliefs are critical and must be factored into STEM education research, and perhaps influence the conceptual framework from which to proceed. Their voice is important for more reasons than one; primarily, these teachers are the ones who are entrusted with the responsibility to enact this approach in classrooms, and their conceptualizations can serve to inform decisions with respect to student learning outcomes, curriculum implementation, and pedagogical practices.

Integration of STEM Disciplines in Mathematics Teaching and Learning

Integration of STEM disciplines within mathematics teaching and learning ought to consider two critical ideas. Firstly, why the focus on mathematics and secondly, how do teachers view incorporating the integration of disciplines in their mathematics teaching. Mathematics could be seen as the underlying connecting thread in the STEM tapestry, mainly because mathematical concepts are inherently interwoven with many aspects of science, technology, and engineering. It can be challenging to imagine teaching many topics in science without students having the necessary prior mathematical knowledge for them to accomplish the lesson's objective(s). For example, if students are attempting to understand how a specific animal population is affected by pollutants over an extended period of time, this relationship can best be depicted and interpreted through the use of graphical representation. Additional content-specific examples include rates of change, displacement, scalar drawings, and forces. Muir (as cited in Limbaugh & Lewis, 1986) stated that "when we try to pick out anything by itself, we find it hitched to everything else in the universe" (p. 110). In the same manner, STEM disciplines are intertwined; therefore, pedagogical practices that attempt to employ and maximize these connections can be advantageous.

In a joint position statement from The National Council of Supervisors of Mathematics (NCSM) and the National Council of Teachers of Mathematics (NCTM), educators emphasized that the effective teaching of mathematics is a critical component of a comprehensive STEM program (NCTM, 2021). This statement further explained that mathematics, for the most part, transcends beyond the boundaries of the disciplines in STEM and encompasses knowledge and content that can be utilized as "tools for tackling integrative STEM problems” (p. 3). Hence, it is important for teachers to think about, and use integrated STEM instruction because of the many benefits that can be gained for both student learning and teaching approaches. When students are exposed to an interdisciplinary approach to learning STEM content within the mathematics classroom, in particular, there can be phenomenal benefits (Stohlmann et al., 2012). These benefits include the transfer of knowledge across disciplines, promotion of problem-solving skills, and contextual appreciation of mathematical concepts (Martinez & Ramírez, 2018; Shaughnessy, 2013). Moreover, to promote effective STEM education, Shaughnessy (2013) advised that mathematics teachers ought to make “mathematics more transparent and explicit” (p. 324), and further advocated that for the M in STEM to bear more prominence, there must be an intentional move to “shine the light on mathematics” (p. 324). Additionally, Shaughnessy (2013) proposed that there are three necessary ingredients that should constitute any STEM activity: 1) the solving of a problem, 2) significant mathematics embedded within the problem, and 3) the process should necessitate collaborative work that facilitates knowledge, skills, and approaches from other disciplines. This call for significant mathematics to be the main constituent in STEM activities exemplifies the importance for mathematics teachers to consider integrated STEM instruction. The mathematics classroom presents a window of opportunities to channel knowledge acquisition and transference of concepts to other disciplines. For example, a mathematics teacher who is teaching a unit of volume can use activities requiring measuring instruments common to science to seamlessly connect these two disciplines. Additional instances of what STEM integration looks like in the mathematics classroom will be discussed later on.

Integrating other disciplines within mathematics teaching is a promising approach that could successfully improve students’ mathematical problem-solving abilities. Integrated approaches can entail adopting some of the common tenets or elements of integrated STEM education (Johnson et al., 2020; Moore et al., 2014; Morrison, 2006) in mathematics classrooms. An integrated STEM approach is centered on elements that include: having the lesson concept(s) based on the real world, immersing students in hands-on inquiry and open-ended exploration, student-centered pedagogies, emphasis on teamwork and communication, and, most importantly, the integration of STEM disciplines (Moore et al., 2014; Shaughnessy, 2013; Thibaut et al., 2018a).

Some of these above-stated STEM practices are already being used by mathematics teachers, however, they are not necessarily in a format that reflects integration with other disciplines. For instance, at present teachers of mathematics often have students work in small groups to problem solve. Since teachers have an essential role in implementing such integrated STEM practices, it is imperative that research be conducted to explore and document their conceptualizations and enactment of this phenomenon.

Statement of the Research Problem

There is a critical need to improve students’ problem-solving skills in mathematics and by extension their conceptual understanding of mathematical concepts. One potential solution to facilitating the development and application of these problem-solving skills and understanding in mathematics teaching can be enhanced through the use of interdisciplinary approaches such as integrated STEM education. One of the most important change agents and catalysts in this facilitation are mathematics teachers. The pedagogical approaches which teachers tend to adopt in their classroom practices are a result of their conceptualizations, perceptions, and/or beliefs (Srikoom, 2017). Additionally, in an effort to speak to the policies and school structures that affect teachers' conceptualizations and enactment of integrated STEM, it is necessary to examine the factors that teachers identify as influential.

Currently, there is a dearth of literature that specifically explores how mathematics teachers conceptualize and enact integrated STEM education. Notably, much of the research in this area was conducted with in-service science teachers or pre-service teachers (e.g., Bartels et al., 2019; Dare et al., 2019; El-Deghaidy et al., 2017; Radloff & Guzey, 2016; Ring et al., 2017). Other research has sought to explore conceptualizations and/or perceptions of integrated STEM education for teachers in general (Bybee, 2013; Margot & Kettler, 2019; Smith et al., 2015; Srikoom et al., 2017; Vasquez et al., 2013; Wang et al., 2011). Specifically, Srikoom et al. (2017) advised that with regard to the integrated STEM approach, teachers' perceptions, as well as conceptualizations, are critical because these can influence teachers' decision-making in classroom instruction. These studies reiterate the importance of involving teachers in aspects of curriculum development as they are the ones who will ultimately decide if they will implement an integrated approach or opt to continue teaching each subject in isolation. Additional studies have captured the views, perceptions, and conceptualizations of integrated STEM education, however, the focus for these studies was specifically on science teachers (Dare et al., 2019; Ring et al., 2017). Also noting that, interestingly, there is also previous research seeking to determine how faculty in higher education institutions conceptualize STEM, such research has revealed an understanding of separate disciplines and not necessarily integrated descriptions (Breiner et al., 2012).

With respect to teachers' beliefs, more so that of mathematics teachers, Stipek et al.'s (2001) study sought to assess the relationship between their beliefs and practice. The findings from Stipek et al.'s (2001) study revealed consistent associations between teachers' beliefs and their practice. It should be noted that one's conceptualization of phenomena may ultimately affect one's beliefs. Negueruela-Azarola (2011) proposed that "beliefs as conceptualizations transform our cognition because they transcend our understandings in practice" (p. 361). It is therefore fundamental that we seek to investigate how mathematics teachers conceptualize what they teach as this will influence their beliefs, which are inevitably reflected in their everyday practice. It is worth considering that since there is a need for students to better understand mathematical concepts, especially through integrated teaching, it is important to initially assess where teachers are on this undertaking. Once this is accomplished and a change in teacher practice is needed, the first step in the transformation is changing teachers' beliefs. As Srikoom et al. (2017) highlighted, teachers' beliefs, conceptualizations, approaches to instruction, and student learning outcomes are inherently connected. Hence, it is necessary that research be done that attempts to elicit from mathematics teachers their conceptualization of integrated instruction. Also needed is the research that highlights teachers' enactment of integrated STEM education in their mathematics teaching, and the contributing factors that are critical to influencing these teachers in achieving and enhancing their classroom practice.

Purpose of the Study

The purpose of this phenomenographic case study was to investigate K-8 mathematics teachers' conceptualizations and their accounts of enacting integrated STEM education. This study also explored the factors that influence teachers' use of an interdisciplinary approach in their mathematics teaching. An understanding of these influencing factors can inevitably inform future policy decisions through which guiding and supportive measures can be operationalized to assist teachers in transforming and enriching students' mathematical experiences through the integration of STEM disciplines.

Research Questions

The following research questions were addressed to accomplish the above-stated purpose of this study:

1. In what ways do K-8 mathematics teachers conceptualize integrated STEM education?
2. What are K-8 mathematics teachers' accounts of enacting integrated STEM education in their classroom teaching?
3. What factors did these mathematics teachers identify as influencing their enactment of integrated STEM education?

Statement of Significance

This study has implications for education policy and schools' administrative structures with respect to pedagogical practices, particularly in the teaching and learning of mathematics. In this study, the researcher captured mathematics teachers' accounts of enacting integrated STEM approaches in their mathematics teaching. A look at the school or education system structures that influenced teachers' interest and abilities to facilitate integrating disciplines is covered. Knowledge of these structures is critical and plays a pivotal role in potential policy decisions and implications for effective teaching and learning of mathematics. Shernoff et al.'s (2017) preliminary findings reported that K-12 teachers are indeed interested in integrated approaches to STEM education, but they do not feel adequately prepared. Participants in that study, which included mathematics teachers, suggested that meeting the need for adequate preparation in integrated teaching, will require a great deal of rethinking and redesigning of teacher education policy (Shernoff et al., 2017). Such a redesigning of teacher education policies ought to capture practicing teachers' voices starting with how they conceptualize STEM integration, as is being currently addressed in this work.

The current study has implications for teacher preparation programs (pre-service) and professional development initiatives (in-service). One of its objectives is to bring to light and contribute to the change that is required in teacher training so that educators, in general, are exposed to and equipped with alternative approaches to effective mathematics education through STEM integration. Improving students' learning outcomes and interest in mathematics classrooms require a paradigm shift in the way this subject is taught and the environment that is created within these mathematics classrooms. Previous studies on integrated STEM education have noted the need for a shift in classroom practice and culture (Bruce-Davis et al., 2014; Lesseig, 2016; Margot & Kettler, 2019). In fact, teachers perceive that "STEM pedagogy requires some fundamental shifts in how they establish classroom environments and teach" (Margot & Kettler, 2019, p. 11), which, for example, can see classroom instruction changing from teacher-led to student-led. This change in role was identified as one of the common elements of STEM education (LaForce et al., 2016; Moore et al., 2014). This current work, through teachers' accounts of integrated STEM teaching, discovered to what extent such STEM pedagogical practices are a reality.

In this present study, I highlighted factors that K-8 mathematics teachers identified as influencing their enactment of integrated STEM education. Exploring these factors was an important component of this work because in spite of teachers' conceptualizations of integrated STEM, there are other conditions that impact their enactment of the phenomenon. As noted by Johnson et al. (2020), "Important to understanding how to cultivate early STEM learning is to consider the identified challenges, or perceived barriers… of STEM learning in the elementary grades" (p. 102). With there being absence of a common definition of integrated STEM education (Angier, 2010; Bybee, 2013; Dare et al., 2019), its enactment will be problematic. Thus, one of the main factors which inhibit teachers from enacting integrated STEM is the uncertainty of exactly what it means as well as "limited interdisciplinary understandings" (Ryu et al., 2019, p. 504). Ryu et al. (2019) also cited "school structures, curriculum, and instructional approaches" as impediments to implementing integrated STEM education (p. 504). Considerations of these factors can in turn inform recommendations and policy on how to encourage and ultimately support teachers in embracing and successfully executing an interdisciplinary approach to mathematics teaching and learning. A change in teachers' conceptualization and their practice, along with school administrative support and structural accommodations (Kennedy & Odell, 2014), can positively impact students' understanding of concepts in mathematics. Hence, the mathematics teachers' conceptualizations identified in this work, along with the intersection of how integrated STEM is enacted and factors, such as schools' administrative support have significance for student learning.

Assumptions and Delimitations of the Study

The following assumptions were taken into consideration. Firstly, mathematics teachers would willingly and openly share their conceptualizations and accounts of enacting integrated STEM education. To fulfill the requirement of an effective phenomenographic study, participants' truthfulness and unbiased understanding, beliefs, and implementation of the phenomenon being investigated are fundamental. Another assumption I made was that integrated STEM education is already being practiced to some extent by mathematics teachers in their classrooms; this was shaped by the intentional selection of STEM-designated schools in which teachers were actively working. Lastly, teachers' conceptualizations of integrated STEM education are paramount to their self-efficacy, classroom practice, and by extension student learning.

With respect to delimitations, participants were only recruited from schools within the South Florida education district. The study did not focus on mathematics teachers in general, instead, participants were specifically teachers who are currently teaching mathematics in K-8 STEM-designated centers. For the purpose of this study, K-8 STEM centers were categorized as schools with grades K-8 that have been so designated by their respective educational district, and hence a STEM curriculum is expected to be operationalized as part of the school's curriculum.

Definition of Terms

For the purpose of this study, the terms given below are defined as follows:

STEM: acronym used for science, technology, engineering, and mathematics

STEAM: acronym used for science, technology, engineering, arts, and mathematics

Integrated STEM Education: an intentional effort by teachers to combine two or more of the four disciplines (science, technology, engineering, and mathematics) within a lesson or unit with attempts to connect concepts from these disciplines in solving real-world problems (adapted from Smith & Moore, 2014).

STEM/STEAM designated school: a school with an identified STE(A)M designation program. Such a program encompasses a rigorous year-long process that focuses on areas such as state and national assessments, course offerings, teacher professional development, student competitions, showcases for all stakeholders, community partnerships while challenging today's digital learners through the infusion of higher-order thinking skills through a standard-driven intentional STE(A)M integration (adapted from Division of Academics - STEAM, 2022)

CHAPTER TWO

LITERATURE REVIEW

This chapter provides a review of the academic literature on STEM and integrated STEM education. It starts with defining integrated STEM education and then presents a conceptual framework for the study that draws from the literature. Also presented are some common elements and noted benefits of integrated STEM education to student learning and teachers' classroom practice. An examination of what integrated STEM could look like in the mathematics classroom is then provided, followed by a consideration of teachers' perceptions and conceptualizations of this phenomenon.

Integrated Stem Education

Defining Integrated STEM Education

The concept of STEM has its genesis with the National Science Foundation (NSF) in the 1990s (Bybee, 2010; Sanders, 2009). Bybee (2010) noted though, that when professionals in STEM-related fields were surveyed on their perceptions of STEM, most lacked an understanding of the acronym. Since there still exists some elusiveness and ambiguity in a common understanding of this phenomenon (Dare et al., 2019), what has been growing in interest is examining teaching that attempts to foster an integrative approach among the STEM disciplines. A distinct definition of STEM education is also still at times, opaque (Angier, 2010; Bybee, 2013; Vasquez et al., 2013). Angier (2010) reiterated that "everybody who knows what it means knows what it means, and everybody else doesn't" (p. 2). Bybee (2013) further noted that in many instances, there is a reference to the four disciplines, but that sometimes one discipline is emphasized, at other times the disciplines are presumed to be separate but equal, and still other perspectives reveal an integration of the disciplines. Even within this integrative perspective of STEM education, there exists variation and ambiguity for a clear-cut definition. Some definitions focus on aspects of the degree of integration among the disciplines. For example, Sanders (2009) highlighted the interconnectedness of the disciplines and stated that it ought to encompass approaches that “explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects” (p. 21).

By extension, other definitions go a bit further to state that knowledge of its applicability to the real-world is also critical. For instance, Vasquez et al. (2013) noted that STEM integration is “an interdisciplinary approach to learning that removes traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students” (p. 4). Similarly, Smith and Moore (2014) stated that “integrated STEM education is an effort to combine the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections among these disciplines and real-world problems” (p. 5). Additionally, Kelley and Knowles (2016) defined integrated STEM education as “the approach to teaching the STEM 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). Although these definitions may vary, it is clear that integrated STEM education must exhibit connections to the real-world in some way.

For this study, an adaptation of the definition provided by Smith and Moore (2014) was considered for integrated STEM education - an intentional effort by teachers to combine two or more of the four disciplines (science, technology, engineering, and mathematics) within a lesson or unit with attempts to connect concepts from these disciplines in solving real-world problems. With this definition in mind, it was best to select teachers who currently work at STEM-designated schools with the only changing variable being individual teachers' varied interpretations of the phenomenon.

Conceptual Framework

Mutch (2019) noted that curriculum theorists contrast two approaches to curriculum. The first maintains that, when the school disciplines are kept siloed, they maintain their original disciplinary boundaries. The second denotes a vision in which these disciplinary boundaries are less distinct, this category is referred to as an integrated curriculum. Kelly (2001) described an integrated curriculum as one that "implies learning that is synthesized across traditional subject areas and learning experiences that are designed to be mutually reinforcing...developing the child's ability to transfer their learning to other settings" (p. 553). This idea of transcending across disciplines as outlined by Kelly (2001) appears to be synonymous with the interdisciplinary nature of integrated STEM education.

For teachers to develop self-efficacy for interdisciplinarity in education, a clearer understanding of its meaning ought to be established and appreciated. It is critical that teachers know the underlying philosophy behind this approach before employing such pedagogies (Fulton & Britton, 2011). Repko (2008) explained that interdisciplinarity "is a process by which ideas, data, and information, methods, tools, concepts, and/or theories from two or more disciplines are synthesized, connected, or blended" (p. 3). Jacobs (1989) attempted to demystify integration within curricula and offer a continuum of curriculum integration options, ranging from concurrent teaching of related subjects to a fusion curriculum focus. Hence, Jacobs (1989) further defined interdisciplinarity as “a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience” (p. 8). Wernli et al. (2016) purported that the driving force behind interdisciplinarity is powerful science and societal needs. They reaffirmed the perspective that a collaboration of disciplines is a critical and necessary complement to each discipline.

Such complementing of disciplines is present in research that explores integrated STEM education. For this study, it is therefore worthwhile to examine common elements of quality integrated STEM teaching as addressed in the existing literature.

Common Elements of Integrated STEM Education

Moore et al. (2020) highlighted the absence of a consensus for defining STEM integration. In spite of this absence of a definition, what is clear in the literature is some agreement on common elements or tenets which should be found within effective integrated STEM education. These common elements reflect: (1) an interdisciplinary approach that seeks to connect STEM disciplines, (2) contextual learning in that student learning is facilitated within a real-world context, (3) problem-solving where students are encouraged to use previously acquired skills to problem solve, (4) student-centered pedagogies in which learning is facilitated through hands-on, inquiry-based approaches, and (5) communication/collaboration among students throughout the learning process. The following section highlights these common elements that are characteristic of effective integrated STEM education found in the literature.

Interdisciplinary

Stinson et al. (2009) pointed out that the “call for making purposeful connections across various academic disciplines is nothing new or exceptional” (p. 153). In fact, Berlin and Lee (2005) professed that there is considerable history in efforts made to link mathematics and science. Understandably so, as suggested by (Furner & Kumar, 2007), once done effectively, the “integration of mathematics and science could bring together overlapping concepts and principles in a meaningful way and enrich the learning context” (p. 186). In fact, Jolly (2014) recommended that STEM lessons include rigorous mathematics and science content, in which intentional efforts should be undertaken to connect and integrate the content from these two disciplines. Furthermore, Stohlmann et al. (2012) advised that research on a more authentic application of mathematics and science, which incorporates integration of these two closely related disciplines, provides a credible basis for teaching and appreciating integrated STEM education. Also noting that reform in science and mathematics education was sparked by events that surrounded the Sputnik launch (LaPorte & Sanders, 1995). This occurrence also contributed to a shift in educational reform that was geared more so toward science, mathematics, and technology education in the United States.

Hence besides science, there was intersectionality between mathematics and technology as well. In an attempt “to address possible roles of technology within STEM education” (p. 473), Ellis et al. (2020) underscored the “lack of a definition of the T in STEM education.” Even in the absence of a clear definition for technology within STEM, Kelley and Knowles (2016) have acknowledged the efforts of The Standards of Technological Literacy (STL) to establish “content standards for grades

K-12 that provide students opportunities to think critically about technology beyond technology as an object and in doing so prepare students to become technologically literate" (p. 6). Kenney (2011) has also noted that over time, there has been a gradual shift in terms of the implementation of technology in classrooms. Moreover, Ellis et al. (2020), in their summary of technology initiatives across science and STEM education, concluded that by using "authentic STEM tools and techniques, students can learn both the content and the practices of science, engineering, and mathematics" (p. 489).

On the other hand, the inclusion of engineering within STEM integration was also explored in the literature. Moore et al. (2014) suggested that for students to experience "high quality integrated STEM learning experiences" (p. 5), one of the features should be engaging them "in engineering design challenges that allow for them to learn from failure and participate in redesign" (p. 5). English (2016) concurred that engineering design and thinking, which are an integral part of K-12 engineering education, afford for essential linkages across STEM disciplines. The importance of discipline integration was also recognized and incorporated into the Next Generation Science Standards (NGSS). Its inclusion as part of its Science and Engineering Practices seeks to not only describe what scientists engage in as they investigate the natural world but also what engineers engage in as they design and build systems. In practice, an example of integration along with a call for an interdisciplinary approach to teaching was offered by Kopcha et al. (2017). More specifically, these authors sought to support the development of an integrated STEM curriculum in the teaching of robotics, here reference was made to facilitating students' learning of each discipline as well as the interconnections among the STEM subjects.

Real-World Context

Kelley and Knowles (2016) advocated that most of the content covered in STEM education can be grounded within situated cognition theory[2]. Foundational to this concept of situated cognition theory is the idea that the ability to understand how knowledge and skills can be applied is just as important as learning the knowledge and skills itself, and therefore, contexts are fundamental to the learning process (Brown et al., 1989; Vasquez et al., 2013) reiterated that an important facet of an integrated STEM program requires that the intended content be presented in a real-world context. Additionally, the work done by Dare et al. (2018) on understanding science teachers' implementation of integrated STEM curricular units was driven by a framework that included six major tenets for successful STEM education, the first of which was "a motivating and engaging context" (p. 4). The notion of making provision for the application of the combination of STEM disciplines with connections to real-world problems was also purported by Moore and Smith (2014). An example of situated integrated STEM education, specifically science and engineering, within a real-world context was explored by Barth et al. (2017) in which fifth-grade students, using prior knowledge of the water cycle, were required to design a water purification system. In accomplishing this task, Barth et al. (2017) professed that students' learning outcomes were enhanced via the integration of science and engineering instruction.

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[2] Situated cognition is the theory that people's knowledge is embedded in the activity, context, and culture in which it was learned. It is also referred to as "situated learning." (Brown et al., 1989).

Problem-Based/Project-Based

Kennedy and Odell (2014) purported the use of problem-based and project-based learning to support student learning. Although somewhat similar, these approaches can be differentiated. Krajcik and Blumenfeld (2006) described project-based learning as a constructivist approach that facilitates students' deeper understanding of concepts through engaging in investigation, exploring a question in a situated, authentic inquiry, while collaboratively problem solving to create a tangible product driven by a question. However, problem-based learning, on the other hand, is characterized by a skill in which students are placed in a "meaningful learning situation that is focused on the solution to a problem taken from a real situation" (Lou et al., 2011, p. 197). Lou et al. (2011) suggested that students can situate STEM knowledge in their lives via continuous problem-solving processes. To this end, problem-based learning strategies afford students opportunities to integrate and apply experience with STEM knowledge. A further distinguishing criterion for both of these closely related approaches is that when a project is used, the task is usually done over a longer period of time as a problem and hence a project-based approach allows students to be involved in activities such as organizing, investigating, or accomplishing and these ultimately lead to a tangible outcome. (Freeland,1926). However, Freeland (1926) continued to explain that the primary feature of a problem is to stimulate thought processing in students.

Integrated STEM education can be facilitated through problem-based and/or project-based learning, in such instances, students are usually working on coming up with a solution to a problem or working on an engineering design challenge (LaForce et al., 2016; Shaughnessy, 2013; Thibaut et al., 2018a). Specifically, Shaughnessy (2013) expressed that with respect to any STEM activity should consist of three fundamental ingredients, the first one being “a problem to solve” (p. 324). Shaughnessy (2013) further added that there ought to be significant mathematics embedded in the problem. Thibaut et al.’s (2018a) work on integrated STEM instructional practices explained that with problem-based learning “there is no predetermined end product and students are required to identify and define the problem on their own” (p. 6). These authors further highlighted that the goal of problem-based learning is primarily for student development of problem-solving skills by means of “going through a realistic self-directed problem-solving process” (p. 6). While Thibaut et al. (2018a) clarified that despite problem-based learning and project-based learning having similarities in that they were all student-centered, facilitate active student learning, and involved the use of authentic real-world problems, their pedagogical practices bore differences. According to Jacques (2017), project-based learning “is a cornerstone pedagogy for STEM/STEAM approaches in the classroom as it allows the integration of several disciplines within one project” (p. 428). Results from Jacques’ (2017) study reported that for the instances in which project-based learning occurred in mathematics teaching, there was primarily an integration of engineering principles with mathematics and science. Project-based learning was also highlighted by Kennedy and Odell (2014) as one element of engaging high-quality STEM education programs and curricula. Kennedy and Odell (2014) stated that such high-quality STEM education programs ought to “present a balance of STEM by offering a relevant context for learning and integrating STEM core content knowledge through strategies such as project-based learning” (p. 255). An example of a project-based approach within an integrated STEM context was presented by English (2019) in which fourth-grade students were required to design and construct their own pair of shoes.

Communication/Collaboration

In elementary classroom settings, students can be encouraged to work collaboratively in small groups through which they will be engaged in cooperative learning (Slavin, 2011). When students are presented with opportunities to collectively communicate concepts in science, mathematics, and engineering thinking through reading, writing, listening, and speaking, they are more prone to develop effective communicative and collaborative skills (Stohlmann et al., 2011). Moore et al. (2014) also noted that collaborative teamwork and communication are effectively facilitated through cooperative learning in integrated STEM sessions. Cooperative learning, as described by Siegel (2005), involves groups of students working collectively on completing a common task. Siegel (2005) further explained that cooperative learning is “a rich educational strategy because it affords elaborate student interactions” (p. 339).

Although not exclusive to integrated STEM education, collaboration through cooperative learning has been manifested as a common element in integrated STEM research throughout the literature (Bryan et al., 2015; Dare et al., 2018; Guzey et al. 2016; Shaughnessy, 2013; Thibaut et al., 2018). In fact, Dare et al. (2018) incorporated an emphasis on teamwork and communication as one of six tenets included in their research framework. During such teamwork and student-to-student collaboration, students are given opportunities to acquire cognitive and sociocultural development. This social component as purported by social cognitive theorists is a direct relationship between how individuals acquire knowledge through their observance of and interactions with other equally or more competent peers (Vygotsky, 1933, as cited in Moll, 1992). These social interchanges and experiences that occur during problem-solving activities can promote students' critical thinking skills (Hurst et al., 2013) and ultimately their sustained achievement. Such learning opportunities also create in students an appreciation and respect for their peers' opinions (Hurst et al., 2013). This level of collaboration and social interdependence (Johnson & Johnson, 2002) can be heightened when they are encouraged to work in different classroom layouts, these include whole class, small group settings, and/or in pairs. Within this type of cooperative learning setting, students are divided into small groups and are given opportunities to explore or discover a new concept collaboratively as they support and learn from their peers.

Student-Centered and Inquiry-Based

Another common element found within integrated STEM education research is an approach that facilitates student-centered and inquiry-based learning. Such approaches focus on more student-centered and hands-on techniques. In these instances, there is a shift in teaching away from a traditional method, where the teacher is the primary knowledge source and is often viewed as the epistemic authority in the classroom (Raviv et al., 2003). Zain et al. (2012) suggested that student-centered learning, as opposed to teacher-directed instructions in the classrooms, results in students being less passive in the knowledge acquisition process, more responsive, and they are able to relate to their learning experiences. Agreement on the use of student-centered pedagogies within integrated STEM lessons and activities was concurred by Guzey et al. (2016). These authors reiterated that pedagogical inclusion ultimately results in students acquiring better understanding and skills as they actively participate in STEM learning activities. In addition to meeting the needs of critical thinking as a 21st-century skill, Keiler (2018) suggested that research on student-centered teaching in STEM instruction also allows for students to take the leading role in the learning process instead of simply being passive recipients of teacher-initiated information. The use of inquiry-based learning in integrated STEM education also facilitates student-centered learning. Research has also noted in instances when teachers engage students in integrated STEM activities, they at times use instructional practices that foster such inquiry-based learning (Lai, 2018). With an inquiry-based approach, students are encouraged to participate in activities that promote problem-solving and experiential learning through exploration and guided high-level questioning.

Whether used singly or as different combinations, the elements outlined above were found to be common in instances in the literature among proponents of integrated STEM education. Table 1 below presents a listing of these common elements along with examples of research as noted in the literature.

Table 1

Common Elements of Integrated STEM Education

Common Elements of Integrated STEM Education	Instances in the Literature
Interdisciplinary	- Integrate technology and engineering into mathematical and science curriculum (Kennedy & Odell (2014) - Content integration of mathematics and/or science content and engineering (Moore et al., 2014) - An engineering design challenge of relevant technologies (Moore et al., 2014) - Draws on knowledge and approaches from several disciplines (Shaughnessy, 2013) - Integration of the content (Thibaut et al., 2018a)
Real-world context	- Water cycle to design a water purification system (Barth et al., 2017) - Provide a real-world context to students (Dare et al., 2018) - Science, technology, engineering, and mathematics applied to real-world situations (Kelley & Knowles, 2016) - Demonstrate understanding of STEM disciplines in an environment that models real-world contexts (Kennedy & Odell, 2014) - STEM disciplines interconnected in real-world problems (Moore & Smith, 2014) - Two or more disciplines applied to real-world problems (Vasquez et al., 2013)
Problem-based and Project-based	- Project-based learning – a cornerstone pedagogy for STEM/STEAM approaches Jacques (2017) - Problem-based and project-based learning to support student learning (Kennedy & Odell, 2014) - Problem-Based Learning (LaForce et al., 2016) - Problem to solve (Shaughnessy, 2013) - Problem-centered learning (Thibaut et al., 2018a)

Communication/collaboration	- Promote student communication skills and teamwork (Dare et al., 2018) - Teamwork and communication have to be at the core of STEM activities (Guzey, 2016) - An emphasis on teamwork and communication (Moore et al., 2014) - Students developed teamwork skills, critical-thinking and communication skills (Stohlmann et al., 2011) - Require teamwork (Shaughnessy, 2013) - Cooperative learning (Thibaut et al., 2018a)
Student-centered/Inquiry-based	- Student-centered pedagogies as a major tenet for successful STEM education (Dare et al., 2018) - Lessons and activities in an integrated STEM unit should be student-centered (Guzey, 2016) - Use of inquiry-based instruction can improve students' STEM education learning (Lai, 2018) - Personalized learning (LaForce et al., 2016) - Student-centered Pedagogies (Moore et al., 2014) - Student-centered pedagogies as an Integrated STEM Instructional Practice (Thibaut et al., 2018a)

Benefits of an Integrated STEM Approach to Mathematics Learning

Based on the common STEM elements highlighted above and their occurrences in the literature, exploring their benefits to student mathematics learning will be explored. Johnson et al. (2020) noted that fundamental to integrating the STEM disciplines is that they share similar big ideas and concepts, their integration allows for students to draw on the disciplines' content knowledge in different ways and ultimately make connections that facilitate the transfer of knowledge across disciplines. It is therefore beneficial to consider the gains of such an interdisciplinary curricular approach for mathematics teaching and learning.

There is an increased awareness and popularity of integrated STEM education in the U.S. and internationally. There are school districts and other entities that continue to promote integrated STEM-like activities and competitions, for example, the Southeastern Consortium for Minorities in Engineering (SECME) regional competitions. As stakeholders, inclusive of researchers in education and policymakers, attempt to advance a clearer and more coherent understanding of integrated STEM education, there is still some uncertainty as to what this should look like in the K-12 space. There is, however, an agreement that the approach should take the form of a combination of science, technology, engineering, and mathematics of some sort for it to manifest benefits and relevance (Bybee, 2010; English, 2016; Stohlmann et al., 2012). The models of interdisciplinary STEM education as purported by Bybee (2013) and Vasquez et al. (2013) have suggested benefits to learning STEM content; these models will be explored deeper later on. When students are exposed to an interdisciplinary approach to learning STEM content and within the mathematics classroom, in particular, there can be phenomenal benefits to student learning (Bennett & Ruchti, 2014; Stohlmann, 2019). Particularly noted by Stohlmann (2019) was a greater focus on student-centered learning and student motivation and interest. Additionally, some other noteworthy benefits for student learning are contextual appreciation, promotion of problem-solving skills, gains through collaboration, and enhancement of higher-order thinking through justification.

Appreciation for Interconnectedness of Disciplines

At the elementary level, many teachers are considered generalists, in that they teach more than one discipline. Hence the opportunity to integrate disciplines such as mathematics and science is more feasible. An integrated curricular approach with mathematics content is beneficial as it can afford students to have an appreciation of the interconnectedness of the disciplines and the role of mathematics in other disciplines. Stohlmann et al. (2012), for example, suggested that research on a more authentic application of mathematics and science, which incorporates integration of these two closely related disciplines, provides a credible basis for teaching and appreciating integrated STEM education. Pang and Good (2000) also argued for this discipline integrated approach as it improved students' scientific and mathematical understanding. Additionally, in real-world problems, the disciplines of science, technology, engineering, and mathematics do not occur as compartmentalized entities. Generally, the real-world application of knowledge is not siloed in the manner that is often taught in schools. In fact, to understand and solve problems, typically requires that individuals utilize a sometimes unidentifiable merging of the knowledge from multiple disciplines (Wang et al., 2011).

In addition to the benefits to student learning gained from a combined mathematics and science approach, technology use in mathematics learning must also be noted. Employing an integrated approach in mathematics instruction has the potential for productive use of digital and non-digital technology; its use is paramount as individuals acquire 21st-century skills. Technology use within the classroom setting is beneficial to both teachers and students as it can serve as both a teaching and a learning aid. The

NCTM's Principles to Actions (2014) clearly stated that an effective mathematical program ought to intentionally integrate the use of mathematical tools and technology as important resources which can assist "students to learn and make sense of mathematical ideas, reason mathematically, and communicate their mathematical thinking." Through an integrated STEM education approach in the mathematics classroom, students can be made aware of the power and extent of technology. In mathematics, technology can in fact be broadly seen as a "tool" that is used by the teacher to enhance the delivery of the content to students. It can range from the simple use of calculators to more technical devices such as smart boards, simulation applications, and other digital platforms. Students can also successfully use technology in mathematics classrooms; for example, using computers or tablets to conduct research, using calculators to perform a variety of computational tasks, accessing online manipulatives/tools, or using interactive games to reinforce mathematical concepts. The use of technological manipulatives and simulation in grades K-12 grades is effective in facilitating interactive mathematics learning and instruction. More specifically, students in grades K-8 can use technology in the form of online manipulatives to help them understand topics, for example, Place Value, Number Operations, and Fractions concepts.

Contextual Appreciation

When mathematics learning is presented in real-world contexts, this allows students to have a contextual appreciation and application for the mathematical concept(s) being developed. In this sense, a contextual appreciation indicates that students will acquire an understanding of the integral role mathematics play in their everyday lives and will value the importance of learning it. Students have oftentimes questioned the need for learning certain topics in mathematics with which they are unable to relate or see its importance (Larkin & Jorgensen, 2016). When presented with opportunities where they are made aware of the relevance of mathematical concepts, this may motivate students to learn and appreciate them. For example, if students are made aware of the importance of the geometrical knowledge that was needed for the precise construction of ancient Egyptian pyramids, noting that similar geometric concepts are needed in the construction of bridges and other everyday conveniences. Relevant contexts and situational learning can also accommodate the transference of knowledge to similar situations. These opportunities also set the stage for experiential learning. Kolb (2014) explained that experiential learning in education is a process in which knowledge is formulated via the transformation of firsthand experiences. Kolb (2014) further suggested that knowledge from these settings is the result of the combination of grasping and transforming the experience. Presenting mathematical concepts in a real-world context can be synonymous with problem-based learning. Hmelo-Silver and Barrows (2006) asserted that problem-based learning should constitute students collaboratively exploring authentic, rich, real-world problems.

Promotion of Problem-Solving Skills

Van de Walle (2019) suggested that one of the features of a worthwhile mathematical task for promoting problem-solving is that there should exist multiple entry and/or exit points. This opportunity can be accommodated in an interdisciplinary setting and prove to be beneficial to students' cognitive development. For example, a lesson on the linear transformation of enlargement or scaling can be presented in an environmental science context, in which the habitat for a group of ducks must be relocated to higher ground. Students, being allowed their choice of materials, will be required to create a scaled prototype for a structure that should be sturdy, as tall as possible, and cost-effective. When students are given this agency to choose their approach, strategies, and/or resources to attempt assigned tasks, it can enhance their creativity and ingenuity (Martínez & Ramírez, 2018) and in the case of the aforementioned scaled prototype example, facilitate a number of mathematical approaches. As they draw on their prior knowledge and repertoire of strategies or even invent 'new' strategies based on their experiences, it is expected that students will explore the multiple approaches and concepts from different disciplines to seek out solutions. For example, they can use electronic devices to do research on constructing tall structures, they will be engaging in engineering practices as they design and redesign their prototypes.

As previously stated, one of the common elements of integrated STEM education found in the literature is the use of problem- and/or project-based approaches. In the mathematics classroom, this approach can encourage them to be engaged in productive struggle as they make several attempts to problem solve. Hiebert and Grouws (2007) advised that when students 'struggle' in problem-solving to make sense of mathematics, this forms an essential component of learning mathematics with understanding. It should also be noted that in such scenarios students could learn from their mistakes or misunderstandings. Zager (2017) reiterated that "mistakes are golden opportunities for students to examine and refine their mathematical thinking" (p. 57), but unfortunately "it is rare for students to know how to turn a mistake into productive learning and growth" (p. 57). As students try to problem solve by exploring different ideas and conscientiously making sense of the mathematical concepts, they inherently 'stumble' through "a bunch of misunderstandings" (Zager, 2017, p. 56). The teachers' role is critical in these classroom experiences as success and effectiveness are pivotal on how well they can facilitate students' persistence and learn through their errors.

Gains through Communication/Collaboration

Effective collaboration among students can be accomplished when an integrated educational approach is done in the mathematics classroom (Shaughnessy, 2013). This level of collaboration can be heightened when they are encouraged to work in different classroom layouts, these include whole class, small group settings, and/or in pairs. Within this type of cooperative learning setting, students are divided into small groups (Slavin, 2011) and are given opportunities to explore or discover a new concept collaboratively as they support and learn from their peers through listening and speaking (Stohlmann et al., 2011). Particularly in mathematics, when students share mathematical ideas, strategies, and solutions, this communication can promote teamwork among them especially when they work on tasks in small group settings. Acknowledging here that allowing students to work collaboratively in groups is a dominant form of pedagogy used in both science and integrated STEM teaching. NCTM also considered the need for student collaboration, in its Mathematical Practices (MP 3). Noting in one of its Process Standards, NCTM outlined that students are expected to not only justify their conclusions but also effectively communicate them with others. In general, Tomlinson (2014) advised that for some students, the small group setting facilitates better learning than when they are in the whole group setting. Though not restricted to science, mathematics, or integrated STEM teaching, allowing students to communicate through small group collaboration makes for effective means of social interaction and development. When students interact socially with their peers in such educational settings, they elicit from each other different perspectives about the content being taught. The teachers' role here is to facilitate the learning process through guidance, appropriate questioning, and responsive listening. Empson and Jacobs (2008) defined responsive listening in the mathematical context as "listening in which the teacher not only intends to listen carefully to the child's thinking but also actively works to support and extend that thinking" (p. 270). In these settings, students should be provided with opportunities to explain their mathematical thinking while at the same time co-constructing knowledge from the thinking of others (Peterson & Leatham, 2009). César (1998) in a deep analysis of peer interactions, depicted the importance of the social aspects of learning mathematics in students' performance in mathematics classes. As students work in groups to solve mathematical problems which are embedded in interdisciplinary activities, they can draw on each other's prior knowledge, experiences, and strengths of the multiple disciplines.

Support Student-Centered/Inquiry-Based Learning

A constructivist approach to learning is one in which individuals construct knowledge rather than passively receiving information, in other words, learning originates from inside the learner (Kamii & Ewing, 2012). The use of student-centered and inquiry-based learning within mathematics teaching and integrated STEM education facilitates a constructivist approach to learning in that, students are the ones generating the knowledge and are integral to the learning process. The benefits of such approaches include enhancing students' higher order thinking, and motivation, especially in STEM activities (Keiler, 2018). As mentioned previously, student-centered pedagogies such as cooperative learning are prominent within integrated STEM education and were listed among the common elements found in the literature. In the same manner that student-centered and inquiry-based learning increases student engagement in integrated STEM learning as they discover and construct knowledge, this can also be the case in mathematics learning. In mathematics classrooms, when students are placed in groups to work collaboratively on a problem or project for which neither the procedure nor solution is known beforehand, they first experience cognitive dissonance (Piaget, 1975), from which they strive to regain equilibrium. As students work with their peers, they can develop dedication and persistence in problem-solving as they experience this disequilibrium and are engaged in productive struggle as they make several attempts to collectively figure out an appropriate strategy and solution. As they work on the problem together, this promotes their ability to work independent of the reliance of the teacher whose role in such student-centered classroom settings should be that of a facilitator (Clifton, 2006).

With respect to inquiry-based learning, although Lai's (2018) work was done at the college level, the findings are worth considering. By using inquiry-based strategies in STEM education, Lai (2018) concluded both students and teachers were satisfied with this approach. In that study, students approved the inquiry-based approach while teachers also expressed their approval and preference for inquiry-based instruction.

Integrated STEM Elements and Mathematics Curriculum Documents Overlap

Examination of the common elements for effective integrated STEM teaching revealed that there are existing overlaps between these and current mathematics teaching as encountered in the previous section which sought to explore the benefits of an integrated curricular approach in learning mathematics. In actuality, there are aspects of these elements are already found in mathematics curriculum documents, for example, the Principles to Actions - Ensuring Mathematics Success for All (NCTM, 2021); Principles and Standards for Mathematical Practices (NCTM, 2021); and Florida Department of Education - Florida B.E.S.T. Mathematics Standards (2021).

The overlaps with the common elements in integrated STEM education and mathematics curriculum documents include discipline integration, real-world context, problem-solving, and communication/collaborative work. Table 2 below displays the common elements within integrated STEM that are found in mathematics curriculum documents.

Table 2

Overlap: Common Elements in Integrated STEM Education and Mathematics Curriculum Documents

Common Elements in Integrated STEM	Mathematics Curriculum Documents	Supporting Reference/Description
Discipline Integration	8 Common Core School Standards	Use appropriate tools strategically (e.g., calculator, dynamic geometry software)
	5 Essential Elements of Mathematics Programs (Principles to Action-NCTM)	Integrates tools and technology to help students learn and make sense of mathematical ideas
Contextual Application	Florida B.E.S.T. Standards	MA6.DP.1.2 Given a numerical data set within a real-world context, find and interpret mean, median, mode, and range
	5 Essential Elements of Mathematics Programs (Principles to Action-NCTM)	Develop important mathematics along coherent learning progressions and develop connections to the real world
Problem-Solving	5 NCTM Process Standards 8 Common Core School Standards	Make sense of problems and persevere in solving them
	8 Mathematical Teaching and Learning Practices (Principles to Action-NCTM)	Implement tasks that promote reasoning and problem-solving
	5 Strands of Mathematical Proficiency	The meaningful and flexible use of procedures to solve problems MA.3.AR.1.2
	Florida B.E.S.T. Standards	Solve one- and two-step real-world problems involving any of

		four operations with whole numbers
Communication	5 NCTM Process Standards 8 Common Core School Standards	Construct viable arguments and critique the reasoning of others
	8 Mathematical Teaching and Learning Practices (Principles to Action - NCTM)	Facilitate meaningful mathematical discourse

Based on the presence of these integrated STEM common elements within mathematics curriculum documents, for this study, it is worth exploring what K-8 integrated STEM instruction looks like and speak to what is currently being done. Firstly, one needs to consider the hierarchical process involved in implementing educational initiatives. It is primarily a top-down process where policies related to education are established at levels where the intended standards are formulated, these are then disseminated to departments of education and districts, and then further channeled to schools and teachers for classroom practice. Bullough and Gitlin (1985) reiterated school reform tends to adopt a top-down model, and they further recommended that in actuality, meaningful school reform can indeed be a bottom-up initiative. In fact, Skedsmo and Huber (2019) noted that top-down models may not have a positive influence on school development and student learning outcomes as bottom-up approaches. Furthermore, Skedsmo and Huber (2019) warned that top-down models seem to in fact “produce a range of unintended consequences, and perhaps questions could be raised as to whether they are in danger of contributing to the de-professionalization of teachers” (p. 4). Hence, one of the objectives of this present research is to take K-8 mathematics teachers’ conceptualizations and experiences into account and afford them an opportunity for their voices to be heard.

With regard to integrated STEM education, the extent to which what occurs in the classroom actually coincides with what is outlined in policy documents is still indecisive and could perhaps be a bit controversial (Martín-Páez et al., 2019). A study that explores the different ways that mathematics teachers conceptualize integrated STEM education may bring to the surface some of these disconnects as they relate to mathematics teaching and learning. Many school districts in the U.S. are intentionally exploring initiatives to engage students in STEM education as well as eliciting support in conceptualizing exactly what this should look like in the classroom (Stohlmann, 2019).

STEM integration can be factored into the mathematics curriculum at varying levels as presented in the following examples. Based on present school systems, these accommodations can be accomplished through the mathematics content standards, the effective planning of instructional units/models, and intentional classroom practice. Bennett and Ruchti (2014) presented an overarching perspective to revisiting the Standards for Mathematical Practices (SMP) through STEM lenses. These authors offered a common framework and proposed to inform educators as to how integrative STEM is conceptualized across the different grade levels. The examination of the eight Standards for Mathematical Practices (SMP) was specifically done in an effort to demonstrate how these practices span beyond mathematics and bridge other STEM disciplines. Parallels were drawn among the practices for these four disciplines; for example, how the practice which states “make sense of problems and persevere in solving them” can be straddled across mathematics, science, and engineering. Several experiences, student-centered in nature, were presented with explanations as to how the four STEM disciplines could “infuse each SMP to promote a cohesive approach to developing STEM reasoning” (Bennett & Ruchti, 2014, p. 20).

Based on the cross-referencing done above the overlap with the common elements as identified in the literature and the mathematics curriculum documents are evident. This shows that there already exist these common elements for integrated STEM education embedded in several mathematics curriculum documents. Hence, when mathematics teachers use these documents as guides in their classroom, they employ some of these elements. To what extent mathematics teachers are aware of this warrants some investigation. Hence, it would be worthwhile to consider what are teachers’ perceptions, conceptualizations, and beliefs of integrated STEM education.

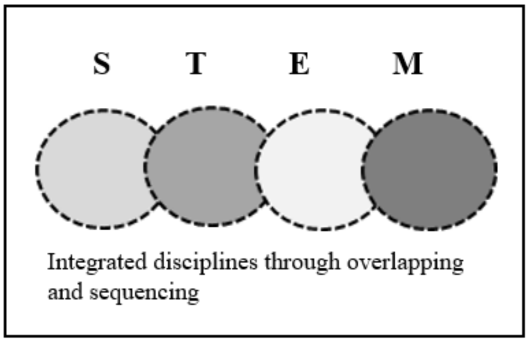
Perceptions, Conceptualizations, and Beliefs of Integrated STEM

In an effort to consider mathematics teachers’ perceptions and beliefs about integrated STEM education, it is worth exploring how teachers in general and researchers in education perceive this phenomenon. Srikoom (2017) noted that there is a need to identify how teachers and even students think about integrated STEM education in order to advance it. Srikoom (2017) further suggested that STEM integration may be perceived differently based on a person’s background, attitude, job title, teaching styles, and other factors.

In an attempt to traverse the variation in perspectives of STEM integration, Bybee (2013) compiled a listing of nine common descriptions that may be reflective conceptualizations of this phenomenon. These interpretations were derived from a series of discussions, articles, reports, and projects. The interpretations ranged along a continuum which increased in the degree of conceptualization from left to right, on one end it is perceived as a standalone discipline, for example, mathematics or science. The other extreme veers towards an understanding that connotes an interdisciplinary then a transdisciplinary merging of its sub-disciplines. In Bybee's (2013) continuum, the first version reflects a more multidisciplinary approach to STEM education and is in keeping with what is being done in many classrooms, where the discipline is taught as a standalone subject and oftentimes students may not be exposed to any connectivity with other disciplines. As we move along the continuum, it is observed that STEM is viewed as science or mathematics as a separate discipline, with some attempts to incorporate technology and/or engineering as appropriate. One perception considers STEM as a quartet of separate subjects in which the four disciplines are covered separately or as separate units in one course. From another perspective, Bybee (2013) explained that the phenomenon takes on the idea of beginning to reflect some coordination across the four disciplines. Yet another interpretation perceives STEM as any combination of two or three of the disciplines. The eighth perspective, referred to as Integrated Disciplines, depicts an overlapping and sequencing of the disciplines, where STEM is the primary emphasis of the students' educational experiences (Figure 1). The final interpretation reflects an all-encompassing perspective embracing a transdisciplinary approach that involves students considering a major issue where there is a mixing of the disciplines as well as other non-STEM disciplines.

Figure 1

STEM Means Complementary Overlapping across Disciplines



Note: STEM can be integrated by sequencing disciplines in units or courses, or in lessons so STEM becomes a central emphasis of the educational experiences. Adapted from Bybee (2013).

These latter perceptions on the continuum, as outlined by Bybee (2013), represent intentional integration with respect to STEM education, affording for the complementary and almost seamless overlapping across the disciplines when presented in lessons, units, or courses. This interdisciplinarity in approaches is aligned with the ability to solve problematic situations which necessitate tools, knowledge, and theories from multiple disciplines and eventually lead to developing students' skills base (Klein, 1990). The degree and clarity in this interconnectedness of the disciplines appear to be one of the issues leading to a variation in conceptualizations of integrative STEM education among educators and researchers.

Similar to Bybee's (2013) models presented above, comparable models of STEM integration have been offered. For example, Vasquez et al.'s (2013) proposal for the conceptions of integrated STEM also reflects increasing levels of integration of STEM disciplines. Unlike Bybee's (2013) model, which has nine different interpretations, Vasquez et al. (2013) presented a set of four. These degrees ranged from *disciplinary* -

concepts and skills learned separately; *multidisciplinary* - concepts and skills learned separately but within a common theme; *interdisciplinary* - concepts and skills are closely linked from two or more disciplines aimed at deepening knowledge; and *transdisciplinary* - knowledge and skills learned from two or more disciplines with real-world application.

While the two contributions to the conceptions of integrated STEM education above involved both interpretations that looked at both content integration as well as variations of pedagogical approaches. Becker and Park (2011) presented additional models for variations in the conceptualizations of integrated STEM, which predominantly reflected the content of content integration for varying combinations of science, technology, engineering, and mathematics. Becker and Park’s (2011) work offered a meta-analysis of 98 studies investigating the effectiveness of integrated approaches among STEM disciplines. Among these approaches were varying permutations of models for at least two disciplines; engineering (E), mathematics (M), science (S), and technology (T), these included: E-M-S-T, E-S-T, E-T, M-S-T, E-M, E-S, M-S, and S-T.

Overall, the outlines above speak to definite variations in conceptualizations and perceptions of integration among the STEM disciplines, the major difference being a focus on solely content integration versus a mix of pedagogical approaches and content integration. An additional component to interdisciplinary teaching is the inclusion of the visual and performing arts, hence the emergence of the acronym STEAM (science, technology, engineering, arts, and mathematics).

The State Education Agency Directors of Arts Education (as cited in Huser et al., 2020) describes STEAM as “an intentional, collaborative pedagogy for teachers that empowers learners to engage in real-world experiences through the authentic alignment of standards, processes, and practices in science, technology, engineering, the arts, and mathematics" (p. 1). Dell'Erba (2019) further noted that including the arts in STEM education offers an opportunity to enhance students' cognitive development in meaningful and intentional ways.

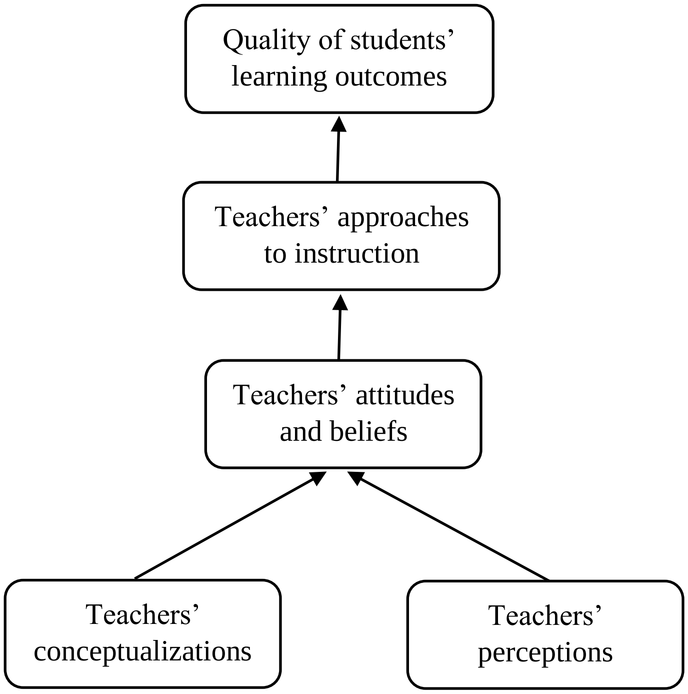
In as much as there exist these multilayered interpretations within existing literature for integrated STEM education, it is understood why researchers would experience challenges in attempting to formalize a definite model or conception for which there is unanimous agreement. Consequently, teachers as well may have challenges in conceiving this phenomenon as there is no specific framework with which they can adopt or be guided for their classroom practice at this time. Hence, there is no surprise that there also exists a vast variation among teachers in terms of their conceptions or perceptions of integrated STEM education. Research confirms that variations in teachers' conceptions exist (Radloff & Guzey, 2016; Ring et al., 2017). Ring et al. (2017), for instance, explored how teachers not only possessed different conceptions of integrated STEM but these conceptions transformed over a professional development experience. These notable shifts in conceptions can be paralleled to aspects of the models proposed above by Bybee (2013) and Vasquez (2013). Throughout the iterations that tracked participants' changes in their conceptions, the shifts revealed a tendency to more "discriminate and complex" models (p. 462).

Moreover, Wei and Chen (2020) suggested that individuals, inclusive of teachers, possess their own perception of integrated STEM education, and notably, they understand, accept, resist, and at times may circumnavigate existing policies. In most instances, what maps out as integrated STEM education in mathematics classrooms could be reflective of the teachers' conceptualizations, perceptions, beliefs, and attitudes towards this phenomenon.

Teachers' conceptualizations, perceptions, and beliefs about integrated STEM education will ultimately impact/influence both their content and pedagogical knowledge, their classroom instruction, and students' learning outcomes as illustrated in Figure 2 below (Al Salami et al., 2017; Srikoom, 2017). Also sharing a similar notion, however more specific to STEM, Margot and Kettler (2019) affirmed that educators, persons who are critical in the holistic development of students, have prior views and experiences which are influential in their STEM instruction. Moreover, Wong and Dillon (2019) shared that in general, teachers' use of an integrated approach in their teaching is influenced by their perceptions and competencies.

Figure 2

Teachers' Conceptualization and Perceptions in Relation to Student Learning Outcomes



Note: Adapted from Srikoom et al. (2017) - Perceptions of in-service teachers toward teaching STEM in Thailand. *Science Learning and Teaching, 18*(2), p. 5.

Some teachers believe that when students are exposed to an integrative STEM curriculum, they are motivated to learn (El-Deghaidy et al., 2107; Lesseig et al., 2016; Margot & Kettler, 2019). The findings of Margot and Kettler (2019) revealed that teachers found integrating STEM education was "inherently motivating to students" (p. 10), the participants in this study stated that when engineering was incorporated into their mathematics and science curricula, it brought life to those disciplines. Lesseig et al. (2016) documented findings showing that teachers found that students seemed to be both motivated and empowered by open-ended challenges in STEM.

It is also important for teachers to note that effective learning can be facilitated when students are actively engaged (Aldemir & Kermani, 2017; Bruner, 1966; Dewey, 1938). Dare et al. (2014) acknowledged teachers’ perception that the use of hands-on activities within integrated curricula contributed to classroom success. The use of this student-centered approach to teaching integrative STEM is beneficial to student learning and can be accomplished via the use of problem-based and project-based learning. Erdoğan et al. (2016) indicated that for some teachers these types of learning approaches are essential when teaching STEM areas and introducing STEM-related issues that are relevant to students’ everyday lives. Teachers also expressed appreciation for the interconnectedness of disciplines in STEM education. Margot and Kettler (2019) stated that teachers perceived that the cross-curricular nature of integrated STEM education manifests beneficial attributes.

Despite these beneficial features of using integrated approaches to teaching and learning, some teachers’ perceptions are that they feel underprepared to effectively execute it in their teaching (El-Deghaidy, 2016; Margot & Kettler, 2019; Nadelson et al., 2013; Shernoff et al., 2017; Srikoom et al. 2017; Stohlmann et al., 2012). Nadelson et al. (2013) attributed K-8 teachers’ perception of unpreparedness and lack of confidence in teaching STEM content to the minimal amount of STEM education that was required by most elementary teacher education programs. This was also evident in focus group discussions with teachers, in which participants identified the need for pedagogical content knowledge to support their implementation of STEM education (El-Deghaidy, 2016). In addition, Shulman (1987) offered that a teacher’s self-efficacy in STEM teaching is contingent on three factors: adequate background knowledge in the respective disciplines, pedagogical content knowledge - the ability to efficiently disseminate that knowledge and understanding to students, and confidence in both areas.

Teachers have expressed a desire for change. Lesseig et al.’s (2016) findings highlighted teachers’ desire of the need to foster a “culture of inquiry” (p. 181) also that implementing STEM-related activities necessitated a major shift away from teacher-directed instruction. Both teachers and administrators throughout STEM schools agreed with the significance of shifting classroom practices to opportunities that challenge students to engage in thinking that is more critical and creative via the means of authentic learning experiences (Leeseig, 2016).

The preceding sections highlighted some of the variations in conceptualizations, perceptions, and beliefs of integrated STEM education. Critical to initiatives in facilitating mathematics instruction that incorporates an integrated STEM approach is considering of teachers’ conceptualizations and perceptions of this phenomenon. As noted by Bybee (2013), the intent ought not to be to assess and make a judgment as to which perception is the “correct” or “most acceptable,” but rather to heighten the awareness of these among the necessary stakeholders. The main effort is to clarify and categorize the varying perspectives and conceptions so that this can inform any attempt to facilitate and advance initiatives relating to promoting integrating STEM education and using this knowledge effectively in the future, particularly when teaching mathematics.

Factors Influencing Integrated STEM Education Enactment

Factors in implementing integrated STEM education are variables that are either positive or negative in influencing teachers to enact integrated STEM education. A review of the literature showed that there were a number of such factors.

English (2016) noted that “one of the problematic issues for researchers and curriculum developers lies in the different interpretations of STEM education and STEM integration" (p. 2). As a result of these multiple interpretations, deriving an established definition makes it challenging. As noted by Moore et al. (2020), the fact that "a single, consensus definition of STEM integration does not yet exist" (p. 10) poses a challenge in any attempt to advance STEM education. Together with teachers' own conceptions of STEM integration, this lack of definition (Angier, 2010; Bybee, 2013; Dare et al., 2019; Vasquez et al., 2013) also has implications for them enacting this phenomenon in classroom teaching (Nadelson et al., 2013). In their study, Ryu et al. (2019) also reported that for teacher participants "The limited understanding of the relations between STEM subjects restricted the scope of integrated STEM lessons." Additionally, Lamberg and Trzynadlowski (2015) concluded that educators, both general elementary school teachers' and some STEM teachers' approaches to STEM education reflect uncertainty.

Even with an established definition for integrated STEM education, without the needed support systems in place, there still can be challenges. One critical source of support for teachers stems from their school administrations (Ernst, 2017). A lack of support from administrations, for example, the absence of the necessary school structure in place will negatively affect teachers' initiative to enact STEM integration (Ryu et al., 2019). Such school structures should include the availability of resources, workshops, and collaborative planning time for teachers. Other factors highlighted by Ryu et al. (2019) as being counterproductive in effective integrated STEM implementation include curriculum and instructional approaches. Such instructional approaches and strategies used by teachers to facilitate STEM integration are dependent on teachers' pedagogical knowledge of the respective disciplines separately and collectively, as well as their beliefs and self-efficacy in the approaches. Based on the results of Nadelson et al.'s

(2013) findings on teachers' self-efficacy, confidence, and attitudes toward STEM education, it was noted that the extent to which STEM education is covered in teacher training programs may contribute to K-8 in-service teachers' beliefs. One suggestion for addressing factors such as unpreparedness, lack of confidence, and self-efficacy in implementing integrated STEM education as perceived by in-service K-8 teachers is ongoing professional development (Loucks-Horsley et al., 2010).

The literature also indicates that while professional development workshops are critical, teachers can also take initiatives to seek out opportunities to make themselves more knowledgeable and apt in improving their pedagogical and content knowledge and ultimately their practice. These initiatives, Huiskamp (2002) referred to as participatory action research. In this type of action research, individuals self-consciously engage in incremental and dynamic steps in an effort to transform and positively impact their environment through their own practice.

Another factor that affects teachers, in general, to provide students with opportunities in student-centered learning as with integrated STEM activities is insufficient time. Research has noted that time affects teachers' planning, implementation, and creativity in instruction (Carless, 2003; Shernoff et al., 2017). Based on findings from Carless' (2003) study done on primary schools in Hong Kong, teachers perceived that the "pressure of time presents some barrier to the implementation of task-based teaching" (p. 493) as in the case when enacting integrated STEM activities. Shernoff et al. (2017) concurred that those opportunities for teachers to plan collaboratively and teach STEM integration were impacted by the schools' schedules.

In general, varying interpretations of STEM and integrated STEM education, the importance of schools' administrative support, teachers' beliefs and self-efficacy, and time availability were identified in the literature as some factors influencing teachers' enactment of integrated STEM education in their classroom teaching. For the most part, these factors outlined above had more of a negative effect on teachers' enacting integrated STEM teaching.

Summary

This chapter presented a review of the literature pertaining to definitions and interpretations of integrated STEM education, this was followed by a conceptual framework on interdisciplinary education on which the study was premised. Common elements of integrated STEM education and the benefits of an integrated STEM approach to mathematics learning were explored. After which insights into the overlap that currently exists with the presented elements and mathematics curriculum documents followed. Then the perceptions, conceptions, and beliefs of integrated STEM were presented. Finally, the chapter examined the factors identified as influencing the enactment of integrated STEM as noted in the literature. The following chapter outlines the methods used in this work.

CHAPTER THREE

METHODS

Introduction

The purpose of this phenomenographic study was to develop a deeper understanding of the different ways mathematics teachers in grades K-8 conceptualize integrated STEM education. This study sought to contribute to the literature on conceptualizations of integrated STEM from mathematics teachers' perspectives. Also considered were teachers' accounts of their enactment of integrated STEM teaching and factors they identified as influencing their classroom practices when integrating disciplines.

This chapter first presents the research questions used to address the study's purpose, then an autobiography on my experience conceptualizing integrated STEM education, followed by a phenomenographic framework for the study. The data sources, data collection process, and data analysis are also described in detail. The ethical considerations are presented followed by a summary of the chapter.

Research Questions

To accomplish the objectives of this study the following research questions were explored:

1. In what ways do K-8 mathematics teachers conceptualize integrated STEM education?
2. What are K-8 mathematics teachers' accounts of enacting integrated STEM education in their classroom teaching?

3. What factors did these mathematics teachers identify as influencing their enactment of integrated STEM education?

Researcher Autobiography

Tenni et al. (2003) noted that an essential and expected feature of much research is for the researchers to reflect on and document their own lived experiences and practice as they relate to the study. Engaging in such retrospective activity can help to frame the researcher's interest and choice for the topic. I believe reflecting on my experiences as a mathematics teacher and teacher educator assisted me in understanding the experiences of the participants in this study. Additionally, this reflection helped me understand my journey in experiencing the phenomenon.

The following section gives a synopsis of my introduction to STEM education and a brief account of my experience with conceptualizing this phenomenon.

My Conceptualizing of STEM Education and Integrated STEM Education

> "…education is transforming Liz, and so too is teacher education...we are moving away from that all too familiar transmission approach in teaching to a more transformative approach…to be an effective mathematics teacher educator you must get acquainted with cutting edge research and practices in education and bring these to your pre-service teachers (PSTs)...Inclusivity, STEM education, Differentiated Instruction..."

I received this advice from Dr. L. Simmons, who was then head of Elementary Mathematics Education at the University of Trinidad and Tobago (UTT), back in 2013 when I was a neophyte in teacher education; it was my first encounter with the term STEM. Dr. Simmons and I had many thought-provoking educational conversations when she would jokingly say, “I am on my way out, but you are on your way in, I am passing on the baton.”

My self-designated task that weekend, when she first shared these terms with me, was to do some research on these “cutting-edge research and practices in education.” As I researched STEM education, I thought to myself that it was straightforward. I would just tell my teacher trainees what the acronym meant and explain to them that when they teach mathematics, they should try to incorporate some aspects of science, technology, and/or engineering; that was my conceptualization at that time. This was an approach that I could certainly relate to - the idea of linking the disciplines - as I always perceived that mathematics content was oftentimes being taught in a way that was static and detached from everything else. I planned my first “STEM lesson” for my group of year four PSTs, all of two PowerPoint slides: the first explained the acronym and a bit on its inception and the second attempted to elicit from these teachers their ideas about how to transform mathematics lessons in a way that attempted to incorporate the other three disciplines. In retrospect, I admit that my superficial and limited conceptualization of STEM education resulted in a very cursory teaching of this phenomenon. That first lesson, however, morphed considerably in the following semesters and I truly started developing an interdisciplinary approach within my mathematics education courses. I proceeded in promoting a clearer understanding to the PSTs of what STEM education and integrated STEM education were, based on the existing literature that was available. Lessons became more informative and engaging while simultaneously becoming less teacher-directed. I made efforts to not only explain the acronym but to have these teachers delve deeper, explaining and exploring what STEM education is, requiring them to engage in research that highlighted why STEM and STEM education are important. By the fourth semester, teaching STEM education became a full module in the course. Teacher trainees closely examined their mathematics lessons and identified other embedded science, technology, or engineering concepts. They created lessons with activities that addressed objectives from both science and mathematics curricula, using technology where needed, and they gradually shifted their mathematics lessons to more problem-based and project-based learning.

Fast forward to 2018, I started as a graduate assistant with the Department of Teaching and Learning at Florida International University (FIU). My duties were assisting in two elementary methods courses, coincidentally one in mathematics and one in science. This was yet another experience that helped revolutionize my conceptualization of STEM education. I noticed that more emphasis was placed on this phenomenon in the science methods course than in the mathematics methods course. On examination of the literature, I understood why this could probably be so; there was exceedingly much more research and focus paid to STEM in science and science education spaces. As I observed the science lessons that focused on STEM education, I gained more insight and a deeper understanding of the concept of integrated STEM education. I witnessed PSTs being involved in hands-on activities that incorporated an intentional merging of STEM disciplines, and I watched with great interest their enthusiasm and appreciation for this integrated approach to education.

When I had the opportunity to be the instructor of record for a section of one of the mathematics methods courses at FIU shortly afterward, I also attempted to infuse a lesson on integrated STEM. I believe at this point I had a more conceptually coherent understanding and felt more confident in engaging students with this phenomenon. My experience and knowledge were also complemented by a graduate course in STEM education research that I enrolled in, coupled with attendance at mathematics education conferences.

Throughout these experiences, my knowledge, conceptualization, perception, and beliefs about integrated STEM education have evolved along with my interest and appreciation of its benefits. Collectively, these experiences have contributed to constructing my own reality of integrated STEM education and have subsequently informed and positively impacted my practice.

Phenomenographic Framework

Wellington (2000) suggested that reality is a human construct and with this premise in mind, it is understood that there can exist a multifaceted view of any phenomenon. Hence, there is no single view of the world, a real-world "*out there"* and a subjective one "*in here"* (Bell, 2016; Marton & Booth, 1997). This notion, as Marton (2000) explained, gives rise to a "non-dualistic ontological approach" (p. 105) regarding conducting research. This is an approach where knowledge is not restricted but integrates multiple perspectives of knowing, actions, contemplation, and overall sense-making.

This variety in perspectives can be manifested in a phenomenographic study. Phenomenography has its philosophical orientation embedded within the interpretivist paradigm, which purports that reality is conceived to be multi-layered and complex; hence, a single phenomenon can yield multiple interpretations across a group of individuals. Phenomenography, as described by Marton (1986), is a "research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of phenomena in the world around them" (p. 31). Since this type of study investigates how individuals perceive and conceptualize a phenomenon, the researcher's primary focus is centered on the "act of perception and conceptualization itself" (p. 144). Marton (1986) advised that the researcher should strive to encapsulate the process of perception and thought in general terms. Within this context, he further explained that "research is never separated from the object of perception or the content of thought" (p. 144). Phenomenographic studies afford the researcher the opportunity to discover the varied understandings individuals have of a phenomenon and then attempt to classify them into conceptual categories. The purpose is not necessarily to describe things as they are, nor is it important to ponder whether they can be described as they are; rather, the aim is to make attempts to hone in on and characterize how things appear to people (Marton, 1986). Bell (2016) also emphasized that phenomenography as an approach to research is intended to describe a phenomenon, and ought not to seek explanation, justification, or assigning of meaning to it. A phenomenographic approach to research is a process that reflects more on discovery as opposed to verification with the intent of highlighting variation in the collective, which unearths alternative views instead of focusing on the individuality of experiences (Åkerlind, 2005; Marton & Säljö, 1997).

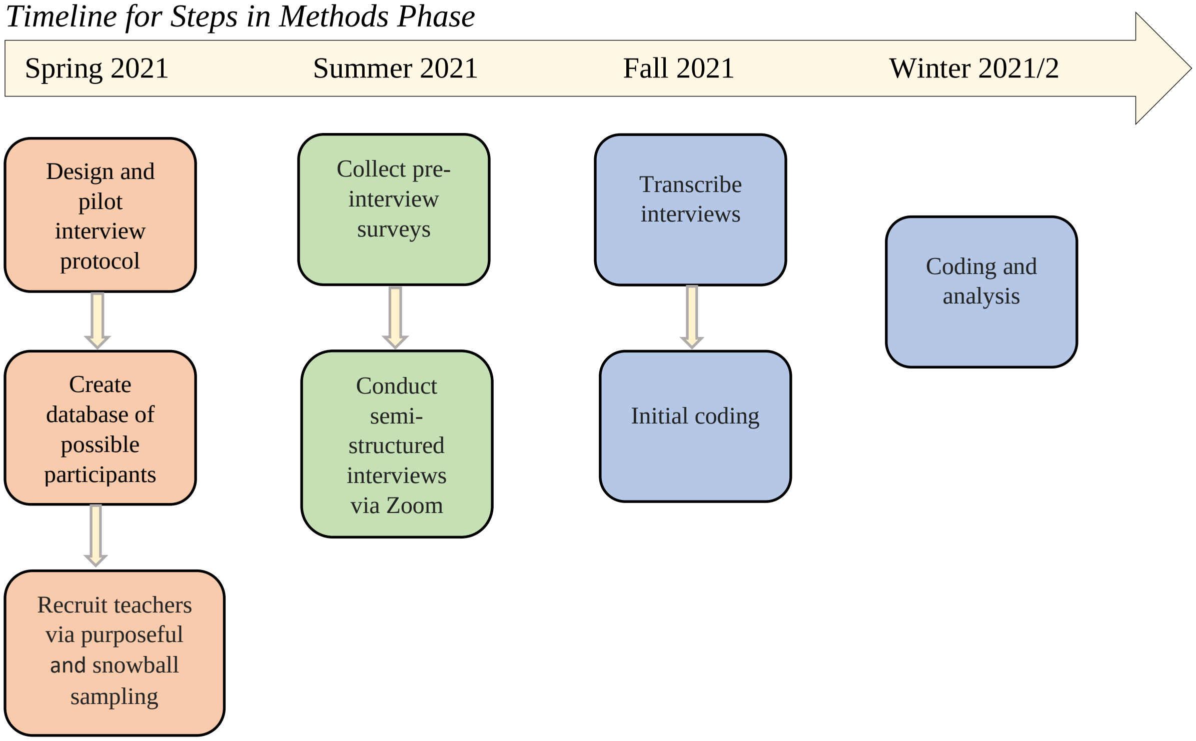
Regardless of what the phenomenon of study is, there are a limited number of ways in which it can be described (Marton, 1994). When conducting a phenomenographic study, the researcher must be mindful that their own perceptions or preconceived notions are not unconsciously filtered into what is being studied, but rather reflect the awareness, thoughts, and reflections of the participants. This practice is referred to as bracketing (LeVasseur, 2003). Despite bracketing having its origins positioned within phenomenology (Tufford & Newman, 2010), it has transitioned into phenomenographic studies, understandably so, since phenomenography is an offshoot of phenomenology. It is also important to note that one of the primary objectives of phenomenographic research is to “investigate variation in the meaning of a phenomenon” (Åkerlind, 2005, p. 103). Åkerlind (2005) suggested that this can be done to the extent that the variation within a chosen sample is synonymous to/representative of the variation within the desired population. Hence, the findings from this study can be predictive and produce insights into the different ways integrated STEM education is conceptualized by mathematics teachers. The following section provides the process that was used throughout the methods phase of this study.

Methods

The steps for the methods phase of this study spanned a period of eleven months, from Spring 2021 to Winter 2021/2. Figure 3 below presents a visual representation of the timeline along with the tasks that were undertaken with respect to participants’ recruitment, selection, data sources, data collection, and data analysis.

Figure 3

Timeline for Steps in Methods Phase



Participant Selection

Patton (2002) described purposeful sampling as a popularly used technique in qualitative research for identifying and selecting cases rich with information. Purposeful sampling, and more particularly, criteria sampling, was utilized in this study to capture thick descriptive data as it relates to the variation in conceptualizations and accounts of enactment practices within a group of mathematics teachers. Palinkas et al. (2015) cautioned that this range in variation within a purposefully sampled group of participants is not often known at the initial stage of the research. This notion of initial uncertainty served as a reason as to why the use of a phenomenographic approach was appropriate for this study as its main objective strived to explore the varying ways of understanding and enacting integrated STEM education that exists among mathematics teachers.

Another important factor that weighed in on the choice of this purposeful sampling method was the accessibility of K-8 mathematics teachers who fit the criteria for participants of this study.

A second non-probabilistic sampling method, snowballing, was also used as a means of sourcing additional participants for this study. Terrell (2016) explained that snowballing sampling tends to proceed after initializing the study. The researcher then asks participants to recommend others who also fit the participant criteria. This snowballing recruitment method was used during interviews with the initial participants. These participants were asked to recommend other teachers who met the criteria of teaching mathematics in grades K-8. Snowball sampling was primarily employed during the data collection phase to increase the sample size; this strategy allowed the researcher to recruit potential participants who may be interested in taking part but were not notified through preliminary recruiting attempts. This snowballing sampling method resulted in three additional teachers being recruited. The following section will discuss in more detail the criteria used to recruit participants for the study.

The selection of participants for this study was based on the following criteria, currently teaching grades K-8 mathematics in a STEM-designated school within the South Florida region. Teachers from STEM-designated schools were purposefully chosen because it is anticipated that their schools' agenda or focus is one that seeks to institutionalize integrated STEM education in some form. Additionally, these institutions received designation from their respective education districts based on their expected emphasis on STEM education and anticipated enactment of integrated approaches. I opted to work with mathematics teachers in grades K-8 for this work because it is customary that many teachers who work in these grades are assigned other disciplines to teach, especially science and other STEM courses. As such, they will most likely have opportunities, whether intentionally or not, to integrate at least two disciplines in their planning for instruction and implementation. To determine the number of participants to interview, I was guided by the suggestion that with respect to phenomenographic studies, the researcher should aim to work with 10 to 30 participants (Trem, 2017; Trigwell, 2006). Trem (2017) suggested that this amount makes an appropriate pool "with the actual size sample erring to the lower end of that range as long as sufficient variation is found...it is likely that this will be about 15" (p. 16).

To initiate the participant recruitment process, I considered two educational districts in South Florida: Miami Dade County and Broward County. I also directly contacted two school district officials and two FIU pre-collegiate departments that employ mathematics teachers for their elementary and middle school programs. I first compiled a list of STEM-designated schools and then visited the schools' websites to browse their home pages, mission and vision statements, academic programs, and faculty listings. From this, I created a database that contained two school districts, 34 schools, and 256 names of mathematics teachers, along with email addresses, and current teaching grade level(s). I reached out to prospective participants via email (Appendix A), in which they were provided with the particulars of the study, my contact information, and an invitation to participate in a 45- to 60-minute online video-recorded interview on a voluntary basis. Interviews were scheduled with participants who responded and expressed interest. After a two-week period, a second email was sent to teachers from whom no response was received for the first email. A third round of emails was sent a month after the initial email to participants who either did not respond to the first email or who were interested in participating but had not scheduled an interview date and time. Although 18 teachers expressed interest in participating in the study only 17 were interviewed because different schedules posed a challenge. Of these 17 teachers, one had been reassigned to a high school between the initial contact and the date when the interview was conducted. Therefore, only 16 interview transcripts were considered for this study, two of whom were teachers from Broward County and 14 from Miami Dade County. Of these 16 participants, there were 14 females and two males, and they ranged in years of teaching experience from less than five years to more than ten years. Participants also reported diverse educational backgrounds and whether they taught one discipline or a combination of disciplines. At the time of this study, participants were assigned to grades ranging from kindergarten to 8th grade. While most participants taught one grade level, Dan, Fiona, Julia, and Leah worked with multiple grades. Table 3 summarizes the information for participants in the study, including pseudonyms, gender, current grade level(s), years of teaching experience, and other disciplines taught in general.

Table 3

Participants' Information

Pseudonym	Gender	Grade Level(s)	Teaching Experience (Years)	Mathematics/ Educational Background	Other Disciplines Taught
Ann	Female	1	5 - 10	Bachelor of Education	Science
Beth	Female	4	5 - 10	Bachelor of Education and Master of Education	Science and Social Studies
Celia	Female	7	> 10	Bachelor of Education and Degree in Accounting	None
Dan	Male	7 and 8	> 10	Certificate in School Counseling, Masters in Counseling, Minor in Math	None
Eve	Female	8	> 10	Bachelor of Education	U.S. History
Fiona	Female	K-5	< 5	Bachelor of Education	Science, Information Technology, and Robotics
Gary	Male	6, 7, and 8	> 10	Certificate in Integrated Curriculum, Certificate in Mathematics Teaching, Bachelors in Business Administration and Masters in Educational Leadership	Science and Information Technology
Hazel	Female	6	> 10	Bachelors in Elementary Education	Science

Ida	Female	7	> 10	Bachelors in Accounting and Masters in Mathematics Education	None
Julia	Female	K-5	< 5	Bachelor of Education	Science
Kim	Female	5	> 10	Masters in STEM Education	Science
Leah	Female	6, 7, and 8	> 10	Certificate in Mathematics teaching	Science
Mya	Female	4	> 10	Bachelor of Education	Science, Reading, and Social Studies
Olivia	Female	6	> 10	Bachelor of Education	Science
Pat	Female	4	< 5	Bachelors in Mathematics	None
Racquel	Female	1	< 5	Bachelor of Education	Science, Language Arts, and Social Studies

< - less than; > - more than

Data Sources

The primary data sources used for this study were pre-interview surveys and semi-structured interviews. The pre-interview survey was conducted first to collect preliminary data from the participants, this was then followed by the semi-structured interview, which gathered more in-depth information from participants related to their understanding and experiences teaching integrated STEM education in their K-8 mathematics classrooms.

Pre-Interview Survey

As part of this work, I developed a pre-interview survey to gather information about each participant prior to conducting the interview. This survey was created as a Google form which allowed each participant to complete the survey at a time convenient to them. The information requested allowed me to gather preliminary data from the participants pertinent to the study (e.g., number of years at current school and other disciplines taught in addition to mathematics).

This pre-interview phase turned out to be advantageous for me, the participants, and the data collection process. First, having participants complete the pre-interview survey saved time during the actual interview, as they had already answered some initial questions. Second, I gathered background information from each participant that was instructive for transitioning into the online interview, for example, the number of years they have been teaching mathematics as well as other STEM disciplines that they may have taught.

The questions used for the pre-interview survey were as follows:

- How long have you been a teacher?
- How long have you been teaching at this school?
- Why did you decide to get into teaching?
- How did you decide to become a mathematics teacher?
- Besides mathematics, do you teach any other subjects/disciplines?

Semi-Structured Interview

Semi-structured interviews were selected for this study rather than fully structured interviews, as the latter may not have provided rich, in-depth information that is needed for me to obtain participants' diverse understandings and unique descriptions of integrated STEM education. Additionally, interviewing is the primary method of phenomenographic data collection (Larsson & Holmstrom, 2007), as interviews afford for experiences to be systematically categorized and placed in descriptive structures that can be used to eventually develop educational interventions (Forster, 2013). Further, these interviews provided valuable information about individuals' conceptions or perceptions of a specific phenomenon via their speech and actions.

For this study, the interviews were designed so that participants were provided with opportunities to speak freely about their conceptualizations of integrated STEM education, this was done in such a way to create an uninterrupted chance for participants to share specific and authentic descriptions of this phenomenon. Once I provided the initial question or prompt, participants were allowed to respond openly and elaborate as they wished, as the goal was for them to reveal their own conceptions related to integrated STEM education. Accessing in-depth information shared by participants about their conceptualizations of this phenomenon was paramount to addressing the first research question for this study.

Bruce (1997) explained that generally qualitative interviews tend to concentrate on either the phenomenon or the participant, however, for phenomenography, the interviews highlight the relationship between the participant and the phenomenon. Therefore, the interview protocol for this study was set up in such a way that it mainly contained pre-defined, open-ended questions which were sometimes accompanied by a couple of follow-up questions based on the participant's responses, to afford participants the opportunity to reflect closely on their own experiences (Yates et al., 2012).

Specifically, Åkerlind (2005) offered that with respect to phenomenographic interviews, follow-up prompts are more fundamental to eliciting "underlying meaning than the primary questions" (p. 65).

Interview Protocol Development

The first step undertaken was the construction of an interview protocol. This interview instrument was created with the guidance of existing policy documents, including Florida B.E.S.T. Standards and the NCTM Principles of Actions. Additionally, as recommended by O'Leary (2014), existing protocols with a similar focus should be used as a guide when constructing an interview instrument. The policy documents listed above, along with a suggested conceptual framework for STEM as proposed by Kelley and Knowles (2016) were used as references to better inform the interview design and items. These documents outlined some specific elements that are synonymous with those that are currently being practiced in integrated STEM education. For example, using a problem/project to introduce a lesson or unit of instruction, discipline integration, student-centered learning, and teamwork. I made efforts to avoid questions that may be ambiguous for participants and leading questions, which can adversely affect the quality and precision of participants' responses.

The interview questions for the study were divided into four sections. These sections were created to assist with the organization of data being collected; therefore, the layout of the interview questions was sectioned to intentionally match the order of the study's research questions. Section 1 was designed to elicit background information about participants' experiences with teaching mathematics in general. Section 2 consisted of questions that addressed the first research question by asking participants about their conceptualization of integrated STEM education, and if/how they incorporate other disciplines into their mathematics teaching. The interview questions in Section 3 sought responses to the second research question. These questions were designed to prompt teachers to share the classroom practices they use to enact integrated STEM teaching. Questions in Section 4 asked participants to share factors that they believed influenced their conceptualizations and enactment of integrated STEM. This last section captured the barriers that participants faced while teaching or attempting to teach using integrated approaches.

When the first draft of the interview questions was constructed, I reached out to members of my dissertation committee who vetted and provided feedback as to improving the instrument. For example, suggestions of additional critical follow-up questions which could be asked to probe participants' initial responses were recommended. Another suggestion of attempting to elicit from participants additional barriers they face in their attempts to enact integrated STEM, in case they only gave one. After making the edits as suggested by my committee co-chairs, I proceeded to pilot the protocol.

Interview Pilot

Prior to conducting interviews with study participants, interview protocols should be piloted to ensure that the collected information suitably provides good and relevant responses to the study's research questions (Buschle et al., 2021). This is especially important for phenomenographic interviewing as Åkerlind (2005) purported that "conducting pilot or mock interviews and using them to analyze your interview technique is essential" (p. 65). To adhere to both recommendations, prior to conducting the semi-structured interviews for this study, the intended interview protocol was piloted with four teachers. These teachers were intentionally chosen to pilot the protocol as they possessed similar attributes to the intended participants' demographics in that they were all mathematics teachers working in South Florida who have prior knowledge and experience with integrated STEM education in grades K-8. In addition to providing an opportunity for me to practice questioning skills, this piloting process also resulted in revisions and improvement to items on the initial protocol. For example, one teacher voluntarily suggested some recommendations that she thought would help teachers, school administrations, and district officials in facilitating integrated approaches to teaching integrated STEM. This question was subsequently incorporated into the interview protocol. Thus, for the last section participants were asked to share both barriers as well as any recommendations they may have to offer the respective stakeholders to support teachers' efforts in implementing integrated STEM teaching. The final version of the interview protocol contained the interview questions and how they aligned to the respective research questions (see Appendix B).

Data Collection

The data collection process involved gathering information from the pre-interview surveys first followed by the semi-structured interviews, this process spanned a period of two months. Once participants expressed interest in being interviewed, before collecting data, they were asked to sign and return an informed consent document via email (see Appendix C).

Pre-Interview Surveys

After participants indicated their interest and willingness to participate in the study, they were contacted via email and sent a link to the pre-interview survey Google form. Participants were asked to complete this form at least one day prior to the semi-structured interview. I was able to draw on most of the responses from the pre-interview surveys to initiate the first section of the interview protocol which referred to participants' mathematics teaching experiences. Specifically, the data collected from the pre-interview surveys contained the number of years each participant had been teaching, the number of years assigned to the STEM-designated school as well as the other subjects they teach. This preliminary data collecting exercise served as a precursor for setting up an initial rapport between each participant and me.

Semi-Structured Interviews

The in-depth semi-structured interviews were conducted on the Zoom online platform (https://zoom.us/), utilizing both audio and video features. Permission was sought from participants to record the interview, and they were assured that the data collected would be used solely for the purpose of this study. Opdenakker (2006) suggested that online synchronous forms of communication lend themselves to advantages, for example, wide geographical access. The use of the Zoom online platform allowed me to access teachers across a wide geographical area inclusive of schools in both Miami-Dade and Broward counties. Using this online interview platform saved time as well, as it was not necessary for me to commute to meet each participant at different locations. Hence, the scheduling of interviews was done quickly and efficiently. Because of this degree of flexibility, participants in this study were able to do the interview at their homes, in their classrooms after school, or during their lunch break. Additionally, I did not have to seek permission from respective districts or school administrations to conduct the interviews as they were conducted outside of regular working hours. The online format also served as a health safety measure with respect to the Covid 19 pandemic. Another advantage of using the synchronous online platform as opposed to conducting phone interviews was being able to observe participants' facial expressions and gestures. Since Zoom made it possible to record both audio and visual, I was able to easily refer to both aspects of these recordings repeatedly during the data analysis process.

To begin the online interview, I shared a brief introduction of the study's objectives, assured participants of the confidentiality of the information they provide, and their prerogative to opt out at any time during the interview. Based on the questions from the interview protocol, I was able to collect extensive data from each participant about the following: their teaching background in general and in mathematics, conceptualizations, and enactment of integrated STEM education, factors influencing their enactment, barriers in implementing and recommendations for facilitating discipline integration in mathematics teaching. To wrap up each interview, I first asked the participant if they had any questions or additional thoughts/comments that they wanted to share. Next, I asked participants to recommend colleagues who they thought would fit the study's criteria. This snowballing data collection technique was used in an attempt to elicit more mathematics teachers and increase the sample size as stated in the Participation Selection section above.

The data collected from both pre-interview surveys and in-depth semi-structured interviews produced direct quotations from participants in relation to their experiences, opinions, feelings, and knowledge (Patton, 2005). Furthermore, after each interview, I took a few minutes to engage in memoing. Birks et al. (2008) advised that memoing can serve as a springboard and help the researcher to make conceptual leaps from the raw data collected to certain abstractions that lead to explanations of the research phenomena in the specific context it was examined. My memos were later compared to the audio recordings and interview transcripts. For each participant, the recording generated by Zoom was uploaded to Otter.ai, an online tool that converts speech to text transcriptions. Upon completion of the data collection process, another critical component of a research study is analyzing this data. In this study, the initial aspects of this analysis started as the data were being collected via notetaking during the interviews and writing memos after each interview.

Data Analysis

With respect to phenomenography, Trigwell (2006) pointed out that this methodology adopts a second-order rather than a first-order approach. Thus, instead of the researcher describing or defining the phenomenon, as *they* perceive it, what is important is the experience of the phenomenon as described by *participants*. The importance of this second-order approach was taken into consideration throughout the data analysis process.

As noted above, during the interview process, I made memos in the form of brief notes about the responses from the participants and my initial thoughts about certain points that I felt stood out to me. For example, if I heard common or contrasting comments that were recurring throughout the interviews. After each interview, the audio recordings, verbatim transcriptions, and my notes were all cross-referenced to doublecheck and ensure accuracy and consistency. This double-checking is critical as these transcriptions were fundamental for data analysis (Collier-Reed & Ingerman, 2013).

All data collected for the study via memos, consent forms, pre-interview survey responses, audio and video recordings of each Zoom interview, and interview transcriptions were used collectively throughout the data analysis. The transcriptions were reread multiple times for familiarization, which was followed by coding. Based on an inductive coding process (described below), the following were established: Categories of Conceptualizations, Enactment Themes, and Factors Influencing Teachers' Enactment of Integrated STEM Education.

Once all participants' interview transcripts were reread and checked for accuracy, initial coding in which the researcher came up with first impression phrases was undertaken (Saldaña, 2009), and these notes were inserted as side comments on each transcript. Merriam (1998) suggested that at this point brief comments, notes, and initial thoughts can be recorded. These comments took the form of descriptive, linguistic, and/or conceptual ones (Smith et al., 2009). Smith et al. (2009) further explained that descriptive comments described the content of what the participant said, for example, I identified key phrases that participants gave pertaining to their explanations or descriptions for their understanding of integrated STEM teaching. Linguistic comments explored the specific use of language. Here I made comments on transcripts about how the participants said what they said (Cooper et al., 2012). For example, some participants used terms and intonations that indicated their preference or lack of preference for incorporating engineering practices when teaching mathematics. Lastly, conceptual comments engage in an interrogative, questioning, and conceptual level, in that "the questions indicate key concepts the researcher feels may be emerging from their analysis of the data" (Cooper et al., 2012, p. 5). At this point of the analysis, I noted and made comments for which certain points or thoughts seem to be conveying similar ideas for potential codes. It was important here to ensure that any preconceived notions I had about the phenomenon of integrated STEM education did not interfere with participants' descriptions of conceptions or enactment practices. Throughout this phase of the analysis, certain chunks of transcripts were also bolded or highlighted so as to place emphasis for reference later on in the analysis process. Afterward, the coding process continued with the chronological order of the different sections of the interview questions. In other words, chucks of codes related to how participants conceptualized integrated STEM education were considered and reviewed collectively and used to address the first research question.

Following this, I created a spreadsheet with 16 tabs, one for each participant. On each tab, the research question was aligned with the corresponding interview questions and respective response(s) from participants. From the participants' responses, several codes were observed, and I started noting similarities and differences among these codes. Emerging from these codes were the varying ways participants described their understanding of integrated STEM teaching; these categories of descriptions were labeled as Categories of Conceptualizations, in which those that were similar were grouped together and illustrated on a diagram. This "diagrammatic representation" (Bruce, 1997) is referred to as an outcome space. In phenomenography, an outcome space is formed as a result of sorting the qualitatively distinct perceptions surfacing from the data analysis process (Marton, 1986). In spite of their variations, these phenomenographic categories are often related logically to one another (Bowden, 2000; Marton, 1994).

The inductive coding process revealed the emergence of codes associated with the ways teachers described their enactment of integrated STEM teaching, these codes were compiled in a codebook. Based on the emergence of the codes, subthemes were identified and subsequently categorized into main themes. The codebook thus consisted of a spreadsheet (see Appendix D) recording the main themes, descriptions, subthemes from the codes, and excerpts from participants' responses. The online cross-platform application, Dedoose (https://www.dedoose.com), was used in organizing, collapsing, and analyzing of the themes. The use of Dedoose also made it more manageable to revisit, compare, and refine the themes and subthemes as these were categorized into parent codes and child codes.

Parent/main codes were also created in Dedoose to organize the factors that mathematics teachers identified as influencing their enactment of integrated STEM education. These factors were grouped into four main categories based on similarities and differences among them. Other parent codes were added to group the barriers participants highlighted they encountered as they implemented integration as well as any recommendations they proposed.

Åkerlind (2005) cautioned that an important principle that phenomenographic data analysis should focus on is seeking the collective meaning of responses instead of just describing specific individuals' responses. As I analyzed the data, I made efforts to refrain from simply presenting the teachers' responses in relation to the enactment themes without identifying variations and relations among them (Bruce, 1997). As these variations and relations were being established, attempts were made to reduce the initial set of themes to ensure succinctness; however, cautiously ensuring to capture the participants' accounts of the different approaches or initiatives accurately and sufficiently as they enact integrated STEM teaching. The transcripts, codes, and themes were repeatedly reviewed on Dedoose to ensure that the categories of conceptualizations and themes accurately reflected the collected data. To ensure bracketing throughout the data analysis process, efforts were intentionally made to avoid letting my understanding of integrated STEM education or how I perceive it should be enacted interfere with or prejudice the thoughts, ideas, and interpretations shared by participants.

Linneberg and Korsgaard (2019) suggested that when coding inductively, a researcher may have created several codes in an effort to precisely capture the complexity and diversity of the data, these authors cautioned that it could be challenging "finding a balance between having a workable number of codes and capturing the complexity and diversity" (p. 263) of the collected data. For this study, to establish a manageable number of themes from the first cycle of coding, a second round of coding was performed from which higher-level categories were generated (Gioia et al., 2013). Initially, 37 codes emerged with respect to participants' descriptions of their enactment of integrated STEM education, these were subsequently collapsed into subthemes then four higher-level categories/main themes: Contextualizing the Learning, Teacher as Facilitator, Cooperative Learning, and Formative Assessment. Table 4 below presents these higher-level categories, subthemes, and participants who used the corresponding themes to enact integrated STEM teaching.

Table 4

Teachers' Enactment of Integrated STEM Education

Higher Level Categories (Main Themes)	Subthemes (from Codes)	Participants
Contextualizing the Learning	**Project-Based** - use of a project to contextualize learning **Problem-Based** - use of a problem to contextualize learning **Thematic** - learning is contextualized around a theme	Ann, Beth, Celia, Dan, Eve, Fiona, Gary, Hazel, Ida, Julia, Kim, Leah, Mya, Olivia, Pat, Racquel
Teacher as Facilitator	**Teacher:** - coaches/guides/facilitates - helps students, check in on weak/quiet/lost students - listens/ answers questions - makes suggestions to students - makes connections (among disciplines) - extends students' knowledge, shows them how to apply knowledge (different disciplines) - models - clearing up misconceptions/ confusion/ mistakes - changes roles - emphasizing the important stuff, reinforcing/highlighting skills/ concepts - provides feedback - walks around; moves from group to group/stations; circulating; traveling - ensures that students stay at task; classroom management	Ann, Beth, Celia, Dan, Eve, Fiona, Gary, Ida, Julia, Kim, Leah, Mya, Olivia, Racquel
Cooperative Learning	**Students:** - appear to be doing all the work	Ann, Beth, Celia, Dan, Eve, Fiona, Gary, Hazel,

	- do the teaching - lead the lesson/activity - were always engaged - work independently **Teacher:** - groups students - allows for collaboration - allows for kids to learn from each other - uses a “hands-off”/“hang back” approach; appears “lazy”; leaves “it up to the kids” - does less teaching/talking	Julia, Kim, Leah, Mya, Olivia, Pat, Raquel
Formative Assessment	**Teacher:** - asks questions - makes observations	Fiona, Gary, Ida, Julia, Kim, Leah, Mya, Olivia, Racquel

Ethical Considerations

It is imperative that researchers be guided by certain ethical principles when conducting research. Pearson et al. (2015) cautioned that in instances where studies include the collection of data by means of interviews or other methods with human subjects, it is critical that participants be treated with respect, dignity, and care throughout the process. Furthermore, Miles and Huberman (1994) suggested that “any qualitative researcher who is not asleep ponders moral and ethical questions” (p. 288).

One of the steps taken to address ethical concerns was to provide interviewees with a FIU IRB Adult Consent form to read and complete prior to the interview, once participants indicated their consent by returning a signed form, the interview date and time were arranged that were convenient to them. At the onset of the interview, participants were informed that all efforts will be undertaken to ensure the confidentiality of the data gathered. They were told random pseudonyms will be assigned to each participant to guarantee anonymity. Participants were also informed that all research records will be stored securely, and only I will have access to the records. They were assured that they will not be exposed to any undue risk and there were no incentives being offered to participate. For credibility and accuracy purposes, throughout the data collection and analysis phases, I reported data just as given by the participants and made every effort to withhold assumptions, biases, or preconceived notions.

Summary

This chapter first presented an explanation and justification for a phenomenographic study as this was used in this work. The sampling methods and process used to select participants were provided. Details about participants and their recruitment into the study were also included in this chapter. Descriptions of how the data were collected and analyzed were then outlined as well as the ethical considerations fundamental to the study were stated. The following chapter presents and explores the findings from interviews that were conducted for this study. Excerpts from the interview transcripts are shared as they pertain to the categories of conceptualizations, the enactment themes that emerged, and factors teachers identified as influencing their enactment of integrated STEM education.

CHAPTER FOUR

FINDINGS FROM DATA ANALYSIS

This phenomenographic study examined the qualitatively different ways mathematics teachers conceptualize integrated STEM education and explored the accounts of how they enacted integrated STEM in their mathematics classroom. The findings from these two objectives addressed the study's first and second research questions. This work also investigated the factors that teachers identified as influencing their enactment of this phenomenon; the findings from this investigation addressed the third research question. As a result, the findings are presented in the following three sections: Categories of Conceptualizations, Enactment Themes, and Factors that Influence Teachers' Enactment of Integrated STEM.

Categories of Conceptualizations

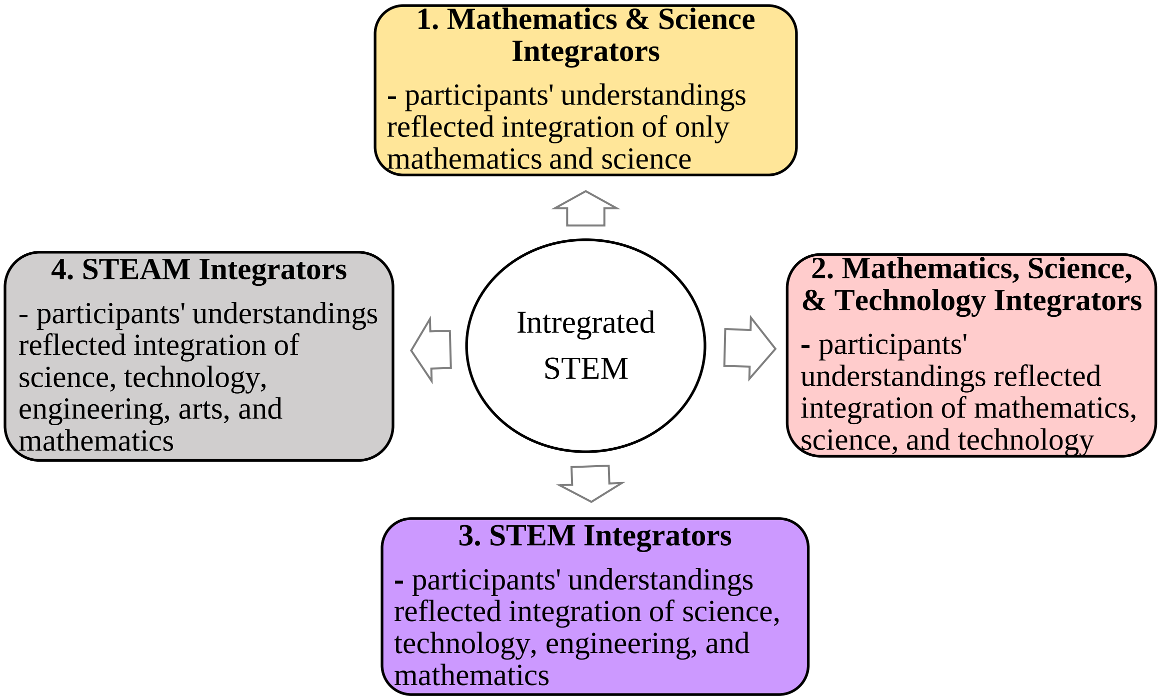
The Categories of Conceptualizations were formed based on similarities and variations in the ways participants described their understanding of integrated STEM education. These descriptions mainly reflected content-integrated interpretations and hence were grouped according to how participants felt STEM disciplines were incorporated when teaching through integration. Based on the similarities and variations in their descriptions, the four categories identified were: Mathematics and Science Integrators; Mathematics, Science, and Technology Integrators; STEM Integrators; and STEAM Integrators. The data gathered from analyzing these four categories were used to address the first research question:

> Q1. In what ways do K-8 mathematics teachers conceptualize integrated STEM education?

To establish the Categories of Conceptualizations, I carefully examined each transcript which unfolded comprehensive accounts from participants as to what they understood integrated STEM education means. These Categories of Conceptualizations were organized into an outcome space, which grouped participants' interpretations of STEM integration based on similarities and differences in their varied understandings. Figure 4 presents a visual representation of the outcome space for the Categories of Conceptualizations along with a brief description of each category. For additional details on the Categories of Conceptualizations for each participant see Appendix E.

Figure 4

An Outcome Space for Categories of Conceptualizations of Integrated STEM



Category 1: Mathematics & Science Integrators

This first category was derived based on participants’ explanations of integrated STEM education as primarily placing focus on integrating mathematics and science. In their initial explanations, Beth, Kim, and Mya hinted at the use of approaches that seemed to suggest they taught a combination of several curriculum areas. For example, the terms “cross-curriculum” and “putting everything together” were used by Beth and Mya respectively, however, the rest of their descriptions of integrated STEM solely reflected the integration of mathematics and science. Beth shared “You're teaching math through science and teaching science through math. And that's the best way, like in layman's terms that I can explain it.” In her response to the question that asked participants about their understanding of integrated STEM education, Mya explained, “So that's what it is. I am putting all these subjects together to get the kids to see where math and science go together. And so, we don't teach in isolation.” Kim’s conception of connecting the two disciplines was also clear as she described it as incorporating the “math in science.” She explained that she had that perspective because she felt it was “an easier connection with the kids that way.”

Based on the descriptions given by teachers with this Mathematics and Science Integrators’ conception, integrated STEM education predominantly integrates content from the disciplines of mathematics and science. This in essence showed that their understanding of the phenomenon was exclusive of technology and engineering.

Category 2: Mathematics, Science, and Technology Integrators

The second conceptualization was shared by Ann, Dan, and Raquel who described integrated STEM education in a way that included technology. However, while they acknowledged the integration of science, technology, and mathematics, their descriptions of how they conceived this phenomenon did not mention engineering content or practices.

Ann, for example, believed that integrated STEM education is supposed to connect aspects of science, mathematics, and technology. She explained, "mostly, you know, pulling in from other subject areas and connecting them… And so obviously, the science, the math, the technology is, you know, obvious for the STEM." Although in her initial description, Ann used the term "cross-curriculum," she only referenced science, mathematics, and technology. With respect to including technology in his understanding of integrated STEM education, Dan expressed "I think strongly in the technology." Racquel's understanding is a combination of mainly science, mathematics, and "a little bit of technology."

Although these participants understood that technology ought to be part of integrated STEM education, their accounts did not explicitly show how technology was prevalent in their understanding of integrated STEM education, especially with Ann and Racquel. These first two categories in which engineering was absent in conceptions, had a total of six out of the sixteen participants.

Category 3: STEM Integrators

The third conception shared by Fiona, Eve, Hazel, Pat, and Gary indicated integrated STEM as including the integration of all four STEM disciplines: science, technology, engineering, and mathematics. Their accounts depicted an interdisciplinary, overlapping of the four subjects (Bybee, 2013; Vasquez et al., 2013). Fiona expressed being a “big believer” of integrated STEM teaching and reiterated that the disciplines can be interwoven:

> There's a way to rope that in some way, shape, or form… the engineering is where the math comes in. Um, you know, measurement, I'm counting you know, how high or how far can I get this thing, if we're doing like rockets, how far did I make my rocket go, or if I'm building a tower, how high am I getting it using the measures…when they're doing engineering and STEM projects they work in groups of four a lot of the technology things we do they'll do in pairs with their programming.

Eve and Hazel justified why they thought that it was beneficial for students to be taught using approaches that integrate the four components. Eve stated that in her conception “Integrating, focusing on science, technology, engineering, and math, putting in critical thinking, producing children that can go out into the STEM world and succeed.” Hazel explained:

> So, I would take it as you know, being able to involve, obviously, science, technology, right, the engineering and the math process in my case… And it's, you know, breaking it down again, for each portion of it, and each portion having its own job, let's say, in the integration process, and then it kind of coming together.

Despite being at a STEM-designated school, Pat hesitated to confidently describe her conception of integrated STEM. She eventually formed a response based on her experience of having seen other teachers integrate science, technology, and engineering in their mathematics teaching, and she shared this understanding based on her observation:

> I'm at a STEM integrated school. So, I know that some STEM integration happens. I just see the teachers really touching upon content from all parts of the STEM. So, from science, technology… the children would be really focused on, like, using computers and making sure that they're doing things digitally, discussing like careers and engineering, and then just doing math in their projects.

In Gary's explanation, he conceptualized integrated STEM as an "inter-curricular" approach and gave specific examples of how this understanding encompasses science, technology, engineering, and mathematics:

> It [integrated STEM] means incorporating on a consistent basis in your instructional planning some inter-curricular activities or lessons. And to incorporate all subject areas…it's a lot of work to do that we're going to create what they call the science, technology, engineering, once you're in mathematics, it lends itself pretty easy.

STEM Integrators' conception encompassed the four disciplines of science, technology, engineering, and mathematics. In her initial explanation, Pat indicated that she felt like she did not integrate other subjects in her mathematics teaching, noting here, however, that there was evidence of Pat enacting integration of the other STEM disciplines in her mathematics teaching which is documented in the section related to teachers' accounts of enacting integrated STEM education.

Category 4: STEAM Integrators

Some participants noted the inclusion of the arts in their integrated STEM classroom teaching. This fourth category of participants: Celia, Ida, Julia, Leah, and Olivia, conceptualized integration in education to be an approach that not only incorporates science, technology, engineering, and mathematics but also encompasses aspects of the arts curriculum, i.e., STEAM. Leah's description acknowledges that the arts form part of the integration, however, she feels that it should not be "forced" into the curriculum.

For Celia, she felt like discipline integration is part of how students learn, and it is not necessarily a separate curriculum discipline, her conception incorporated science, technology, engineering, the arts, and mathematics. Her reference to the arts here was, “bring in the reading,” and she gave an instance of doing “an informative reading on catapults.” Celia admitted that based on her understanding, she believes that her students usually end up doing STEAM projects:

> When you're integrating the science, technology, engineering, the arts and the math…Integration to me, it has to do with not specifically stopping what you're doing to go into teaching STEM. It's part of how they're learning…do feel like the kids ended up doing a STEAM project

Similarly, Olivia’s conception is one that is inclusive of language arts being integral in interconnecting the disciplines, she gave an example to be including “math stories.” She explained, “Science, technology, engineering, math, and they added the arts too…a curriculum for reading language arts, math, science, social studies.”

Ida also shared the idea that disciplines are related, and students should be made aware of the importance of each discipline and how they are interconnected. She referred to an understanding of, for example, integrating science, technology, and art when teaching geometry:

> So, they know that everything is related, they need to know a little bit of everything… because it's embedded in other ones… all the subjects are linked together there… So, STEM and STEAM are very important because they show them how they need to put all these things together… they need to know a little bit of science, math, technology and, art. As we're doing geometry, as we're doing things, creating and drawing things.

Julia’s conception of this phenomenon was based on her love for arts and crafts. She believes because she has been “really crafty as a kid,” this has shaped her understanding and appreciation for the arts in STEAM.

For Celia and Olivia, their conceptions of incorporating aspects of the language arts curriculum met the expectation of the ‘A’ in STEAM. Ida’s perspective showed that integration of the arts included drawing and visual representation. Julia's interpretation of the arts was a more hands-on understanding that relates to the inclusion of craft.

Summary

In the Categories of Conceptualizations outlined above, participants gave accounts of what they understood integrated STEM education to be. Based on these teachers' descriptions, ten of the 16 participants' conceptualizations were categorized as either STEM Integrators or STEAM Integrators. The other two categories, Mathematics and Science Integrators and Mathematics, Science, and Technology Integrators were less represented in the group with only three participants each sharing the same conception.

Enactment Themes

Another aspect of the data analysis resulted in the identification of themes that emerged based on participants' descriptions of the different ways they enacted integrated STEM teaching. These themes addressed the second research question:

> Q2. What are K-8 mathematics teachers' accounts of enacting integrated STEM education in their classroom teaching?

The emerging themes identified by teachers were clustered into four main groups: Contextualizing the Learning, Teacher as Facilitator, Cooperative Learning, and Formative Assessment. Teachers' enactment of integrated STEM education within these themes was influenced by several factors which was the focus of the third research question and will be explored later on.

Theme 1: Contextualizing the Learning

Based on the themes that emerged during the data analysis, participants used three approaches, either singly or collectively, to contextualize students' learning throughout their integrated STEM teaching: project-based, problem-based, and/or thematic. To implement project-based approaches, participants facilitated student learning using a project that was centered on a topic which encapsulated more than one discipline. Eleven participants in this study utilized project-based approaches with their students. While in instances where a problem-based approach was used, eight participants facilitated integrated STEM lessons through problems. Participants Gary and Olivia adopted a combination of project-based and problem-based approaches.

The third approach participants used to contextualize student learning was by means of central themes. Notably, no participants used this thematic approach as a standalone approach. Instead, teachers established an overarching semester- or year-long theme that transcended across their instruction and incorporated projects to facilitate student learning within a context, as were the cases with Kim and Fiona. In other instances, teachers used a thematic approach in conjunction with problem-based approaches, namely Ann and Eve. Overall, seven participants used a combination of two approaches when enacting integrated STEM teaching. Table 5 below displays participants and the approach or combination of approaches they used to contextualize student learning as they facilitated integrated STEM teaching within their classrooms.

Table 5

Teachers' Approaches to Contextualize Students' Learning

Participants	Approaches		
	Project-Based	Problem-Based	Thematic
Ann		✓	✓
Beth	✓		
Celia	✓		
Dan		✓	
Eve		✓	✓
Fiona	✓		✓
Gary	✓	✓	
Hazel	✓		
Ida	✓		
Julia	✓		
Kim	✓		✓
Leah	✓		
Mya	✓		
Olivia	✓	✓	
Pat		✓	
Racquel		✓	

Project-Based Approach

Participants described how they used projects to facilitate the implementation of integrated STEM lessons. Mya recalled how practical and beneficial this approach is, she used projects often and incorporated multiple disciplines, “Well I give them class projects all the time. Because I'm not the test type teacher. I do hands-on projects and stuff like that. So, projects all the way.” Julia gave an example of a muffin project she does annually with her classes which integrates the STEAM disciplines:

> When students like, do these integrated activities or lesson, it’s a mess! we'll make the muffins and it shows the matter changing from you know, liquid to solid. But then it's also that you have to measure the ingredients to make it right.

Ida emphasized the importance of working on STEM/STEAM projects and shared her students’ interest in doing them. Her account indicated that she attempts to do a “bigger” integrated project every nine weeks and “simpler” ones in between, she went on to give examples of these projects:

> So, STEM and STEAM are very important because they show them how they [students] need to put all these things together to create this project or whatever invention they decide to come up with and to test things that they need to know a little bit of Science, Math, and Technology. One that I did this year was spool cars, called Racing cars. There's a certain criterion they must go at least half a meter. Using technology, science, art, as we're doing geometry… Although we don't teach engineering here, it all comes in to be the same thing.

Similar to Ida, Hazel also spoke about “intricate” versus “quick” projects. Hazel proceeded to give examples of some integrated STEM projects done with students:

> Maybe three [projects] in a year, possibly four, depending on the year, and how intricate the STEM assignment, making the toothpick towers, and things like those, making the bridges... So again, depending on what the actual STEM project would be, I would be able to maybe do a couple of more. So, you know, the book stack challenge. Those don’t necessarily take the amount of time that maybe another one, like building a roller coaster would or building a solar oven and putting it outside.

Celia’s account also revealed that annually, her students did one “big” project that they presented and approximately three or four projects which could be either STEM or STEAM, two such projects were mousetrap cars and catapults:

> On an annual basis, I would say that I do quite a few integrated projects, and would fall into one of those categories, either STEM/STEAM or some integrated approach. Our first time through STEAM, I had like seventy projects all across the room. The Mousetrap Cars is a big one, our favorite one has been the catapults. I do feel like the kids ended up doing a STEAM project. So, it has become a little bit more of a project-based, you know.

Beth, who had a Mathematics and Science Integrators’ conception of integrated STEM education shared one of the projects her students worked on for a science fair. Although it was for a science fair, she was adamant that students’ submissions must have aspects of mathematical content, if not, she insisted that it would be a “disservice to teaching.” She explained that she instills in students that “real scientists” have to do mathematics. She fondly shared other examples of projects done with students, one of which is a Million Dollar Project done annually:

> I will not submit their science fair project, unless it has a graph, a chart, some form of math in it, I need to see the math, because I let them know real scientists chart their work, real scientists graph their work. And that's the math component. I need them to understand that real scientists and real science projects, have math components in there. We're doing a project called the Million Dollar Project. So, it really is tying into different domains [disciplines] there.

Leah also shared a couple of examples of projects she did that involved the integration of disciplines. She referred to a roller coaster project and another one that students did while learning the concept of integers. For this second project, to help them understand the relationship between positive and negative integers, students designed and constructed a game. Leah explained that in the games, students incorporated upward movements (positive integers) and downward movements (negative integers).

> Every time that you were moving, you could go to a high mountain, or just for some reason, like a slide took you below the zero level with people below sea level, and then up again, and you needed to keep your score all the time, they design their own board game. So that was to me like the engineering part and the art part. And they came with amazing ideas, artistic ideas.

The participants’ accounts above showed that these mathematics teachers provided opportunities for students to engage in integrated project-based learning. In the examples summarized above, the projects outlined by participants, whether short-term or long-term, were used to contextualize students’ learning and draw on concepts from the different disciplines. The projects were hands-on and facilitated creativity from students.

Problem-Based Approach

While engaging students in integrated STEM lessons, seven participants indicated they would use approaches/lessons that would be framed as real-world problems. For instance, Pat stated that she intentionally selected problems that were meaningful, related to student’s personal experiences, and incorporated other disciplines:

> I think the really good word problems are ones that discuss like, I've seen stuff that look at cars, like cars driving and speed, and that gets into like science, the things that they can apply back to their life, like are relevant.

Ann also shared that she attempts to have students work on challenges that are embedded in word problems that need to be solved. She accomplishes this by presenting opportunities for them to use “all the knowledge from all the subjects… to come up with solutions to problems.” Dan’s use of problems for integrating disciplines was evident as he recounted how STEM integration was done in his classroom. The problems were usually taken from the end of chapter exercises, and along with another teacher who co-taught with him, they will also “make up problems”:

> With the integration, you present a problem. And even now, in my math curriculum, at the end of each chapter, there's a section called STEM, so there, we have problems that are more oriented with the STEM style. So, we see, how math questions relate to science, which they do, because to me, math is the language of science.

As noted in the problem-based lesson examples stated above, integrated STEM teaching can be achieved through the use of selected problems. The main difference between problem-based approaches and project-based approaches in this study is that the former required students to draw from different STEM disciplines and write the solution for problems, which did not necessarily require the design and construction of a three-dimensional object as with project-based approaches.

Combined Project- and Problem-Based Approaches

All teachers in this study used at least a problem-based approach and/or a project-based approach in their integrated classroom teaching. There were teachers who opted to use a combination of both approaches, for example, Gary, Olivia, and Pat. Gary explained that his approach takes the form of an engineering design challenge where initially students would plan how they would approach the problem, and then they would proceed to work on the project:

> Depending on the phase [of the lesson/activity], let’s say in the beginning stages where they need to plan out how they wish to tackle the problem. So, it's to take ideas on how they're going to get a solution. For example, let's say that they are dealing with a hurricane, with science and math, let's say they have to build a structure to withstand hurricane force winds [project]. Oh, yeah, those innovative projects still incorporate everything, computer, technology with autoCAD also include the math aspect for drawing graphs, central measures of tendency.

Olivia allows students to discuss their ideas about the real-world problems first, and then students proceed to solve the problems in groups. She explained:

> They had the freedom to solve it [problem] in whatever way they could, and then we will talk about it. And then we will discuss ideas, so we read the problem, talk about it, make sure everybody understands and then they [students] will go to their groups.

Olivia further shared that her integrated units were designed with the knowledge students needed to acquire from the STEM disciplines. With this in mind, she "created some experiments and projects" that reflected standards from the different STEM disciplines.

Combined Project-Based and Thematic Approaches

There were participants who, while using project-based approaches in their integrated STEM teaching, opted to base their lessons/units on a central theme. For example, participants chose themes that were locally, seasonally, or environmentally relevant. The descriptions given by two participants, Kim and Fiona, suggested that their approaches to integrated STEM teaching would be a combination of project-based and thematic approaches. For Kim, she admitted to centering her projects on a theme "just a bit," and always envisioned her "ideal STEM" run school or classroom as being project-based and thematic. Her themes were based on whatever current event was happening at the time of the integrated STEM unit, "Yeah, when doing my STEM projects, I work with whatever theme I have happening, if I could do it that way all the time, that's great." Kim further reiterated that from her perspective, "integrated STEM education is project-based, like thematic units across the board in all grade levels, are in all subjects in the grade level."

Although Fiona did not specifically label her approach as thematic, she gave an account showing that she did integrated projects with her students which were geared around topics/themes. She explained that these themes were often associated with the students' "local" experiences – reflecting a place-based approach to learning. She shared that her school is located close to the Everglades, so she has used this theme previously:

> A lot of times we're doing STEM, we're doing engineering projects, you know, sometimes we're doing a science focus topic, like Everglades or something like that. So engineering is where the math comes in… I try to make it local, like stuff on the Everglades at my school, some of the animals we see in our local environment.

Fiona then explained that mathematics concepts covered in such integrated STEM activities have to do with students doing linear measurements in terms of the height and depths of objects.

Although only two participants combined themes in their project-based approaches to integrated STEM education, the enthusiasm in their accounts conjured a sense of autonomy in them selecting the themes as they saw fit. Connection to current events or relevance to students' environment guided these teachers' choices.

Combined Problem-Based and Thematic Approaches

Another combination of approaches was seen by two participants, Eve and Ann. For these two teachers, their integrated STEM lessons were done with the use of problems connected to themes around which the subjects' content revolved. Eve explained how the problems she used integrated disciplines and incorporated real-world applications. She referred to the theme as a "genre" and recalled examples such as - The Desert, "oceany", and cultural:

> I give them a couple of minutes to work on it [a real-world problem]. And then I guide them through the rest of the problem. So, we integrate other disciplines when we are working with problem-solving, I only did interdisciplinary. So, for real-world application problems that address geography, that address the weather, that address science, that we're working on, we are talking about the rise and fall of temperature, and climate change. So, in that sense, we will touch on other disciplines.

Eve went on to further explain that every nine weeks during the school year she focused on a different theme, for example, in one quarter she chose “The Desert.” For that quarter her entire class was transformed into a desert and examples and problems for the different disciplines were based on that theme. Her reference to interdisciplinary suggested that she attempted to incorporate different STEM disciplines in an intentional and almost seamless way.

Ann also combined both problem-based and thematic approaches. She shared that preparation for incorporating themes would start during her action planning over the summer, “And that would be a plan for all subjects. And I would tie through themes, I would start with social studies. I align them all together and be thematic about the approach instead of learning different subjects in a bubble.” Ann often explained to her students that when using projects and themes in their lessons they are “bringing in how we are using our brains and all the knowledge from all the subjects” to help them “come up with solutions to the problems.” Eve’s desire to use themes in her problem-based teaching also showed the level of autonomy she had in her integrated STEM teaching. Her themes changed over the school year and allowed for the interconnection among disciplines. This intent of planning the teaching of the different subjects to “tie through themes” was also explained by Ann.

Overall, the approaches to contextualizing student learning explored above showed that teachers situated discipline-integrated learning opportunities either within a project, problem, and/or around a theme. There were some connections between the

Categories of Conceptualizations in which participants were grouped with the classification of project-based, problem-based, and/or thematic approaches.

Table 6 shows this relationship between the Categories of Conceptualizations, participants, and the respective pedagogical approach(es) to contextualizing the learning in integrated STEM teaching.

Table 6

Categories of Conceptualizations, Participants, and Pedagogical Approach(es)

Categories of Conceptualization	Participants	Approach(es)
Mathematics & Science Integrators	Beth	Project-Based
	Mya	Project-Based
	Kim	Project-Based Thematic
Mathematics, Science, and Technology Integrators	Ann	Problem-Based Thematic
	Dan	Problem-Based
	Racquel	Problem-Based
STEM Integrators	Eve	Problem-Based Thematic
	Fiona	Project-Based Thematic
	Gary	Problem-Based Project-Based
	Hazel	Project-Based
	Pat	Problem-Based
STEAM Integrators	Celia	Project-Based
	Ida	Project-Based
	Julia	Project-Based
	Leah	Project-Based
	Olivia	Problem-Based Project-Based

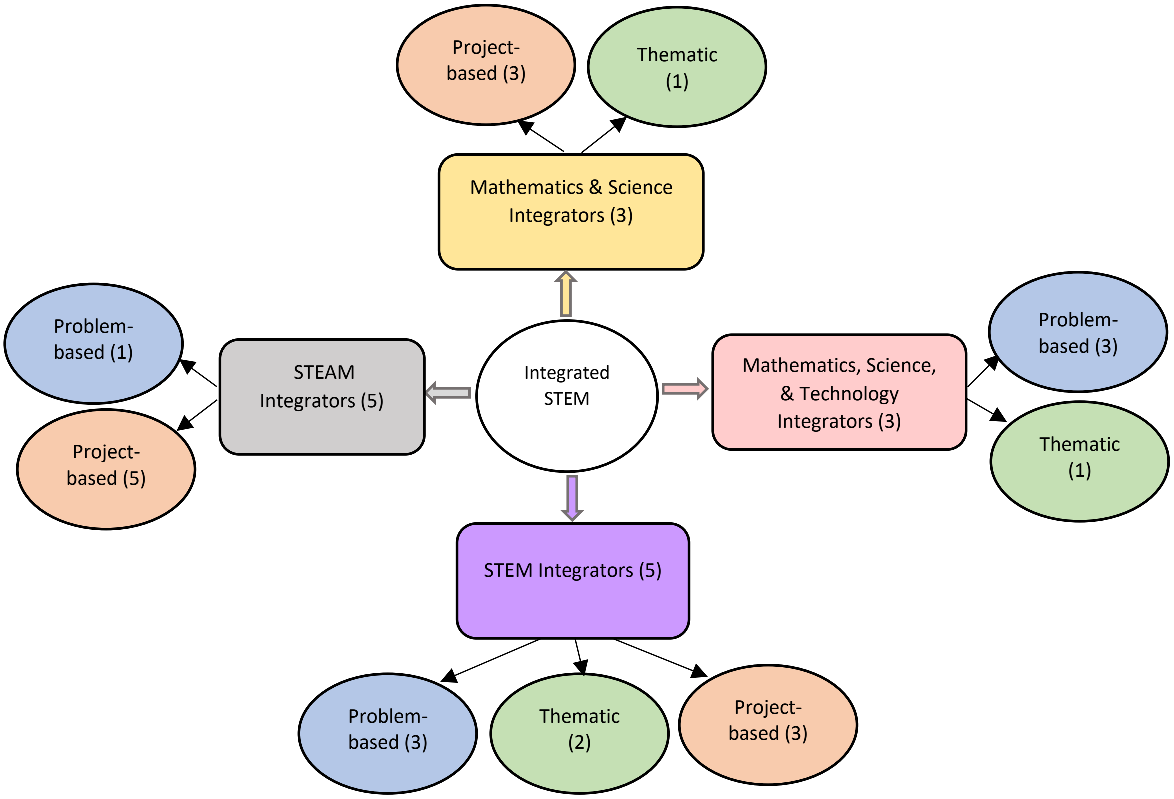
Based on the information presented in Table 6 above, three participants, Beth, Mya, and Kim, who were categorized as Mathematics and Science Integrators, utilized a project-based approach as they taught integrated STEM lessons. Additionally, Kim focused her teaching on predetermined themes. A commonality noted among the Mathematics, Science, and Technology Integrators (Ann, Dan, and Racquel) was that they all employed problem-based approaches in their integrated teaching; additionally, Ann incorporated a thematic approach. STEM Integrators (Fiona, Gary, and Hazel) used project-based approaches, with Fiona and Gary combining this with thematic and problem-based respectively. Eve was the only STEM Integrator who combined problem-based and thematic approaches. Celia, Ida, Julia, Leah, and Olivia, all STEAM Integrators, illustrated the use of a project-based approach as they gave accounts of how they contextualized student learning in integrated STEM lessons. Olivia's integration efforts reflected the use of projects and experiments in conjunction with a problem-based approach.

Based on the combinations of project-based, problem-based, and/or thematic approaches used by teachers above, it is evident that there were distinct commonalities within some specific categories of conceptualizations. For the first two categories: Mathematics and Science Integrators and Mathematics, Science and Technology Integrators, teachers in these groups used the same approach to contextualize student learning, project- and problem-based, respectively. This observation was also made of the fourth category, STEAM integrators, for which project-based approaches were used by all teachers. For the third category of conceptualization, STEM integrators, there was a combination of project- and problem-based approaches used by teachers. While the

Thematic approach was found with some teachers within Mathematics and Science; Mathematics, Science, and Technology Integrators; and STEM Integrators conceptions, there were no teachers in the STEAM conception who indicated that they incorporated themes in their integrated lessons. Figure 5 presents a visual representation of the relationship between Categories of Conceptualizations and pedagogical approaches used to contextualize student learning.

Figure 5

Relationship between Categories of Conceptualizations and Pedagogical Approaches



Theme 2: Teacher as Facilitator

Participants in this present study were asked about their specific role(s) during integrated STEM activities, in other words, what they would be doing if someone were to walk into one of their sessions. Many participants assigned different duties to themselves with the main role being a facilitator, from this main role they perform duties as they saw fit throughout the learning process for students.

In the role of a facilitator, participants explained that they were giving help, guiding, coaching, making connections among disciplines, clearing up misconceptions/mistakes as well as providing support to students, especially to weak/quiet/lost students. All 16 teachers exercised different aspects of facilitating in their integrated STEM teaching. For instance, Pat felt like since students learn better from their peers, she thought it best that at some point within the lesson, she just needs to facilitate students' learning experiences, "There's only so much, right, that they're going to be able to get from me, they would learn much better through their peers and just have me facilitate once they have a grasp." Mya also recognized her role as a facilitator and fondly expressed children are very knowledgeable and she emphasized that they learn from doing, "Because teaching right now, is to be more of a facilitating thing. You let the children do [work independently], because you'll be surprised to know what the kids know. Now, when they do it, they learn it!" Kim compared what happens when using a traditional approach, then she expressed that ideally in integrated STEM sessions, the teacher is the facilitator, "Traditional lessons are, you know, teacher says student does. And in my ideal STEM integrated lesson, teacher doesn't say much, teacher guides, they're the facilitator. The students are the drivers." Julia, Dan, and Beth also shared similar sentiments about the teacher being a facilitator in integrated STEM lessons. Julia confessed, “I am mostly a facilitator.” Beth was quite clear in sharing that at the beginning of her integrated lessons, she is a facilitator, “So at the beginning of the lesson, of course, I'm the facilitator, just getting them comfortable with the content, understanding the objective of the lesson, then gradually releasing myself, I would just guide them from afar.” Facilitating for Celia took the form of explaining and offering ideas and suggestions to groups who appear to be a bit lost and are not sure how to proceed, “Sometimes [I’m] offering ideas because some groups, you know, you have that group, they're like, ‘We don't have any idea what to do.’ So, you know, [I’m] offering suggestions.” Fiona recalled that her role as facilitator entailed walking around, watching, explaining, extending ideas, giving feedback, supervising, and providing the learning experience:

> I'm walking around, I explain what we're doing, then they're doing it on their own, I'm supervising, after we discuss and learn about the topic… I'm mostly a facilitator. I see what I can build upon little by little to help them increase their skills all around, not only in math, not only in technology, but science too, it's usually hands-off and I let them work.

As part of this theme, teachers acknowledged that their role as a facilitator shifted during their integrated STEM teaching. For example, Pat shared how her role as a facilitator transforms where in the beginning she is “holding their hands a lot,” but eventually “would allow them to work in groups as much as possible…I just need to be supportive.” Similarly, as a facilitator, Gary gives support to his students, as they engage in integrated STEM projects. He stated “I help them along because when they do the pre-planning stages, planning of any [STEM] activity that we do, they have to write a letter” to him about their proposed plan. He also described the other ways he facilitates student learning in integrated STEM lessons via listening to their ideas, presenting rubrics, explaining expectations, taking questions, giving help, critiquing, and extending their students' learning.

As facilitators, participants shared how they walked around or circulated among students as they were engaged in integrated STEM activities. This transient type of movement occurred across small groups or stations. For instance, Kim shared how she "would just walk around" as students worked in groups. Celia also shared that she is always "traveling around." Mya recalled when "walking around, [I] spend my time with that [lower] small group, spend fifteen minutes with each group but I spend most of my time with that lower group." Also, Dan described how he is literally "running from one station to the other." Ann recalled, "So it'd be a lot more circulating to make sure you know, to see who's understanding and who needs help." For Ida, she allowed her students to try the task "on their own to make sure if they have any questions." Gary stated after giving students an explanation of what they have to do, he "takes any questions." Celia kept "an eye" on students and was "available to answer questions and sometimes offering ideas." Ann assured that she "clarified any questions they [students] have" and if needed, she would go "back to the board" and they will go through some of the stuff again.

Another aspect of participants' duty as facilitators while engaging their students in integrated STEM activities, was maintaining classroom management and a safe environment for students. Based on participants' accounts, maintaining classroom management, ensuring students are on task, and fostering a safe environment were important practices for them as teachers. For instance, Eve explained, that one of her objectives for walking around is "trying to keep them [students] on task, keep them on target." She continued by describing when walking around she is "prompting classroom management." Celia believed that "with middle schoolers, you are definitely making sure everything's on task." Racquel also felt like as she worked with first-grade students, she ensured "that they are on the right track, and I make sure they are on the task that I want them to complete." Julia is particularly concerned about students' safety, "I'm just there to watch them, to observe, to keep them safe, and help them organize themselves."

As mathematics teachers in this study gave their accounts of how they facilitated integrated STEM teaching, it was noted that as facilitators of student learning, their roles changed periodically. These roles were adopted based on several determinants, whether it was the beginning or during the activity, the needs of the students at the time, or the teachers' desire to attend to classroom management duties. As facilitators, participants were performing duties that included giving help, guiding, coaching students as well as asking/answering questions accordingly. While performing these roles, teachers were instrumental in creating opportunities in their classrooms that were conducive to student learning. These teachers acknowledged the importance of their roles and responsibilities throughout the different phases of the integrated STEM activities.

Theme 3: Cooperative Learning

Participants were asked how they typically allowed students to work when engaging in integrated STEM activities. Based on their responses, a third theme emerging from the data was the tendency for teachers to deviate from whole-class instruction and provide opportunities for students to engage in cooperative learning. Mathematics teaching has traditionally reflected a predominantly whole-class format, with the tendency of the typical rows and columns layouts. However, fifteen of the sixteen participants shared how they facilitated this cooperative learning by structuring classroom STEM activities in such a manner that students worked collaboratively either in pairs or small groups. These small-group settings allowed for students to teach and learn from each other, promote students' communication skills, and give way for students to initiate the learning process.

Teacher Creates Small Groups

Teachers expressed a preference for students working in small groups when working on integrated STEM activities rather than as a whole class, as is sometimes seen in traditional mathematics classrooms. Both Beth and Racquel referenced how they facilitated cooperative learning among their students. Beth shared that there are times during the activities she would tell them "to buddy up." She went on to explain one reason she paired up students, "I would pair one of my higher with my low to balance out. So, I would definitely buddy them up and let them work together." Racquel also favored small group settings, "So they can have discussions among themselves as well, I think that use of language among themselves could also be interesting, so I like to do a lot of group work in threes and fours." Similarly, Gary stated that as students worked collaboratively in groups, they were more inclined to be open and share their thoughts and ideas freely and confidently, they would be "pretty much themselves." Kim pointed out that she preferred small group settings as well because she felt it is a bit challenging for students to work in the whole group setting as opposed to working in small groups. Leah and Mya shared that when doing integrated STEM activities, they would usually discuss the objectives of the tasks as a whole group then create small groups for students to complete the tasks. Fiona also expressed similar sentiments about students working together on STEM projects, “I would consider a small group, a group of four when they're doing engineering and STEM projects, they work in groups of four a lot. The technology things we do, they'll do in pairs.”

In addition to stating how they formulated the small groups to encourage cooperative learning, participants gave justification for choosing small group settings. There was agreement among participants that having students working in groups during integrated STEM activities was more beneficial to their learning experiences than having them working as a whole class.

Students Teaching/Learning from Each Other

The idea of students teaching each other and/or learning from each other was reiterated by nine participants. For instance, Fiona jokingly reflected on the thought that “Once I let them go, they’re teaching each other and themselves…they teach each other really good!” Pat, Dan, and Kim also corroborated this idea of students simultaneously teaching/learning from each other. Pat shared, “I would allow them to work in groups as much as possible for them to learn amongst themselves.”

Julia, Mya, and Beth stated that they assigned their grouping in such a way that the “higher”/“stronger” ones are placed with the “lower”/“weaker” ones. Julia shared, “So when I put them in small groups, sometimes I try to do it on ability. So maybe I might have a student that might be struggling with a higher achieving student, I just want them to cooperate, work together.” Ann also suggested that all students gain from working in small groups because, in addition to the “stronger” students assisting those needing more support, it also provides opportunities for these “stronger” ones to concretize/reinforce concepts. Celia shared “Definitely group work when we're doing a

STEM/STEAM lesson, and they work a lot better because they can bounce ideas off of each other in groups." Additionally, Hazel and Gary mentioned that as students engage in integrated STEM activities while engaging in cooperative learning, such exposure will be helpful to them in the future. Hazel shared how this was especially the case for the "STEM world":

> I just think that two or three brains are better than one. Sometimes, I go back to the workforce, like, in the real world, a lot of times, you're gonna be working with people, right? Especially in the STEM world. I mean, very rarely is it just one person focusing on a design.

Gary explained that he allows his middle schoolers to work in groups and then went on to justify this practice, "I always tell them to work in groups, because I want them to build that social interaction, the communication skills that you need."

In general, teachers expressed that cooperative learning created avenues for their students to both teach and learn from each other. The idea that having students who were more familiar or confident with the required concepts for skills reach out to those who needed help was another reason cooperative learning was practiced by the teachers in this study.

Teachers' (In)Actions and Students' Actions

As students worked in small groups and taught or learned from each other through cooperative learning while doing integrated STEM activities, this resulted in certain (in)actions from the teachers and inversely more actions on the part of the students. This was evident as these teachers shifted the focus of instruction from themselves and more towards students. Cooperative learning allowed for participants to facilitate student-centered pedagogy through intentionally minimizing their involvement in the learning process which resulted in, as Kim coined it, students being the “drivers” of the learning process. When asked what someone walking in on one of your integrated STEM lessons would observe, participants’ accounts showed that students’ actions dominated most of the classroom activities, resulting in a decrease in teachers’ actions. Fiona shared that she provides opportunities for her students to experience the integrated STEM knowledge and organizes it for them. Celia explained “I like them [students] to choose their own roles… I'm, you know, a bystander that can help, not necessarily be the one delivering.” Similarly, Beth assumes a “hands-off” approach, instead of just leading them in the right direction.

As teachers adopted a “bystander” or “hands-off” approach, this resulted in students becoming very instrumental and participatory in classroom activities. As Julia stated, “Their job is to just do it [integrated activity], I might model it for them, but it’s their job to do things always.” Celia’s account also noted as students were engaged in STEM activities in groups they had to “figure out who’s going to do the research, and who’s going to put it together and who’s going to type.” Julia stated after she tries “to let them do most of the work,” in fact “most of the time, they’re doing all the work.”

In the examples above related to cooperative learning, participants described how they intentionally created small groups and provided opportunities for students to teach and learn from each other. As these opportunities were established, connections were observed with the previous theme in which teachers performed the role of facilitators of student learning. This was observed as students’ actions were more prevalent and teachers simply guided the integrated STEM activities. Teachers’ facilitating roles throughout these cooperative learning opportunities in the classroom activities encouraged students' self-directed learning as they worked collaboratively in groups. Overall, cooperative learning strategies were popular in most of the participants' accounts of integrated STEM activities. There were commonalities in the way these strategies were utilized as well as an agreement with the benefits to students working in small group settings. These benefits included peer teaching and learning, improving students' communication skills, more social interactions, and increased students' actions.

Theme 4: Formative Assessment

In addition to administering a range of supportive actions to their students and using cooperative learning in their enactment practices for integrated STEM teaching, another theme that surfaced from the data analysis was the form of assessment the mathematics teachers used with students throughout the learning process. Teachers assessed students at different intervals of the lesson to determine how well they were proceeding with the assigned tasks. Nine participants gave accounts of how while enacting integrated STEM teaching, they employed formative assessment via two means: making observations and asking questions.

Teacher Makes Observation

As their students were on task in small groups, participants walked around and visited these groups for several reasons, including assessing student learning. One way by which teachers accomplished this aspect of formative assessment was through observations. For example, Mya explained how observation is an integral part of her assessment process during her lesson and how her observations informed her teaching:

> Of course, this is all observational, but I'm giving them grades for that. So sometimes, when you get the 90% it's not always about a test, observation is always an assessment as well. When I get that observation, I will see where I need to meet them. The assessment is observation at that point.

When utilizing formative assessment during integrated STEM activities, Gary initially presents students with a rubric and after they go through the five or six categories. He then observes the students throughout the activities and assesses them on each category, he also uses this opportunity to determine their ability to work together collaboratively. Similarly, Leah employs aspects of formative assessment with her students as they are engaged in integrated STEM lessons. She noted that for her it is important to evaluate their creativity and take notes of their problem-solving skills throughout the activities.

The use of formative assessment was yet another deviation from the traditional trend in mathematics teaching for which summative-type assessment is usually more popular. Also, traditionally assessment in mathematics was not necessarily done through teacher observation but rather by way of end-of-unit or quarter written evaluation. Participants explained above how they directly observed and assessed students' abilities in real time as they were doing the integrated STEM activities.

Teacher Asks Questions

In addition to making observations, Racquel's and Mya's accounts indicated that they also engaged in formative assessment through oral questioning during their integrated STEM activities, Racquel noted, "Well I will walk around and you know… use oral questioning and use observation, ask them questions."

Mya explained that she takes notes and assigns grades cumulatively as she questions students. Her questions also engage students in higher-order thinking, “I'm like, ‘Okay, why are you doing this now?’ I question them, and I'm taking notes.”

The use of questions as a means of formative assessment was also done by Ann, Pat, Ida, and Kim. In some cases, participants used this continuous assessment to gather information to adapt the learning process to meet the needs of their respective students. Ann stated, “But I'm also asking to gauge where they are. And if they're understanding and target students who may be borderline, you know, I don't want to get someone lost.” Pat also questioned students to determine their “foundational knowledge” before proceeding. Ida asked questions to foster involvement and assess if they understood what they needed to be discussing. For Kim, asking thought-provoking questions is part of formative assessment as well as extending students' thinking.

These teachers made use of formative assessment, whether through observations or asking questions, to evaluate different aspects of students' learning and to be instructive in their own teaching. This type of assessment helped teachers to determine students’ understanding, guide their own instructions, assess/grade students on an ongoing basis, and extend students’ thinking.

In general, teachers’ descriptions of their enactment of integrated STEM showed them using three approaches to contextualizing their students’ learning, being a facilitator throughout the learning process, providing cooperative learning opportunities for students, and/or performing formative assessment within the activities. All participants used project-based, problem-based, or thematic approaches to contextualize the concepts. These approaches were used either singularly or by combining two at a time. Sixteen participants described how they perform the role of facilitator while engaging their students in integrated STEM activities. As they facilitated, they shifted from a teacher-centered style to student-centered teaching as reflected in most instances of their accounts. This shift allowed for cooperative learning among students, fifteen participants explained how they set up STEM activities that had students working in groups collectively and collaboratively.

Factors Influencing Teachers' Enactment of Integrated STEM

Finally, based on the Categories of Conceptualizations and Enactment Themes established, a number of factors surfaced during the data analysis process, both positive and negative, which were influential in participants' enacting integrated STEM. These factors addressed the third research question:

> Q3. What factors did these mathematics teachers identify as influencing their enactment of integrated STEM?

The participants' interviews yielded multiple influencing factors, for organizational purposes, these factors were arranged into main themes and subthemes based on similarities that existed among them. The four main themes that emerged were: *Personal Factors, School-Related Factors, Professional Factors, and External Factors.* The factors/subthemes in each of these themes included both positive and negative effects on how participants enacted integrated STEM teaching, therefore they encompass reasons that either motivated or hindered these mathematics teachers' use of integrated approaches.

The first main theme, Personal Factors, was related directly to how participants personally felt about teaching using integrated approaches as well as their justification for doing so or not doing so. Secondly, those reasons participants gave that were a direct result of factors associated with their schools such as schools' administrative structures or curriculum were categorized into School-Related Factors. Some influential factors given by participants were related to either their teacher training, workshops, or co-planning done with colleagues, these were labeled as Professional Factors. Lastly, the fourth grouping was assigned the title External Factors. These factors were not personal, school-related, or professional in nature so they did not fit into any of the previously stated groupings; for example, district-related competitions or influences from practicing practitioners and online sources. Table 7 summarizes the main themes, descriptions, and accompanying subthemes for the factors that influenced participants' enactment of integrated STEM teaching.

Table 7

Summary of Themes and Subthemes for Factors Influencing Integrated STEM teaching

Theme	Description	Subtheme
Personal Factors	Influences related to participants' personal perspectives or choice	1. Teachers' appreciation for discipline integration (+) 2. Teachers' discomfort/feeling of unpreparedness (-)
School-Related Factors	Influences that emanate from within the school structure or administration	1. STEM/STEAM designation and Administrative expectations/ support (+/-) 2. Standardized testing & Time (-) 3. Curriculum documents (+/-) 4. Availability of resources (+/-) 5. Departmentalized versus Self-Contained (+/-) 6. Classroom and School Initiatives (+) 7. Students' Interest/Curiosity (+)
Professional Factors	Influences that were a result of interactions with other professionals	1. Professional Development/ Professional Learning Communities/ Planning with colleagues (+/-) 2. Pre-and in-service teacher training (+/-)
External Factors	Influences that were beyond the bounds of the school/institution	1. Lack of clear framework/Definition for integrated STEM (-) 2. District competitions/ activities (+) 3. Students' future career choices (+) 4. Media, Internet, and/ or Resource Personnel (+)

+ : positive influence; - : negative influence

Personal Factors:

Within the Personal Factors theme, participants cited factors that positively or negatively influenced their initiatives at incorporating other disciplines when teaching mathematics. The positive influences included valuing the importance of integration and a desire for doing integrated STEM activities with their students.

Teachers' Appreciation for Discipline Integration

Positive Influence. Racquel, Beth, Hazel, and Fiona explained that it was important for students to know the connection between disciplines. Racquel stated that "I want to know the students can see the connection between the science and mathematics." She further suggested that "Well, I'm thinking, you know, I think integration is important because there's an opportunity to reinforce what was rooted in one lesson in another." Hazel explained, "I'm just again, expanding knowledge, expanding new horizons, as far as having them know how some things automatically are integrated." Beth's choice to integrate was influenced by her belief that this approach was an effective way of tying "curriculums together." She understands how integrating two disciplines, mathematics and science, with her fourth-grade students was aptly preparing them for what they are going to do in fifth grade the following year. Beth also believes that it is important for students to make the connections:

> I think that's the biggest takeaway, students being able to make connections, students realizing that, um, that the world is connected, that everything is connected in one way or another. You know, like, it's not Oh, math to the left, reading to the right, science over there.

These accounts above depicted that the teachers appreciated the importance of teaching through integration to student learning, they saw it as a means of reinforcing the concepts of one discipline in another as well as preparing their students for higher grades. In addition to this benefit to students, participants felt that approaches that promoted discipline integration also bore benefits to their teaching. Julia highlighted that integrated STEM teaching had two-fold benefits, profiting both teachers and students alike. For her, as a teacher, she gets to deviate from the traditional way of teaching and “try something” different and for the students, it is an opportunity to have them “engaged.” Julia admitted that initially she only did it because she had to, but she eventually became aware of the value of integrating disciplines, despite it being time-consuming to plan:

> I think like me as a teacher, the benefits for me is that it gives me a lot of opportunities to do things that I wouldn't normally do. And I think that's a benefit for them [students] that they're engaged. I rather they get engaged in measuring ingredients to make cupcakes and make crayons in the class than look at a book and not know what they're looking at.

Gary also expressed this two-fold benefit for both teachers and students. He shared that since he was trained to teach using discipline integration, he feels comfortable using this approach and believes, “it allows them [students] to understand that all these subject matters are really integrated.” Dan, on the other hand, referred to one instance that even though he felt like one of his students did not quite appreciate the value of the connection of disciplines, he is hoping that as the teacher, he has “planted the seed,” and the student will be able to make the connections as he matures. Here, because of his appreciation for discipline integration, Dan felt the need to still provide opportunities for students to experience the connections.

In the instances above, participants highlighted the value they placed on the importance of teaching through integration. They mentioned the gains to both students and teachers. Some of these benefits to students included reinforcing what was done in other disciplines, having students engaged and making them excited about learning. Participants benefitted in that it allowed them to use a different approach to teaching.

Teachers' Discomfort or Feeling of Unpreparedness

On the other hand, feelings of lack of knowledge, unpreparedness, or underprepared created a level of discomfort in participants who were interviewed for this present study, which negatively impacted their tendency to use integrated approaches.

Negative Influence. One of the reasons participants expressed hesitancy for integrating disciplines is as Pat stated being "underprepared" to effectively do so. Racquel, Julia, Leah, Kim, and Beth also expressed feelings of personal discomfort or lack of knowledge of integrated STEM teaching. Racquel confessed, "The extent of my knowledge would be a barrier, because I don't think it was explored a lot in my bachelor's degree or even promoted more in terms of workshops." Julia also viewed this lack of knowledge as a barrier that created a level of uncertainty for her, especially for engineering, "A barrier sometimes…not knowing how to do STEAM. Because when we first started doing STEAM, I remember looking at the lesson plan and thinking, 'Okay, this can't be too hard.' But then when I got to the engineering part."

Leah and Beth also stated a lack of knowledge of the other disciplines: science, technology, and engineering, and how to integrate them was challenging. For Leah, she felt like not knowing about the "other subject areas" is a "one of the big challenges" for her as well as other teachers:

> One of the big challenges is to know anything about the other subject areas, how well rounded we as teachers are, how much we can have a creative idea, and then put it into words on a project, and then see how the different disciplines will go into that. It's hard for us to join… So, I think that it's probably a lack of having all the other disciplines.

Beth admitted that she struggled with planning and implementing integrated lessons with her fourth-grade students and is yet to see integrated STEM done “nicely.” She explained, “When I'm planning the lessons, we often struggle with implementing a different component in fourth graders, you know, so I find it difficult to do it…I just have not seen it nicely done as of yet.”

Kim shared that integrating can be “intimidating at first,” and that teachers may hesitate to use integrated approaches because of continually feeling judged and the fear of making “mistakes.” Ann confided that for mathematics teachers who have been teaching for a long time, she noticed that there is some hesitancy and discomfort in both using technology as a teaching resource or integrating it as a discipline in their teaching. Ann shared, “And then I think they've been around for long enough that even those teachers who are really not comfortable with a whole lot of technology, a major issue…this leaves them a little bit lost.” Interestingly though, Ann’s specific references to her use of technology in her integrated STEM activities was the use of the “promethean board.”

These feelings of inadequacies expressed by participants led to their hesitancy in teaching STEM integration. With a lack of knowledge for the other disciplines, these mathematics teachers felt challenged by not being able to comfortably integrate all disciplines, which can be intimidating. This lack of knowledge and/or discomfort with technology use was one reason for its absence, noting also as observed within the Categories of Conceptualizations previously discussed, participants Beth, Kim, and Mya, whose Mathematics and Science conception revealed the omission of technology in their understanding of integrated STEM education.

Summary of Personal Factors Theme

Based on the excerpts from the participants' responses above, teachers' appreciation and awareness of the benefits of integrating disciplines fostered a positive influence for them in implementing integration in their classrooms. On the contrary, this Personal Factors category also contained elements that dissuaded teachers from undertaking integrated STEM activities in their mathematics teaching. As outlined above, these discouraging factors included teachers' feelings of discomfort or not being prepared to confidently undertake such integrated approaches.

School-Related Factors:

There were influences noted by participants that either positively or negatively affected their teaching integration of disciplines that were directly related to aspects of their schools. These were coded as using the main School-Related Factors and included the following subthemes: meeting the requirements for STEM/STEAM designation, the lack/presence of administrative expectations/support, testing and time constraints, specifications of curriculum documents, availability of resources, and classroom/school initiatives.

STEM/STEAM Designation and School Administrative Expectations/Support

For participants in this study, STEM/STEAM designation and administrative expectations/support for integrated STEM teaching varied. Eight participants shared how positively influencing STEM/STEAM designation and/or their schools' administration expectations were for integrating disciplines. Despite these levels of expectations, support from the administration was not always present. Two participants explained that the integration of other disciplines was not necessarily expected and hence not supported by the administration.

Positive Influence. For this study, the participants selected and interviewed were assigned to STEM/STEAM designated schools. This designation expects/assumes that teachers at the schools engage their students in activities that reflect discipline integration. Although Beth and Pat indicated that there was no mandate to integrate disciplines all the time by their administration, they did so because they were cognizant of their school's STEM designation. Beth noted that her school's administration would "love" teachers to integrate. She further explained that her administration asked teachers to do at least one integrated activity during the school year:

> I have not had any expectations relayed to me. We are a STEM school… they ask us to at least do one activity like that per year. But that's also geared to the requirements of the STEM Designation. But are there any requirements? no.

Hazel also shared that although discipline integration is not mandated by her school's administration, however, it is certainly "emphasized," as the school aims for a high STEM-designation ranking with the district. Therefore, one of the reasons she does integration is she wants to "do well" for her school. She did admit to feeling a bit pressured at times:

> But my school likes to go for the whole like STEM designation. And they want to get the gold or the silver and the bronze, so it does become almost, I can't use the word mandatory. They do push for it… and the pressure because you want to do well, for your school, at least I do. So that they can get their designation.

Racquel also admitted that STEM integration was encouraged but was not necessarily mandatory, "I don't think document wise it would be, it would be encouraged, but I don't think you know, it is mandatory for teachers to actually do it."

Based on Hazel’s and Racquel’s accounts as well, there appears to be an apparent disconnect between the administration and teachers. In these instances, teachers shared that integrated STEM teaching was emphasized or encouraged but not necessarily expected from their respective administrations. These teachers shared that the level of encouragement and emphasis placed by their administration on integrated teaching influenced them at times to teach through integration, despite not being mandated.

In addition to administration’s expectation of teaching via integration of STEM disciplines, participants also shared aspects of support that was either present or absent from administration. For instance, when asked about her school’s administrative support, Olivia explained that this was the only support she got, though it was not perfect:

> Yes, absolutely, but there weren't that many clarifications on the steps to how to get there. There might be on the steps that you were more responsible for. Yeah, it was with support given by the administration, you know, there wasn't anybody coming to the school to train us.

Mya’s experience with her administration was much more supportive, she received ideas and resources from both principal and assistant principal:

> Well, our principal and assistant principal, I feel like they're very supportive. And they give us our resources. Whenever we go to them with something that we need, they're there… Our AP has been there for the second year going on third year and she is very supportive, and she's resourceful because she came from downtown.

Julia received administrative support from her school in the form of STEM/ STEAM workshops. She also outlined her administration’s expectation of teachers engaging students in one STEAM lesson every quarter and she went on to give an example of an integrated activity she did with students:

> Our school also does some STEAM workshops and STEM workshops on site, because of that expectation that they want us to have all those lesson plans. So

> every year I end up going to some sort of STEM or STEAM-related workshop, we are expected to have at least one STEAM lesson plan every quarter.

Fiona expressed such excitement to be part of the STEM program, it was “new” to her school, and she was happy to have the full support of her administration:

> This is a whole new program for this school. So, I'm very blessed in only being a beginning teacher, but you know, she's [principal] truly, truly happy we have it, we have a very supportive and I want to say a good mentorship type of department.

In addition to support in terms of STEM/STEAM workshops, participants shared that their administration gave support by means of providing documents with guidelines to assist teachers in enacting integrated STEM teaching. For example, Eve recalled that previously her school’s administration provided the teachers with binders from CPALMS. CPALMS is “an online toolbox of information, vetted resources, and interactive tools that help educators effectively implement teaching standards” in the State of Florida (https://www.cpalms.org/). The information provided in the CPALMS document(s) assisted Eve as she got guidelines that gave instructions and ideas for integrated STEM activities from starting the projects all the way to end, “It's from the CPALMS. Usually, my administration will provide us with a binder printed out, they’ll give it to us. When I'm talking about one STEM project, I'm talking like, from inception, all the way through production.”

Negative Influence. Despite the above accounts of administrative support or expectations positively influencing teachers' efforts to integrate disciplines, this was not the case for all the participants in this study. For instance, when questioned about her administration’s expectations for teaching integration of disciplines, Kim responded by explaining that once she can “figure out a way to fit it in,” she would integrate other disciplines; however, she was quick to state that if she was visited by a member of administration during her mathematics session, she was not expected to be doing another discipline:

> I just find the time to do it, because that way I am reinforcing the math skills in science and vice versa… They're integrated only if I can figure out a way to fit it in, you know, because the way that it's set up, if we get walked in on by someone [administration] and we're teaching science during math, then that's a no no!

Ida also explained that her school's administration expected and encouraged teachers to do STEM and STEAM projects in their classes:

> They [administration] would like for us to do STEM and STEAM to make this happen… to make the kids see that no area is in isolation, that everything is put together to create something good. So, they would like for all the teachers to participate in these types of projects. And they encouraged us to do it.

Here, Ida mentioned the expectation of her school's administration, however, she did not indicate if any sort of support came directly from them. Just as Kim stated above, the onus was on teachers to try to figure out a way to make it work.

Schools' STEM/STEAM designation and administration's expectations or support either positively or negatively influenced participants to enact integrated STEM teaching in their mathematics classrooms. The fact that participants were assigned to a STEM-designated school was a motivating factor for them to engage students in integrated STEM activities. Whether they were specifically required to do so by the school's administration or not, they were aware of the designation and hence proceeded to teach using integration. Noting that in instances where there were expectations from the administration for teachers to engage students in integrated STEM activities, the support needed by teachers was not always forthcoming.

Standardized Testing and Time

The school-related factors of testing and time were coded as similar themes as they were both related and teachers made several connections between them. These factors negatively influenced participants using the integration of disciplines. Interviewees shared that preparing students for standardized tests often left little or no time to facilitate integrated STEM activities in their classrooms.

Negative Influence. The Florida Standards Assessments (FSA) were mentioned by 10 participants. FSA are exams that measure students' education gains and progress in schools within the state of Florida. The results from these examinations are ultimately used to, among other factors, drive instruction and establish goals for state schools and, measure students' achievement readiness for graduation.

Kim lamented that continuous testing, such as FSA, makes it challenging to do integration, she recommended "eliminating" some of the testing, "The things that prevent it [STEM integration] from happening is standardized testing. I think a lot of it would be to get rid of some of this testing."

Mya also shared that although she understood FSA testing "has been there," she confessed that it was an issue. She added that at this time she believes students "need intervention" and suggested that discipline integration is a means of achieving that, "So that integration would come in necessarily right now, where children can see science in math, math in reading, reading everything together."

Leah spoke about the pressure of having to prioritize her teaching, she felt that having to do STEAM projects and being faced with an FSA timeline made it difficult:

> You [school district] give me an FSA with a timeline, and I need to get there… You put deadlines for teaching a certain topic, a certain benchmark, and FSA is coming. I have to set priorities, and my priority is my curriculum, because if I set the priority on STEAM, what would happen to my students, when the test comes?

Beth brought up an observation that FSA word problems test using "cross-curriculum," however, classroom teaching is not necessarily done in that way to straddle across curriculum subjects:

> Because on the FSA testing, they have to read their word problems… going back to my example about photosynthesis in our math, they use examples like that. So they themselves will test the kids using cross-curriculum.

Beyond time constraints due to standardized testing preparation, Pat felt like a lot of mathematics and science teachers have lost their "in-class support" and therefore as teachers, they have "very little time to prep and plan" integrated STEM activities. Hazel reiterated that time was the major barrier in terms of doing integration in her classes because integrated projects usually take weeks to complete. She explained that even though it is a challenge to find ample time in the elementary grades, it was still more feasible in those grades because at least at this level, teachers met with their students every day:

> Yeah, time, time, time, time! … It's all about time… That's the main biggest problem is time and pressure, that to me are the main top two… So, time is hard to balance, … because let's face it, a STEM project is not a one-day thing. It takes time to do it properly.

Participants Dan, Ida, Celia, and Leah also lamented on time as a setback when it comes to engaging students in integrated STEM activities. Dan confessed that he did not like doing the integrated projects "too much because of time." Ida also stated that she does projects, "depending on the time we have." Leah admitted that for her it is difficult to plan STEM projects and believes that the "challenge" is time, "I think that it's hard to plan a project like that and the challenge would be how much time do you acquire for that project to make it possible." Eve also felt like there was so much work to cover with her students that it was "impossible to deviate because of time." She recalled being the chair of the math league at her school and added even that extra-curricular activity no longer exists due to lack of time.

In addition to not having enough time to prepare and enact STEM lessons, another aspect of time was highlighted by Fiona. In her opinion, she felt like during certain times in the school year, students responded differently to completing projects, she thinks that the time of year when a STEM project is done is important to get the best out of students:

> The biggest obstacles I see are with the materials and the time to prepare them. You don't have a lot of time. So, time is definitely an obstacle, I think, a barrier is, depending on the time of year, you're going to do a lesson because you know, your kids are in different modes, especially like right now is not a good time. At the end of the year.

The issue of testing and time were barriers to teachers' planning and attempts to enact integrated STEM education in their classrooms. Participants explained that standardized tests were done regularly and that preparing students for these tests was time-consuming. They admitted that an effective integrated STEM project took time to plan and implement. As Leah indicated she prioritized teaching and preparing students for testing over engaging them in integrated STEM activities.

Curriculum Documents

Participants identified curriculum documents that were influential in their integrating STEM efforts, for example, CPALMS and Pacing Guides. The Pacing Guides generally "include the standards to be taught, instructional materials aligned to those standards, instructional strategies useful in teaching the standards, and a timeline"

(Fisher, 2005, p. 10). There were mixed feelings from participants about the effectiveness of these curriculum documents with respect to discipline integration.

Positive Influence. Kim mentioned that she previously used CPALMS to help when she planned her integrated STEM activities. Participants Hazel and Gary spoke about using the Pacing Guides in a positive light. Hazel drew “great ideas” from these curriculum documents that helped her with planning integrated activities, “They [district] just put it in the Pacing Guides, and they have great ideas that they implement there, they break down the whole process, with a guideline sheet, and they'll tell you the science and the technology and the engineering and mathematics.” For Gary, the Pacing Guides serve as a useful resource, along with other district resources. He gets guidelines from this document for aligning different disciplines as well as a source for word problems:

> Well, the district provides us with a guideline, what they call the Pacing Guides, all the content and benchmarks that we have to teach, and I look at all the district resources that they provide us, whether it’s technology-wise or other. So, when I sit down with all the different Pacing Guides for each subject type, I see, OK, these could be aligned.

Negative Influence. On the other hand, Eve and Ida did not necessarily indicate whether the Pacing Guides assisted them in coming up with integrated STEM ideas; however, they felt that the pressure of having to adhere to the work stipulated in these guides took precedent over other classroom initiatives, including teaching through integration. Eve’s comment, “we’re on a Pacing Guide,” demonstrates the urgency she places on prioritizing the completion of the work outlined in the Pacing Guides. Ida’s sentiments are similar, her opportunities to engage students in integrated STEM activities are dependent on whether she covers the work as outlined in the Pacing Guides, “we have a Pacing Guide. And we need to go over all that stuff prior to the testing, and we need time for review." Both Eve and Ida share tensions in their need to stick to the Pacing Guide while also managing to find time to meaningfully engage their students in integrated STEM activities which they value.

Although support from administration, curriculum documents, and standardized testing were coded separately, there was intersectionality with these factors and the pressure of time. Curriculum documents such as CPALMS and Pacing Guides were helpful in some instances for participants. These documents were used both to get guidelines as well as ideas for integrating STEM disciplines. Participants Eve and Ida did not indicate if or how helpful the Pacing Guides were, they did however state that having to cover the work there prevented them from doing integrated STEM activities, thus suggesting that from their perspectives, discipline integration was not factored into the guides.

Availability of Resources

Acquiring resources was not a problem for some participants in this study, for example, Fiona, Pat, and Mya. Other participants Julia, Beth, and Ann, however, were not as fortunate and expressed how much of an inconvenience or setback the lack of resources can be when considering the integration of disciplines.

Positive Influence. One influencing factor that assisted Fiona in facilitating integrated STEM teaching is the ease with which she acquired resources from both the district and her school principal, "I work with the district, because they give me a lot of guidance, they help me with lessons, with resources. In the end, my principal does that as well, with resources, she makes sure I get what I need." Mya explained that she has a colleague who willingly shared resources and information about integrated STEM teaching, “She's resourceful because she came from downtown. So, she has a lot of ideas and stuff, really, really, really resourceful.” Ida shared that teachers at her school may not always have a lot of resources available, but she explained that there were some accessible resources for teachers who wish to engage students in integrated STEM education.

Negative Influence. While the ease of acquiring resources positively influenced some participants in using integration, this was not the case for Julia, Beth, and Ann. Julia felt like teachers are expected to engage students in STEAM activities, but they usually have to “pay out of pocket.” When asked about what are some things that influence her using integrated STEM teaching, Julia responded:

> Lack of resources is a big one. I feel like so much of these activities, as fun as they can be, they always come out of pocket. They're never really provided to us. There's always an expectation that we do STEAM but ‘With what, and how?’ A lot of teachers aren't willing to pay out of pocket.

Beth also shared similar concerns about the lack of availability of resources, when making attempts to engage students in integrated STEM activities. She noted that the most challenging part “is just finding material and actually doing it.” There is evidence of teachers’ willingness to do integrated STEM education, availability of needed resources has manifested both positive and negative influences.

Classroom and School Initiatives

The schools selected for this study were all STEM/STEAM designated. As part of this designation, some teachers and schools initiated integrated STEM-related events. Participants, like Julia and Dan, facilitated integrated activities with students as a result of classroom or school-driven initiatives.

Positive Influence. Julia excitedly shared two annual activities which influenced her in engaging her students in integrated STEM activities; one was at a class level and the other was at a school level. Every year she made mulberry muffins with her elementary students. This baking activity incorporated concepts from both mathematics and science. The second activity, which occurs three times per year, is a school event called STEAM night, which involves students, teachers, parents, and the public. She highlighted some of the benefits of this activity, which included qualification for STEAM designation from the district, a fundraiser, and an opportunity for her and her exceptional students - students with disabilities, to collaborate with general education teachers and students:

> We do have in our school, STEAM nights, like three a year, because we want the STEAM designation for our school. I partner with the general education teachers, and it's actually very cool because we can also fundraise money for field trips this way. Parents usually buy tickets, the teachers and students set up their own booths with STEAM activities. And the kids come, it could be the general education students and it'll be my students… so the STEAM nights are really good for bringing everybody together.

The integrated STEM activities/events identified above were initiated either at the class or school level. In both cases, they positively influenced teachers to engage students in integrated STEM education.

Students' Interests/Curiosity

The enjoyment, interest, and curiosity in STEM learning were also present among students of the participants in this current study. Participants cited that their motivation to engage in integrated activities was that students showed particular interests, curiosity, or love for doing integrated type activities.

Positive Influence. Kim’s drive to enact integrated STEM teaching came from the interests of her students, she stated, “I listened to my kids, I find out what they like.” Also, participants were faced with questions from students about how or when they will need specific mathematics concepts in their everyday life. Ida’s drive stems from her observation that normally some students are not motivated to participate, but their interests change when it is integrated STEM projects. She explained there are times for general class activities, “Well, sometimes you have students that don't really want to participate. Like I said, the majority of the projects [integrated STEM] are interesting to them. So, then they participate.” Mya also made a similar observation, “I think the kids love it, they learn, yes, they learn. And at the end of the day, you as a teacher see that the students are interested in it.”

When asked to share her justification for using integrated approaches in her mathematics teaching, Celia noted that among her elementary and middle school students, the “most popular question” was why they had to learn certain topics:

> The question is always, ‘Why do I have to learn this?’ So, integration answers the question, like sometimes when we're doing something, they're all into it, ‘Oh, but we didn't want to learn this. So, it's honestly the only way at this point for them to understand what the why. So interesting… and that's where we get the connections.

This was also the same question Pat and Dan were faced with from their students, both teachers usually attempt to give appropriate examples. Pat explained:

> The question that I get the most, all the time is, ‘When am I going to use that?’ So, I felt like I needed to be prepared. I'm like, ‘Alright, you want to know when you want to use it?’ I definitely try to give them examples of how this is pertinent.

In addition to creating an awareness in her students, Celia hopes that her efforts in integrating the disciplines can stimulate students’ interest in “areas” that they may not have been previously aware of. She explained:

> To help them to become aware of areas of study that they don't necessarily know about, they may find interests that they didn't know they had. I've got students that because they've taken part in simple projects, they have become part of the Robotics program.

Julia used integrated hands-on STEM activities because she believes it is a lot of fun. Additionally, she confided that her exceptional students are not able to do too much “paper and pencil” work:

> It's a lot of fun. You wouldn't think so when you work with ESC. It's like you have to be creative because I mean, half of these kids can't use paper and pencils, so it's like, you have to kind of think outside the box.

Students’ interest/curiosity led teachers to engage them in integrated STEM activities. Participants observed how students enjoyed and showed more interest in lessons that were based on integrated STEM disciplines. In Kim’s account, she elicited from students what they were interested in as a guide to her activities.

Departmentalized versus Self-Contained Teaching

The organizational classroom structure for schools in this study was of two general forms: departmentalized and self-contained. Participants who previously or currently worked in departmentalized settings described it to be one in which different teachers were assigned to students for each discipline. Whereas, in self-contained classrooms, the same teacher taught most, if not all, disciplines to students. Based on participants’ accounts, both formats have advantages and disadvantages and either positively or negatively influenced their enactment of integrated STEM teaching.

Positive Influence. Classroom settings that were self-contained tended to support and positively influenced mathematics teachers to enact integrated STEM teaching. For instance, having experienced both types of formats, departmentalized and self-contained, Celia expressed a preference for teaching in self-contained classrooms, especially at the elementary level. She further explained that even when being in a departmentalized school setting, in many cases there were indirect opportunities for teachers to attempt discipline integration, if they were willing to. From her experiences, in many instances, the mathematics teacher would teach science as well, and this structure lends itself to integrating disciplines easily.

Similarly, Hazel also mentioned being departmentalized in the elementary school but teaching both mathematics and science, “I've always been departmentalized, and my departmentalization was like math and science in the elementary, because we combine those subjects together like departmentalized teachers.” Eve recalled teaching fifth grade and because it was self-contained, she only did interdisciplinary teaching, “Um, when I first started teaching, I taught elementary, I had a fifth-grade classroom. It was self-contained, so I taught all the disciplines. We weren't departmentalized back then, and I only did interdisciplinary.” Mya clarified that at her school, from fourth grade, the teaching is not departmentalized, because of this, she is able to teach all disciplines, “We have to teach all subjects, when you go to fourth grade, you're not departmentalized. So, I have to teach all subjects reading math, social studies, and science.” This structure she shared made it easier to integrate the STEM disciplines as well.

Participants concurred that self-contained classroom settings were more conducive to integrated STEM activities than departmentalized settings. This was the case because teachers in self-contained classrooms taught all subjects. Based on participants' accounts above, even within departmentalized school structures especially at the elementary level, some teachers were assigned to teach both mathematics and science, so even in those arrangements, integrating these two disciplines was at times feasible.

Summary of School-Related Factors

The above noted School-Related factors either positively or negatively influenced teachers' enactment of integrated STEM teaching. Factors such as Classroom and School Initiatives and Students' Interest/Curiosity only had a positive effect, however, other factors: Administrative Expectations/Support and STEM/STEAM Designation; Availability of Resources; Pacing Guides and Curriculum Documents; and Departmentalized versus Self-Contained revealed either positive or negative influence on some teachers to use integration. The consensus for the factors of Testing and Time was that these served as barriers and hence negatively influenced teachers' attempts to enact integrated STEM teaching in their classrooms.

Professional Factors

In the present study, participants mentioned involvement in professional development workshops, professional learning communities, pre- and in-service teacher training, and planning sessions with department colleagues as factors that influenced them to use integrated STEM teaching. These professional encounters were categorized as Professional Factors and drew both positive and negative accounts from participants. Based on participants' responses, it was noted that some of them voluntarily sought out workshops geared towards STEM integration while others were asked by their schools to attend.

Professional Development/Professional Learning Communities/ Planning with Colleagues

Participants gave accounts of their involvement in professional development, professional learning community, and planning with colleagues. Some of these experiences were positively influencing interactions, while others were not.

Positive Influence. The professional development experiences of Kim, Ida, Dan, and Celia were instrumental in them engaging students in integrated STEM learning.

Kim shared that she has done workshops both at school and at the district levels. She recalled that the workshops she did at a previous school were STEM-oriented, in sync with the administration's vision, and were "very useful" and "amazing":

> I've done district level and then school as well…The ones that I went to with the school that I was at were very useful because the school's administration outlook was the same. So, the school was headed towards a STEM or STEAM curriculum. And they [school] took us on, a training that was a week-long, we went to a conservatory place. And they had a whole bunch of different STEM activities and STEM units, we made fans, we made boats, we made cars, we made an ecosystem. It was amazing!

Ida's professional development workshop experiences were also beneficial, like Kim, she also attended workshops at school and with the district. When asked about these workshop experiences, Ida explained that she attended annually and noted participating in the workshops was optional:

> Every year I participate in one at least, for the past three or four years. And they show you sample activities, how the activity would be a STEAM activity, how you incorporate this and that. So yeah, the district does provide some, they provide professional development, our school also does encourage the teachers to do them, we have done some in-house as well… They are very good because they give you an idea if someone doesn't have an idea what it is to do a STEAM project or what it is when you have to incorporate several subject areas, they get exposed to one of these projects.

Dan explained that in some cases, attendance at some of the professional development workshops was optional, while for others it was mandatory. He went on to say that at the time of the interview, he had exceeded the expected attendance quota, some of which were STEM-related. He also gave some details about aspects of two of the workshops he attended:

> And of course, some of the training was STEM as they had to do with projects like project-based learning and Gizmos, the use of technology. I remember one time we went to a Discovery Education Training and that was STEM also.

Celia recalled details of a professional development experience she had which was an initiative from Miami Dade County entitled I-Heat. She felt that the I-Heat experience was very interesting and supportive for teachers in teaching STEM integration. For this particular professional development, there were professionals coming into her school from the Miami Dade County Public School department and teachers were given guidance on "integrating the lessons." She indicated that she participated in this workshop just prior to her school launching into embracing STEAM, she lamented, however, that the I-Heat program was no longer in existence:

> They made us teachers make a Roller Coaster out of insulation for pipes that was cut in half and I was like, 'I have the kids do this and I don't know how to do this!' And it's good to be on the other end of it, because it was like, 'Wait a minute you have to expand and use that creativity.' That was right before we actually started doing that STEAM stuff, and it was very interesting. That was an initiative we lost here in Miami Dade County… So, it helps us with integrating the lessons and becoming more STEAM- or STEM-like.

Celia continued to share additional positive experiences she had with STEAM professional development, noting that they were all "hands-on" and "very, very informative":

> There's a lot going on, we have a lot of group work. They've been very, very informative. And without those meetings, there's no way we would have been able to do this. It's very specific, it's not just about what we know and putting it together with something else…STEAM instruction is a little bit like our own understanding and helping them [students] to understand what we're teaching them in a practical manner. You know, showing them how math is useful with science and with everything else together.

Beth also had positive experiences with professional development workshops. In one instance, she remembered a STEM PD that she attended at the beginning of her teaching career in which what she learned about integration as she recalled “blew my mind.” She further explained that although the professional development sessions are not mandatory, teachers are given “mandatory workshop days,” so she intentionally looked for those that address implementing integrated STEM in the classroom:

> I've attended some PDs I believe two, one on how to integrate math with science and actually a STEM PD, that's one of the things, taking what you've learned and applying it into the classroom, I think that was an eye-opener. And I actually took the cross-curriculum PD at the beginning of my educational career. And it just blew my mind how you can tie one into the other… So, I'm a firm believer in integrating… For me, I still would like a better understanding of how to successfully implement STEM in my classroom. So, if ever I see those offered, I always try to join.

In addition to attending professional development workshops, some participants were engaged in professional learning communities where they met with teams of teachers. Mya, Celia and Fiona shared their experiences. Celia mentioned interacting with other professionals in education through an online forum, Teachers Pay Teachers. Fiona expressed excitement with respect to how useful her experience was being part of a professional learning community; from this interaction she was able to source ideas for integrated STEM education to use with her students. She went on to explain how beneficial it was for her to participate in a professional learning community that was through her school district. When asked to give some insight on her experience, she shared:

> Amazing, amazing! I must say, I was invited to be part of a PLC just full of other STEM teachers throughout the district this year. And every other week, we met online, and it was just amazing. We shared resources… Because usually at a school you feel like you're kind of on your own…You know, the other teachers have a million ideas and for a new teacher like me, that's like a gold mine.

Participants also had opportunities to plan with colleagues at their schools which were helpful in planning and implementing integrated STEM activities. Ann explained that teaching in the lower grades makes it easier to plan with members of her department because these teachers have synchronous planning schedules. Kim explained that she plans integrated STEM activities with members of her department, however, those who teach the same subject areas collaborate. Similarly, Beth also shared that when she meets with other mathematics teachers, they plan for both mathematics and sometimes integrated STEM activities. She shared how they would, "talk about STEM activities that we will do, so we'll look up different little STEM activities.

Leah also has weekly meetings with her mathematics colleagues in which they plan projects and share ideas. She mentioned that mathematics teachers meet less often with their colleagues in science. Leah remembered inviting a science teacher into one of her classroom sessions to critique a project that was done. She, however, plans on meeting with her science colleagues more often in the future:

> We plan together, we talk about our projects together, we share our ideas. And we really work together, we are very well integrated. We also try to plan together with science, but time does not always allow us to do that.

Both Ida and Hazel met with colleagues who were science teachers. Ida further explained that she met mostly with the science teacher and to a lesser extent with the art and technology teachers. Interestingly, Hazel said that at her school, the STEM department/team is made up of the Dean of Success, the two assistant principals, the professional development planner, and other grade level teachers. She shared that the “grade level chair,” is a science teacher and is the “cheerleader for STEM.” Hazel explained that as a staff they, “try to get ideas from each other, as far as what to implement.” Celia also shared in one instance how the different STEM discipline teachers came together prior to the start of the school year. During this collaborative planning, teachers were, “bouncing ideas off of each other. Everybody is coming from a different side of it. I mean, basic technology teacher with the robotics person, and the science teachers and the math teachers.”

Fiona explained that despite being new to the school, she did make attempts to initiate planning among colleagues, but admitted she started a bit late in the school year. She acquired planning calendars from her colleagues and will continue to work and build from there:

> At least I tried to start doing that this year… Last year was my first year so I kind of started late in the mix. But this year, I tried to get the planning calendars for science. And really, I ended up with all of their subjects together… And I'm hoping each year it's gonna get better.

Although neither Pat nor Raquel had planning meetings with members of their respective departments, they did reach out to either a “mentor teacher” or “senior teachers” for guidance. Racquel shared, “Yes, I would ask for a few senior teachers' opinions and how it can be done, what they think of this idea or alternatives to use in my idea.”

Negative Influence. Despite there being positive results for participants with professional development, professional learning communities, or planning with colleagues, these encounters were not necessarily encouraging to some participants. Such satisfactory experiences were not the case for Racquel, Eve, Leah, Julia, and Mya. Although participants Racquel and Leah expressed being positively influenced to enact integrated STEM education when they planned with their colleagues or reached out to a senior teacher, they were not as positive when recalling their professional development workshop experiences. With respect to STEM workshops and professional development opportunities specifically geared at training teaching integrated STEM, Racquel expressed “there is a lack of workshop or teacher professional development training sessions on STEM.” Eve felt that for the integrated STEM workshops she attended, there was a disconnect between what is expected for integrated STEM programs and the classroom reality, “They're out of touch… the disconnect is so prevalent. The expectations of the STEM program versus the reality of what is to be executed. There's a bridge that hasn't been built yet.” Similarly, Leah conveyed that professional development workshops are not designed to factor in teachers’ needs:

> The PDs that they do, I don't think that they are designed to listen to our needs as teachers, and they are designed as, ‘Here you are, I will give you labs to show you something,’ but they don't hear what our needs are… PDs should be more related to how we see STEAM instead of you telling us how you see STEAM. So let's switch who talks here.

Leah went on to explain that although some STEAM and mathematics professional developments gave ideas for projects and how to make connections, she still felt they did not exactly stand out for her:

> I went to some STEAM PDs where they tell you how to connect things, ideas of projects, how you can do that. But if you ask me, for example, 'What they teach you there?' I haven't found anything, like amazingly opening, like, an eye-opener, I haven't found anything like that. It's always the same thing.

Like, Eve and Leah above, Julia felt that professional development planners were "out of touch" with the limitations that exist within classrooms, as in the case of her exceptional students. When Julia was asked about her integrated STEM professional development workshop experiences, she shared:

> Sometimes a little bit out of touch with how classrooms are. I feel like the assumption of these PDs is that we have everything we need to make those activities work. So, for STEAM PDs in particular, I don't feel like I never get anything out of them, because the activities are just too hard.

Mya did not recall seeing any STEM professional development workshops from the district; however, she is optimistic that since her school recently received the STEM designation there will be workshops at her school now, "Maybe this year, they say we are STEM, I hope they actually really focus on that."

With respect to common planning with other colleagues at their schools, there were participants who did not have such planning opportunities, namely Gary and Dan. Although Gary understood the benefits of collaborative planning for effective discipline integration, planning with teachers in other disciplines did not happen at his school. Gary said his thoughts about planning with colleagues in his department:

> So that's always challenging. There has to be collaboration with peers in order to have a true integration that is effective in helping the students understand what they're learning… I don't have a planning period… So no, we do not collaborate… we pretty much plan in isolation.

In Dan's school, he explained that at the leadership level there are discussions on integrating disciplines but, like Gary, teachers at his school do not have a "common planning time.” Dan shared, “Unfortunately, we don't have common planning time, we don't have a time where I can go to a science teacher and see where they are.”

All the participants who were involved in professional learning communities shared how informative and positively influencing these were in helping them learn more about integrated STEM activities. Attending professional development workshops were helpful to some participants, however, other felt like they did not learn much or that these were “out of touch” (Eve) with teachers’ needs or classroom realities. While some participants had the opportunity to plan with their colleagues, others did not share common planning times, so meeting with colleagues to discuss integrated STEM lessons or activities was not a reality. In some instances, the planning meetings were held with colleagues either from the same discipline, other disciplines, or the same grade level. Some participants also indicated how often the meetings were held and/or how helpful the collaboration meetings were.

Pre- and In-Service Teacher Training

Participants referenced both pre- and in-service teacher training experiences and how these had positively or negatively influenced them in enacting integrated STEM education. Racquel spoke about her pre-service teacher training experiences, while Beth and Olivia shared their in-service teacher training with respect to integrated STEM teaching.

Positive Influence. Olivia took up the opportunity to complete a certificate program in STEM teaching at her alma mater, this she explained had two components one for mathematics and one for science, however, she was only able to do the mathematics portion, “[University name] offered that time the certificate for STEM teaching, I took it for math, so I didn't have time to do it for science, it was offered to all the teachers at Miami Dade County Public Schools." Participating in this certificate program allowed her to get knowledge with respect to integrated STEM teaching. Beth recalled enrolling in two graduate-level courses that focused on integrating disciplines and connecting STEM strategies and standards. She admitted to gaining additional insights into teaching through discipline integration, some tension arose in her accounts though. Beth felt that on completion of both courses, she still felt she had not been fully equipped as she had not seen integrated STEM teaching "nicely done as yet" and left these courses a bit more informed but with some "unanswered questions":

> In my grad classes, I took a class on how we can integrate cross-curriculum, integrating science and math. And I did take a grad course that further pushed those concepts across the curriculum, and tied in those STEM strategies and standards there. Even after the two courses, I still left with so many unanswered questions, 'How would this look in the classroom setting?

Hence, although Olivia's in-service teacher training experience proved to be a positive one for her in enacting discipline integration, Beth had mixed feelings about her teacher training in integrated STEM education.

Negative Influence. Racquel recalled her experience doing her bachelor's degree, she felt that integrated STEM teaching was not "explored a lot" within her bachelor's degree program, more specifically she explained that "with the exception of planning a few lessons during my bachelor's program, I wouldn't say I have specific training in STEM."

Although these three participants had either pre- or in-service training in integrated STEM education, these experiences did add to their skill set on integration but not in significant ways. Both Racquel and Beth felt like they could have gained more from their training.

Summary of Professional Factors

The Professional Factors theme consisted of accounts from participants with influences that resulted from interactions with other educational professionals. These interactions came by way of professional development workshops and/or professional learning communities, planning with colleagues at their schools, and pre- or in-service teaching training. Based on participants' explanations, these professional factors for the most part were supportive of them enacting integrated STEM education except for professional development which had mixed reactions from participants. While attending these workshops positively influenced some participants, others did not share this feeling of satisfaction.

External Factors

The following subthemes were coded as External Factors in the data analysis process: Clear framework/definition for integrated STEM; District competitions/activities; Students' future career choices; Media, Internet, or Resource Personnel. The main theme External Factors were used for these subthemes because as participants spoke about these influences such factors were seen to be existing beyond the bounds of their schools.

Lack of Clear Framework/Definition of integrated STEM

Throughout the interviews, teachers expressed uncertainties when attempting to define or clearly describe the meaning of integrated STEM education. It was obvious that this caused some apprehension in these teachers' attempts to enact this phenomenon in their mathematics teaching.

Negative Influence. Participants explained that such uncertainty in defining STEM education made it challenging to comfortably plan and implement integrated lessons in their teaching. Mya confessed, "This integrating thing is not defined." Fiona spoke about a lack of framework and how the focus of integration changes depending on the school:

> I want to make it clear, it's like all new and there is no like framework, that's the weird thing too, you know, because STEM can be done so many different ways, some schools focus and they have a science teacher, maybe another one has a math teacher and we're here focusing on computer science.

Pat also confessed that in addition to not having a clear understanding of integrated STEM, most teachers do not understand its purpose, especially in her education district:

> I think most teachers are not really understanding the purpose of STEM integration. Um, and I say this as both like a math teacher and also from my peers that teach science. I don't think we quite understand, especially in Miami Dade County, what STEM integration is, and the purpose of STEM integration.

Hazel felt like these indications of uncertainties of what is expected for integrated STEM even existed at the district level. She shared that she had "mixed feelings" about integrated STEM teaching and felt like the district's expectations kept changing. Ann's concerns also existed beyond the school as she was not satisfied with the workbooks that were recommended for use. She expressed frustration with respect to the misalignment between the workbooks and integrated STEM education, calling out the notion that teachers do not have the time to design integrated STEM units. She noted, "They [teachers] have a lot to do, you have that taken care of at the district level." Ann's suggestion of the district being instrumental in assisting teachers by ensuring that the workbooks being recommended or used in schools should reflect discipline integration. This level of support can also be complemented with suggested integrated STEM units.

The lack of definition for integrated STEM education negatively influenced mathematics teachers' willingness to enact this phenomenon. Participants felt that because they were not quite certain what this phenomenon meant and there was an absence of clarity from district-level quarters, then this brought about some apprehension in them attempting to enact integrated STEM education. Participants also spoke about a common understanding of its purpose and the misalignment of books currently being used/recommended in schools with respect to discipline integration.

District Competitions/Activities

Participants shared how the competitions and activities hosted by their respective districts were instrumental in encouraging them to enact integrated STEM activities with students. Both districts represented in this study, Miami Dade and Broward, organized such integrated STEM events on an annual basis.

Positive Influence. Participants Ida, Gary, Eve, and Julia spoke about integrated STEM competitions or activities that they have their students participate in. These teachers mentioned the district hosted SECME competitions. Ida explained how she, along with her students, looks forward to these integrated STEM competitions and that as a result of these activities, her school has a "really good Robotics Club" and therefore partakes in "a lot of competitions" and boasted of her school's successes at these district events:

> They [students] go to competitions, SECME and Robotics, we have a really good Robotics Club here, and they go to a lot of competitions, and they need the math. We got first place and many high places in robotics this year.

In addition to the SECME competitions, Gary and Eve also spoke about mathematics competitions. Along with being a mathematics teacher, Gary takes on several portfolios in and out of school, he is also a science teacher and serves as chair of the mathematics competitions committee both at his school and district level. This degree of involvement at these levels results in integrated STEM teaching and automatically provides opportunities for his students to participate in integrated STEM activities:

> I chair the committee for the Math competitions at my school… I chair a committee here so we take several teams from elementary & middle school to the competitions. And of course, being a science teacher, we also go to SECME and all the Olympiad competitions as well.

Eve also has students participate in SECME as well as the Odyssey of the Mind and Florida Math League competitions. She further explained that as students prepare to participate in the SECME competitions, she has to ensure that her teaching and instructions facilitate discipline integration. Julia also mentioned the SECME competitions from the district, but she maintained that it is primarily geared toward general education students. She is motivated to engage her students in discipline integrated activities because she gets her students involved in other suitable district competitions that are STEAM related in which her exceptional students have participated along with the general education students:

> Most of the competitions at the district level are mostly for gen ed students, for example, SECME things like that, that's all for gen ed… We also participate in a lot of gardening activities, such as Dream & Green, Food Forest, Fair Child…When the kids do projects, they submit the projects with gen ed students, this is usually a lot of STEAM stuff.

Ann shared her students’ involvement in the Fairchild Botanical Gardens challenge. This botanical garden challenge is an:

> award-winning, interdisciplinary, environmental science competition designed to engage students of diverse interests, abilities, talents, and backgrounds to explore the natural world. The program has been recognized as a benchmark for exceptional STEM education and for empowering PreK–12th grade students to become the next generation of scientists, researchers, educated voters, policymakers, and environmentally-minded citizens.

Ann further noted that she and her students are excited to participate in the challenge and preparing for this Fairchild challenge is easy for her particularly because she teaches both mathematics and science in first grade, thus facilitating the integration of disciplines.

Students’ Future Career Choices

Another External Factor that positively influenced participants to enact integrated STEM education was their objective to expose students to possible STEM careers in the future.

Positive Influence. Participants Ida, Pat, Hazel, Fiona, and Leah felt the need to engage students in integrated STEM learning because of the growing demand for careers in integrated STEM fields. Ida shared:

> I think it's a great idea for the kids to be exposed to careers that they're going to see in the future that involve more than one subject. So, they know that everything is related, they need to know a little bit of everything. Not only that, they see the importance of one subject, because it's embedded in other ones, like math is not on its own, science and math go together, technology, art as well. You need this, if you're going to do this career.

Here Ida noted that she opted to enact integrated STEM education in her teaching as a means of preparing her students for STEM careers in the future. Her efforts of integration she explained will allow students to inevitably understand the interconnections of the STEM disciplines and its importance for different careers.

Along similar lines, Kim’s justification for using integration was to spark her students’ interests in future careers, “Yeah, it's what interests can I spark in them, that would make them want to be the next doctors the next scientists, physicists, astronauts.” Kim acknowledges that she can be instrumental in creating awareness and interest in her students for STEM careers in the future, which she hopes to achieve by teaching through the integration of STEM disciplines.

Hazel was very specific in referencing statistics with respect to the increase in STEM-related jobs. This observation she noted is what propels her to engage students in integrated STEM education, as she sees this as an opportunity to prepare them for these jobs in the future:

> I would bring up, ‘Guys, think about this, what can be a career that you could think of that has to do with this, and you can apply it.’ Yes, in bringing in a couple of these different careers from the whole engineering process and technology, it just gives them a little bit more of an opportunity, I do think it's important. I want to say, back in 2018, 2019, there was like, a 17% increase in those jobs. Yes, I have to deal with that.

Fiona emphasized the need for students to acquire problem-solving skills because these are critical for “so many careers in STEM.” She also highlighted the gender inequity that currently exists in STEM-related careers. Fiona shared her desire for getting more of her students involved in STEM careers, especially girls:

> You know, it's [integrated STEM] really needed and it applies to so many careers in STEM, you need to have that problem-solving. It's almost like that hunger to solve that problem. I want to put that thing in them that lets them know, they can do science, they can get into a STEM career, it doesn't matter if you're a boy or a girl, and especially girls. There's just so many more careers that are pulling towards those science, math, geared content technology, there's just a higher demand.

This value for the integration of disciplines and its importance in preparing students for the future was also expressed by Leah. She spoke about students making connections to real life and career choices, “To me, the most important benefit is that finally, my students can find a connection that they learn with real life, it doesn't matter what career they are pursuing in the future.” Leah acknowledged that it was necessary for her students to establish connections between what they learn and what they will encounter in their real-life experiences. Leah believed that despite whichever career choices students make in the future, discipline integration is needed.

Media, Internet and/or Resource Personnel

The subthemes that participants mentioned such as influences from different forms of the media, internet, or resource personnel were coded as External Factors.

Positive Influence: Ten participants noted they were motivated by way of ideas, guidance, suggestions, and inspiration from either the media, internet, or resource personnel in STEM fields. Pat did not hesitate in stating she goes “online a lot” to get integrated STEM activities. Racquel shared the same source by saying, “My resources will be looking at some videos or looking at some research online, research on how it [integrated STEM] can be done.” For Gary, if he does not get anything from the Pacing Guides, he shared “I go to the internet and just start to google different types of activities, if I like it I use it if I don’t, I’ll change it.” Gary explained that to help him integrate the STEM disciplines he draws from different online sources, “For math I do use a lot of Khan Academy, it is a fantastic site. For science, we have I-Excel.”

One of Celia's online resources is from a teachers’ support website, Teachers Pay Teachers. Although she admitted that for some of the links on that particular site there is a cost attached, she is very grateful for this invaluable online resource:

> I purchased a packet that, to me, explains a process that we're going to take part in for our first STEAM project and, print and teach off of it. Other than that, I google, I've gone through and watched all kinds of STEAM and STEM projects, and other professions out there.

Beth mentioned she uses two online platforms to get ideas when planning for integrating disciplines in her mathematics teaching, Brainpop and Gizmos. To initiate her online search for ideas or resources, she first starts by typing in the respective standards of the different disciplines for her grade level, “Brainpop is amazing. Brainpop is really good with cross-curriculum. They tie the science and math in very well… Another one is Gizmos… Gizmos is good with that as well.” Beth went into more details with respect to how she specifically plans her integrate STEM teaching:

> I research… I first started with the standard. I always type this standard and look at resources that's offered for the standard… If when I come across a resource, I'm like, ‘Oh, great, this ties into other things, and I love it.’ I actually do the research, because I want to be effective… So, I research thoroughly.

In addition to media, internet, and other online platforms, teachers also reached out to personnel who they deemed as valuable in terms of sourcing ideas and guidance in implementing integrated STEM education in their classrooms. For example, Olivia recalled being grateful for a parent of one of her students who was doing research in teaching science at the elementary level, she worked along with this parent to plan integrated STEM experiments and activities for her students:

> Well part of it was the curriculum the mom brought to me, she was doing research on teaching science in the elementary grades. She brought part of that curriculum to our class and we joined it with my [mathematics] curriculum… So, we kind of

> combined what was given through my curriculum with the other curriculum that she brought.

Also drawing knowledge and experiences from STEM professionals, Leah shared that her children are both engineers (mechanical engineer and water-resources engineer). She would share her “crazy” integrated STEM ideas with them and ask them to guide her along on possible projects and connect them to their “real-world work”:

> I get a lot of help from them [her biological children]. I say, ‘I have this idea, do you think that it's possible?’ They give me ideas to put it [integrated STEM project] together, then I send them the project and they make corrections. They say, ‘You can use this!’ So, I have a lot of help from that, so, I have a lot of input from them. I know a lot of things that they do for real-world work every day.

Another external source positively influencing Leah’s integrated teaching was being a pre-service teachers’ mentor. She had teacher trainees in her class during their field practice teaching. She confessed that this experience was more helpful than any professional development workshop she had done because she learned a lot from the mentorship program:

> I was an [university name] mentor, and I learned so much with the labs that the guys [teacher trainees] did, where they were trying the critical thinking of questions with science. The students explored first, they go to conclusions, and then they test what they are thinking. That was more helpful than any STEAM PD. The mentors were trained by professionals, the professionals in other areas.

Leah and Fiona use current events to motivate their students into understanding the connections between science and mathematics. Leah once drew her students’ attention to the launching of a rocket. She believed that since the launch took place in Florida, this geographical proximity could serve as a motivation to students. Leah used such scientifically, historic current happenings as an opportunity to indicate to students how disciplines such as mathematics and science are connected:

> So, I tried to show them things. And I said, ‘Listen, guys, I know that today, there will be satellites being launched in a rocket. And that rocket goes from Cape Canaveral. If you go at night, you can watch a little light’… I really try to motivate science with that, even if I'm teaching math.

Kim shared that she taught in two other states prior to coming to Florida, and drew from and combined those different experiences. As she indicated these prior experiences served as a source for integrated STEM ideas and experiments. She shared, “I take a lot of different experiments from all the places I've been, this is the third state that I've taught in. And I, and so I kind of just combine them.”

In order to effectively enact integrated STEM activities, participants in this study drew from resources beyond what was available at their school or district. These included online sources and individuals currently in STEM-related fields. Such external sources all positively influenced these mathematics teachers to enact integrated STEM education.

Summary of External Factors

Overall, three of the four External Factors outlined above had positive influences on teachers enacting integration of STEM disciplines. These factors were District Competitions/Activities, Students’ Future Career Choices, and Media, Internet, and/or Resource Personnel. These initiatives from teachers to seek out resources for enacting integrated STEM education were not only from customary educational spaces such as within their schools. It was noted these resource personnel was also non-mathematics and, in some cases, non-education individuals. For example, Leah drew on the expertise of science educators as well as individuals who were in engineering fields. The only External Factor which negatively impacted teachers’ enactment of STEM integration was the Lack of Clear Framework/Definition of STEM. Participants shared how the absence of a common conceptualization or framework for STEM and integrated STEM education made it challenging to enact the integration of disciplines effectively and confidently in their teaching.

Summary

This chapter presented findings for the analysis of qualitative data collected from participants' interviews and provided similarities and differences in the ways K-8 mathematics teachers conceptualized integrated STEM education in their mathematics teaching. The findings yielded categories of conceptualizations that captured variations in the ways mathematics teachers understood integrated STEM education. Although their descriptions varied, some commonalities were unfolded which allowed for four categories to be formed: Mathematics and Science Integrators; Mathematics, Science, and Technology Integrators; STEM Integrators, and STEAM Integrators. Additionally, this chapter covered how mathematics teachers enacted integrated STEM teaching. The pedagogical approaches gathered based on participants' accounts were grouped into Contextualizing the Learning, Teacher as Facilitator, Cooperative Learning, and Formative Assessment. Notably, all participants employed combinations of these approaches.

Another aspect of the findings for this study addressed factors that influenced mathematics teachers' integration of STEM disciplines. As the factors were identified, it was noted that they had both positive and negative influences on teachers facilitating discipline integration. The following chapter now presents the discussion of these findings along with recommendations, limitations, and implications for further research.

CHAPTER FIVE

DISCUSSION

The aim of this study was to examine the qualitatively different ways K-8 mathematics teachers conceptualize integrated STEM education as well as how they describe their enactment practices and factors influencing these practices. The final chapter discusses the importance and implications of the major findings of these conceptions, enactment practices, and influencing factors in relation to the existing literature. Additionally, this chapter provides recommendations for educators, school administrators, district officials, and researchers for future work on implementing integrated STEM education, addresses the study's limitations, and shares a conclusion.

The research questions that guided this study were:

1. In what ways do K-8 mathematics teachers conceptualize integrated STEM education?
2. What are K-8 mathematics teachers' accounts of enacting integrated STEM education in their classroom teaching?
3. What factors did these mathematics teachers identify as influencing their enactment of integrated STEM education?

The findings of this study reiterated the uncertainty (Angier, 2010; Bybee, 2013; Dare et al., 2019), as well as the complexity and multidimensionality that arise in attempts to define integrated STEM education. Although some commonalities among participants' conceptions were established, there was evidence of disparities. Despite these differences in conceptions of this phenomenon, their accounts of enactment shared some undisputed similarities, such as opportunities for students to contextualize learning, student-centered pedagogies, and being a facilitator in the student learning process. These enactment practices were influenced by several factors, whether intrinsic or extrinsic in nature, the factors resulted in either motivating or discouraging participants from embracing integrated STEM teaching in their respective classrooms.

Conceptualizations of Integrated STEM Education

For the first research question, the data analysis revealed that participants' conceptions of integrated STEM education reflected an array of conceptions, some of which were shared by multiple participants. The existing literature acknowledges that variations in conceptualizing this phenomenon exist (Breiner et al., 2012; Bybee, 2013; English, 2016; Ring et al., Vasquez et al., 2013). Particularly, Breiner et al. (2012) noted that "It appears that people do not have an interdisciplinary understanding of STEM" (p. 6) and therefore do not necessarily share common conceptualizations. This ambiguity that looms over how teachers conceptualize STEM education (Dare et al., 2019) was also apparent during interviews with mathematics teachers in this present study as they shared their conceptions.

From participants' responses, it was evident that they conceptualized STEM integration primarily through the integration of content from two or more of its disciplines. This predominantly content-integrated understanding is synonymous with one of the nine models presented by Bybee (2013) and English (2016). With this in mind, the four Categories of Conceptualizations established in this present study were: *Mathematics and Science Integrators; Mathematics, Science, and Technology Integrators; Science, Technology, Engineering, and Mathematics (STEM)*

Integrators; and *Science, Technology, Engineering, Arts, and Mathematics (STEAM) Integrators*.

In the *Mathematics and Science Integrators* category, participants' descriptions of integrated STEM education reflected a two-discipline conception, M-S, which was noted in Becker and Park's (2011) work as one of the permutations of models for integrated STEM. Teachers in this first category described a conception in which mathematics and science content is taken into consideration simultaneously (Jolly, 2014). Noting that both mathematics and science are timetabled subjects in all elementary grades, there was no surprise with this conception since these two disciplines were already part of their regular teaching and familiarity may have contributed to this level of comfort.

The second conception, however, showed that along with the presence of mathematics and science, technology was explicitly included. One interpretation of integrated STEM education as proposed by Bybee (2013), suggests "a more complex model" (p. 78) combining three disciplines, for example, science, technology, and mathematics. The presence and use of technology in classrooms have evolved throughout the years (Kenney, 2011). The teachers who share the *Mathematics, Science, and Technology Integrators* conception included technology in their conceptualizations varied for different reasons. For example, Dan felt that he was "strong in the technology," and thus conceptualized and described integrated STEM education as inclusive of technology. In Ann's explanation, she perceived that technology should be included, interestingly however, her understanding of this inclusion reflected how the teacher would factor in technology as a digital tool. Such conceptions do not take into account students' use of technology, whether for as a digital or educational tool. This solely teacher-use perspective is different from one in which mathematics education and technology education are both experienced simultaneously by students (Burghardt et al., 2010). In her conception, there was no first-hand experience for students to acquire any technological knowledge or skills while doing mathematics.

The *Science, Technology, Engineering, and Mathematics (STEM) Integrators* conception reflected an interdisciplinary combination of four disciplines: science, technology, engineering, and mathematics. Such an interpretation was described by Gary and others, who shared an understanding that connects curricula from the STEM disciplines. According to Vasquez et al. (2013), this interdisciplinary interpretation diverges from the traditional compartmentalized, multidisciplinary understanding as outlined by Bybee (2013), thus resulting in the four disciplines being integrated within a real-world context.

As research in interdisciplinary education continues to transform in its interpretations, particularly for STEM education which has expanded to include the arts, evidence of this transformation was also present among participants in this study. The fourth conception, *Science, Technology, Engineering, Arts, and Mathematics Integrators* reflected the inclusion of the arts. Within these conceptions though, defining the "arts" varied. For example, Leah and Julia made specific mentions of the visual arts in their conceptions. Celia's understanding of STEM integration, however, showed the incorporation of language arts. Similarly, Olivia's description was considering aspects of language arts such as "stories." This inclusion of language arts for them was synonymous with the A that is present in STEAM. This understanding of the A in STEAM does not necessarily align with the conception of the arts as recognized by Miami-Dade County Public Schools STEAM whose mission for STEAM states:

> to leverage the expertise and capital of the Department of Career and Technical Education, the Department of Mathematics and Science, and the Department of Visual and Performing Arts to increase student achievement in STEAM curriculum to promote career and college readiness.

So, here we see an apparent disparity between what policymakers have in mind when they promote the arts in STEAM as compared to how some teachers conceptualize its inclusion.

Across these different conceptions, teachers shared terms like “cross-curriculum” and “inter-curricular.” For these teachers, such approaches encapsulated perspectives that referred mainly to drawing upon content from different combinations of two or more of the STEM disciplines. It is important to note that this did not necessarily consider pedagogical approaches to this kind of integration. The findings showed that less than half of participants in this study expressed conceptions that combined either two or three disciplines. Noting however, that even with this awareness of the presence of multiple disciplines, explicit accounts of how the content was or ought to be integrated was not always forthcoming by every teacher. Nonetheless, with the majority of participants’ interpretations capturing at least four disciplines, this occurrence signals a positive direction for integrated STEM/STEAM conceptualizations among educators and ultimately a future shift in integrated approaches particularly with how teachers enact integrated STEM/STEAM teaching in classrooms. Teachers’ conceptions and their account of classroom enactment of this phenomenon are critical because these ultimately affect student learning outcomes (Srikoom, 2017).

Enactment of Integrated STEM Education

Despite participants' conceptions of integrated STEM education being grouped into four categories, they used varied combinations of enactment strategies as they taught integrated lessons. Participants relayed impressive accounts of enacting STEM integration within mathematics teaching, which were identified thematically as: *Contextualizing the Learning, Teacher as Facilitator, Cooperative Learning* and *Formative Assessment*. These enactment strategies depicted pedagogical practices that were not reflective of traditional teacher-led instruction, but rather showed more problem/project-based learning and student-centered approaches. For the enactment themes of Teacher as Facilitator, Cooperative Learning, and Formative Assessment, there were no apparent patterns with these themes and the Categories of Conceptualizations in which participants were associated with. There were, however, some trends with the enactment of theme of Contextualizing the Learning and the Categories of Conceptualizations. For instance, all teachers with STEAM Integrators conceptions contextualized student learning using project-based approaches, with one participant using a combination of project- and problem-based approaches.

The first theme, *Contextualizing the Learning*, reflects a common feature of integrated STEM education found in the literature (Kelley & Knowles, 2016; Kennedy & Odell, 2014; Moore & Smith, 2014). For this theme, teachers incorporated the subjects' content within contexts that they deemed appropriate via projects, problems, and/or themes. Teaching that makes use of projects or problems allows for students to contextualize the concepts being taught as well as enhances the learning experiences for individuals because of the meaning brought to the learning (Krajcik &Blumenfeld). The importance of contextualizing student learning was evident in participants' accounts because every mathematics teacher in this study shared how they made use of projects and/or problems to facilitate integrated STEM activities. In addition to using projects/problems, Ann, Eve, Fiona, and Kim incorporated themes around which the integrated STEM units or lessons were based. These themes, in some cases, were drawn from the students' local environment. For example, one participant shared how she centered one nine-week quarter's teaching on The Everglades. Chan et al. (2001) explained that using themes when teaching makes it possible for students to learn such themes from multiple perspectives. More specifically for STEM integration, Assaad and Shi (2017) suggested teaching through themes allows for the integration of various STEM topics by facilitating the effective combination of information from the four disciplines rather than having students learn compartmentalized pieces of knowledge. Therefore, such an integrated approach to education can inevitably benefit students' learning outcomes.

The second theme, *Teacher as Facilitator,* yielded an intentional effort from participants to support student learning in different ways throughout integrated STEM activities. Clifton (2006) suggested for interaction within the classroom to be more facilitative, there needs to be a shift away from the teacher-talk approach and teacher-dominating roles. Furthermore, Clifton (2006) noted that when teachers are facilitators in the student learning process, learners are afforded more participation rights that ultimately allow them to be responsible for their learning, becoming the "drivers" of the learning process as Kim voiced in her interview. This aspect of student-centered pedagogy was observed in participants' accounts that throughout integrated STEM lessons, they allowed students to "lead in their learning," "work independently" (Beth), or be "independent learners" (Mya). In such instances, the teacher did less direct teaching/talking while they worked on solutions or designs for assigned tasks, shifting the learning experience towards a more student-led model (Dare et sl., 2018; LaForce et al., 2016; Moore et al., 2014). This pedagogical approach emanates from a constructivist's view wherein learning occurs as a process of construction and hence suggests that the way teaching is done ought to originate from how students learn (Lindfors, 1984). When this constructivist approach is coupled with the cooperative learning theme which was evident in participants' accounts of their enactment of integration, this pairing of pedagogical approaches gives rise to students learning through social constructivism.

For the third theme, *Cooperative Learning,* a shift away from the traditional rows and columns seating arrangements encouraged collaborative work in small groups. These types of settings, which are very common in integrated STEM classrooms were very popular with participants' preferences. According to Slavin (2011), cooperative learning is a collection of instructional strategies in which students work collaboratively in small groups helping each other. As participants gave accounts of how they incorporated cooperative learning within their STEM lessons, it was noted that a number of benefits surfaced. Some participants, for example, Hazel and Gary, reiterated how these small group settings were critical in promoting communication skills among students. While other participants, Fiona, Pat, and Dan endorsed the use of small groups, they highlighted that it is within such peer settings that students teach and learn from each other. Participants' decision to encourage teamwork, collaboration, and cooperative learning (Dare et al., 2018; Guzey, 2016; Moore et al. 2014; Stohlmann et al., 2011; Shaughnessy, 2013; Thibaut et al., 2018a) was a result of the benefits they felt such settings brought student learning. This cooperative learning setting was also one of the common elements of integrated STEM education present in the literature.

As participants described how they enacted integrated STEM lessons, it was clear that formative assessment took precedence over summative assessment. This was evident as teachers spoke more about observing and questioning students during the STEM lessons rather than having an evaluation at the end of a lesson. The fourth theme, *Formative Assessment,* captured those instances of teachers assessing students throughout the activities. Boston (2002) explained that this type of assessment is categorized as formative and can be accomplished through teacher observation, discussion with students, and analysis of students' work. Additionally, Boston (2002) suggested that the information gathered from such formative assessment interactions can be used to adapt the teaching and learning process to meet the needs of students, as highlighted by participants Ann, Pat, and Kim. In particular, Ann mentioned how she used students' responses to "gauge where they are" and Kim spoke about using these responses to extend students' thinking. Teachers' choice to use formative assessments throughout integrated STEM activities reiterates the concerns raised by participants about the emphasis placed on the standardized, summative assessments that are done by the education districts and department of education.

The enactment practices discussed above align with the common key features of integrated STEM teaching throughout the literature. In general, as participants provided accounts of how they enacted STEM integration, it was evident that they made efforts to engage students and allowed for inquiry-based learning which facilitated student-centered activities. Throughout these activities, teachers incorporated cooperative learning and positioned themselves as facilitators in the classroom as they guided and supported students' learning. Through this facilitation of the integrated activities, it was suitable for some participants to guide, support, and assess students’ understanding throughout the lesson. The feature of contextualizing the learning process in integrated STEM teaching whether, through projects, problems, or themes was notably explored by participants. Although it was found that teachers made conscious efforts to enact integration within their classrooms, as best as they understood it to be, there were factors that either supported or did not support these efforts.

There were enactment practices given by participants that indicated they seemed to primarily associate them with integrated STEM teaching. However, some of these practices they identified were in fact synonymous with what was expected of effective teaching in general. For example, participants associated having students working in groups and engaged in cooperative learning as characteristics of their integrated STEM teaching. Since phenomenography strives to capture how individuals conceptualize or perceive a phenomenon, these instances were coded as shared. However, such student-centered pedagogies are identifiable with effective classroom practices and are not necessarily exclusive to integrated STEM teaching. Student-centered pedagogies are in fact a shift from the traditional, teacher-led approach to a non-traditional, student-focused approach.

Factors Influencing Integrating STEM Education

Despite the apparent willingness and endeavors of mathematics teachers to enact integrated STEM education, some factors posed to be challenging. The third research question explored these factors which were either positively or negatively influential in teachers enacting integrated STEM education. The main factors which influenced participants were: *Personal Factors, School-Related Factors, Professional Factors, and External Factors*.

Day (2004) shared individuals with a “passion for teaching are those who are committed, enthusiastic, and intellectually and emotionally energetic in their work with children” (p. 2). The extent to which individuals are passionate about a subject, topic, or idea will be reflected in the way they approach and/or teach it; this passion and enthusiasm were observed in some participants' accounts as they shared factors that were influential in integrating disciplines. Participants Dan and Gary mentioned being passionate about their knowledge of technology, and as a result, this enthusiasm was reflected both in their conceptions and classroom practices. Other *Personal Factors* such as valuing or appreciating the benefits of integration as a less compartmentalized approach to teaching that stimulates students’ interest in learning (Furner & Kumar, 2007) were mentioned by participants. On the contrary, there were participants whose lack of knowledge or feeling of unpreparedness for teaching integrated STEM (Shernoff et al., 2017), brought about notions of discomfort which resulted in them hesitating to teach using integration. As suggested by Lamberg and

Trzynadlowski (2015) and Nadelson et al. (2013), any uncertainties that teachers possess in their instructional abilities would ultimately be manifested in their teaching. Participants Leah, Beth, Raquel, and Julia cited these personal feelings of uncertainty as factors that at times negatively affected their willingness to integrate disciplines.

Support mechanisms for teachers in schools are critical for successful instructions, especially when it comes to the implementation of effective pedagogical practices on a whole-school basis. A school's STEM/STEAM designation might suggest that discipline integration was expected to be commonplace at all levels and that there would be obvious support systems in place for its facilitation. In some schools within this study, administrative support for integrated STEM education was present and effective, while such support was not forthcoming in others. In this current study, some participants praised their administration's efforts in encouraging teaching through integration in terms of ideas, resources, training workshops, and curricula documents. However, for others, this was not the case, for example, Kim shared that although she was at a STEM-designated school, during class checks, her school administrators would expect her to be teaching the time-tabled discipline. This compartmentalized approach is in keeping with the first interpretation of Bybee's (2013) continuum and lacks a truly integrated perspective of STEM education. These findings suggest that despite teachers' attempts to integrate disciplines, school administrative support may not necessarily be consistent in accommodating it. In fact, Kennedy & Odell (2014) advised that school administrators and principals need to be supportive of teachers' efforts in integrating STEM within schools' curricula.

Moreover, Moore and Smith (2014) reiterated that there ought to be school change initiatives supportive of STEM integration. Once initiatives are orchestrated by the school administration that these can indeed encourage teachers to approach teaching through integration in a positive light. It was evident from this study that the absence of administrative support for participants at times conjured feelings of frustration.

Unsurprisingly, two other *School-Related Factors* which negatively influenced participants in this study were testing and time. The state of Florida administers several standardized tests across grades K-12 at varying times of the school's academic year. Some of these tests include Florida Standards Assessments (FSA), Statewide Science Assessments, Next Generation Sunshine State Standards (NGSSS) EOC Assessments, as well as national and international assessments for example Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). Statewide standardized testing evoked much concern among participants, as they expressed it as a major barrier in preventing them from engaging in integrated STEM activities, projects, or competitions with their students. Participants shared that preparing students for and administering these state and district tests were time-consuming.

In teachers' efforts to compete with standardized testing and complete the stipulations outlined in curriculum documents, they felt lack of time was critical in them not enacting integration in their teaching. Insufficient time affected both planning and implementing of integrated teaching (Carless, 2003; Shernoff et al., 2017). Eight participants in this present study expressed how challenging it was for them to find time to collaborate with colleagues, and plan and/or implement integrated STEM activities in their teaching. Shernoff et al. (2017) concurred that schools' schedules impacted those opportunities for teachers to plan collaboratively and teach STEM integration. Perhaps creating opportunities for teachers to plan integrated STEM activities can also address the concerns expressed by participants in this study with respect to not having all the discipline knowledge necessary to efficiently enact discipline integration.

In addition to testing and time, another *School-Related Factor* challenge mentioned by participants was the availability of resources/materials needed in integrated STEM activities. For teachers, especially in grades K-8, access to resources is integral in effectively facilitating student learning. When teachers incorporate resources appropriately in their classroom, although not exclusive to STEM activities, it enhances the learning experiences of students. As noted by Hestenes (2014), education in schools basically becomes a transaction that occurs between teachers and students. Furthermore, the quality of this transaction hinges on two factors, the expertise, and resources available to teachers (Hestenes, 2014). Eleven of 16 participants in this study utilized project-based approaches to contextualize students' learning. Engaging students in project-based approaches means that the solution/end product is three-dimensional in nature, hence the need for resources is mandatory. Sadly, participants in this study recalled how they at times resorted to using their personal funds to acquire resources so that students can successfully complete integrated STEM projects.

Along with resources, it is imperative for teachers to receive training and support from other educational professionals. Such interactions were categorized as *Professional Factors* for the purpose of this study. Kennedy and Odell (2014) recommended that “Teachers of STEM should seek out and participate in quality professional development opportunities to enhance their knowledge of STEM and its application in meeting curricular requirements, and to gain exposure to practicing STEM professionals” (p. 256). Whether professional development initiatives for workshops stemmed from district or school, participants had mixed experiences and feelings about the sessions they had previously attended. For the most part, participants either felt like these sessions were useful or gave them helpful insights into interesting ideas for planning and implementing integrated STEM activities. However, participants Raquel, Eve, Leah, Julia, and Mya, expressed dissatisfaction with issues related to workshops they attended, including a lack of workshops that specifically focused on how to successfully integrate science, technology, engineering, and mathematics. Ironically, for participants who attended STEM professional development, they shared that the coordinators/presenters were “out of touch” (Eve) with the realities of everyday classroom circumstances, such as availability of resources and time constraints. This gap raises a serious issue and ought to be addressed at the district level. Breiner et al. (2012) suggested that in addition to an apparent disconnect of STEM knowledge among educators, there is also a gap in communication among entities such as policymakers, universities, and K-12 school districts. Granted that STEM education is an evolving phenomenon despite its presence for over three decades, some introspection is needed on how district officials address the concerns of teachers with respect to first listening to their needs, making additional STEM-oriented workshops available as well as capturing the feedback from teachers as to the effectiveness of professional development geared towards STEM integration.

The teachers in this study spoke about factors beyond the bounds of their schools that influenced their enactment of integrated STEM teaching. An interesting result about these *External Factors* emerging from the findings was teachers' disconcerting perspective on the lack of a clear framework for or definition of integrated STEM education. There was no surprise when this concern was highlighted by participants as it is prevalent in the literature - there is ambiguity in the definition or common understanding of this phenomenon (Angie, 2010; Bybee, 2013; Dare et al., 2019; Vasquez et al., 2013). This concern has resulted in a negative influence on teachers' willingness to use the integration of disciplines in their teaching. Such was the concern in Mya's response when out of frustration she shared that "this integrating thing is not defined." Fiona had similar sentiments in her response "it's [STEM] like all new and there is no like framework, that's the weird thing." This lack of definition was identified as an external factor because even amongst policymakers, education researchers, and school districts, defining STEM and integrated STEM is still challenging.

Kennedy and Odell (2014) suggested collaborations with entities outside schools, for example, "stakeholders in education, government, business, the community, and the media should be encouraged to coordinate the development and availability of STEM educational resources" (p. 256). In the data analysis process, these outside influences were also categorized as *External Factors.* In the two education districts represented in this study, Miami-Dade County and Broward County, a common observation made among interviewees' responses was that respective districts hosted STEM/STEAM competitions and activities for students, for example, SECME. The expectations from organizers of these competitions were viewed both positively and negatively. On a positive note, some interviewees saw these competitions as opportunities to not only involve students in integrated STEM activities but to also enhance their school's STEM/STEAM designation status. Schools in South Florida are given either a gold, silver, or bronze rating based on their STEM/STEAM initiatives over a period. On the contrary, for other participants, preparing and competing in district events added pressure in terms of time to their already packed curriculum and test-preparation regime. Results from the current study suggest from participants' perspectives, that districts placed more emphasis on evaluating integrated STEM education efforts rather than providing opportunities for teachers to acquire adequate training on enacting integration.

Another *External Factor* originating from the teachers' accounts is the growing need for individuals prepared STEM professions (Wang et al., 2011). This global demand heightened teachers' consciousness and positively convinced them that attending to this need was critical. The initiative taken by teachers to do their part in preparing students for future STEM careers was highlighted by five participants. Particularly, Ida gave statistical evidence that supported the need for individuals in STEM careers because of a projected increase for those jobs in the future. A second initiative undertaken by teachers grouped in *External Factors* was their use of media, the internet, and/or resource personnel. As participants recalled how they sourced their ideas from the media and internet or drew on the experiences and expertise of practitioners in the industry, it was evident that this undertaking positively influenced participants as to how to do integrated STEM teaching. These initiatives undertaken by participants to reach out to experts in integrated STEM fields in effort to inform and improve their practice, speak to these teachers engaging in aspects of participatory action research (Huiskamp, 2002).

Teachers’ conceptions, willingness to enact, and factors that influence their teaching of integrated STEM are all fundamental to initiatives that seek to promote integrated STEM education in schools. In order to advance with policy makers’ intentions and agenda of STEM integration in school curricula and classroom practice, it is important that we first establish what teachers' perspectives on this undertaking are. It is one thing to develop curricula by way of standards and other policy documents, but it is just as critical to give voice to the teachers who will be implementing integrated STEM teaching. The ambiguity that surrounds a common understanding of what is expected for STEM education in the elementary school and beyond still lingers, however, the fact that there is consensus that it ought to reflect the integration of the disciplines suggests that we are heading in the right direction.

Recommendations

The results of this study shed light on the diversity in conceptions of integrated STEM education among mathematics teachers in STEM/STEAM designated schools in two educational districts in South Florida. As these teachers gave descriptions of their understandings of this phenomenon it was noted that their emphasis was on how the content from the disciplines can be integrated within a unit or lesson. These content-integrated conceptions form just one aspect of integration. Based on this observation, I would reiterate Ring-Whalen et al.'s (2018) contribution that additional work is needed as to how teachers conceptualize integrated STEM education on two fronts, both their content and pedagogical interpretations, in order to appropriately support them in their attempts at teaching using discipline integration.

To support a coordinated and successful implementation of integrated STEM teaching in schools there has to be an "all hands on deck" approach. If teachers are the ones implementing discipline integration in schools, then their opinion and perspectives are fundamental from a democratic stance. Based on the responses received from the interviewees in this study, there is a critical need for more professional development for in-service teachers which specifically addresses how STEM disciplines can be integrated within classroom settings. Participants suggested that these workshops should provide teachers with sample units and lessons which they can use as guides that would allow them to build on their classroom practice. Also, there was a call for opportunities for them to experience integrated STEM learning as suggested by Beth, who lamented that she is yet to see it done "nicely." A concern among these teachers is the limitations they face in terms of time, resources, and their sparse knowledge of integration. They believed that these should also be taken into consideration when planning professional development. Even after teachers have received the necessary support, they need to implement STEM integration in their classrooms, they also need to be given agency and allowed some flexibility within their classroom teaching. Many participants felt stifled by the pressure to conform to the stipulations of sticking to district documents such as pacing guides, feeling the pressure to only focus on what will be assessed in standardized tests.

Responses from some participants indicated that they did not necessarily have the support, guidance, or resources needed from their school to assist them in enacting integrated STEM education. This is extremely counterproductive for its success in schools. Therefore, there needs to be appropriate training as well for these administrators. Just as in the case of teachers, school administrators also may not be knowledgeable about enacting discipline integration nor the ability to accommodate it by rendering the support in terms of resources, training, and allowance for departmental planning time to their staff. One possible initiative, in this case, would be for districts to facilitate integrated STEM workshops geared to simultaneously cater to both school administrators and teachers. Such collaborative learning experiences can assist both sets of educators as to better operationalize a whole school approach to implementing STEM integration.

Another integral stakeholder in progressing a STEM integration agenda in schools are entities like the Department of Education and other policymakers in education. Evidence of the Florida Department of Education's efforts in supporting STEM teaching is evident. While some participants lauded the district initiatives with respect to hosting competitions and activities geared towards promoting STEM integration, other participants insisted more needs to be done. There is also no doubt that the Florida Department of Education is amenable to STEM integration based on its initiative to award STEM/STEAM designation to schools that meet the requirements; however, teachers are voicing their desire for more support in enacting

STEM integration. Teachers' concerns are that professional development initiatives need to be revisited, increasing the number of opportunities as well as the quality of the workshops. Additionally, consideration by school districts to train and make available curriculum experts in integrated STEM education as a support system for both school administrators and teachers.

Participants Racquel, Beth, and Leah addressed the issue of having little or no knowledge about how to integrate STEM disciplines in their initial teacher preparation programs. Thus, a recommendation is to revisit the teacher training program curricula with more effort to include aspects of integrated STEM teaching. This should go above and beyond an introduction to integrated STEM as a concept, but to enlighten them about the benefits of curriculum integration and engage them in initial practice. Addressing these technical inefficiencies at the teacher training level will better prepare them to meet the demands of integrated STEM teaching while simultaneously helping them develop a strong sense of self-efficacy.

These recommendations are indeed worth considering as a move in the right direction for supporting the progress of integrated STEM/STEAM in education. Inputs and coordination are needed from all sectors for its success. Such coordination and collaboration can occur from both ends of the spectrum, as simply but effectively stated by Mya and Leah respectively, “teachers’ voices in the making of the curriculum” are needed, and “let’s switch who talks here.”

Limitations

There are a few pertinent limitations to this study. First, the sample of participants in this study was drawn from only two education districts in South Florida, hence generalizability to other school districts and states ought to be carefully taken into consideration. Although using a sample size of 16 teachers in this study allowed for the qualitative diversity that is characteristic of phenomenographic research, it is possible that conceptions, enactment practices, and factors influencing enacting integrated STEM education captured in this study may not comprehensively reflect those in other educational contexts.

Second, since classroom observations were not feasible at the time of data collection, the study's analysis was done solely on self-reported interview data. Participants' accounts of their enactment of integrated STEM, therefore, meant that there was second-order subjectivity, with no opportunities to directly observe how these teachers enacted this phenomenon or in what ways conceptions were in sync with their enactment efforts. The absence of observations also left room for participants to share what they thought I wanted to hear.

A third limitation of this study was the effects of the Covid 19 pandemic. This research was started in 2021, during the second year of the pandemic in the United States. Teachers were contacted and interviewed during the fourth quarter of the school's academic year, which meant that they would have been back to in-person teaching for only two quarters. Prior to that, both teachers and students were working remotely for approximately three-fourths of the school year. Since participants were asked to give accounts of enacting integrated STEM, it meant that their responses would reflect a combination of pre-, during-, and post-pandemic experiences. The pre-pandemic accounts relied heavily on what interviewees remembered doing in classrooms over one year prior, hence there were instances when they paused in an effort to remember. The during-pandemic accounts revealed some of the challenges teachers experienced as they tried to engage students in integrated STEM education, such as facilitating cooperative learning and formative assessment. Based on the feedback from some participants, discipline integration during the pandemic was reduced due to the additional barriers of online education, which were not directly studied here. While the post-pandemic accounts were more favorable for integration, some teachers were still struggling with high absenteeism, adjusting to Covid 19 protocols, and the ongoing challenge of standardized testing. Hence teachers' interpretations and accounts were provisional and conditional.

Implications for Future Research

Much has been researched on STEM and integrated STEM education, however, studies specifically pertaining to how mathematics teachers conceptualize and enact integrated STEM are underexplored. Future work on these aspects ought to capture not only teachers in grades K-8 but also those in pre-K, high schools, and universities. With respect to implications for practice at these levels, in keeping with Bruner's (1960) theory on the spiral curriculum, Gibbs (2014) explained that it is a curriculum in which "students revisit a topic, theme, or subject several times throughout their schooling, where the complexity of the topic is increased with each visit, so the new learning is connected to the old learning" (p. 42). Hence there are implications for future work on classroom teaching in terms of continuity in both content knowledge and pedagogical approaches in integrated STEM education throughout grades preK-12.

The fact that teachers have a variety of conceptions for integrated STEM education, for example, some understandings are exclusive of technology and/or engineering while others are not, speaks to the work still to be done with respect to the progress of this phenomenon in the education space. Such uncertainties give rise to the question “How can we proceed with conversations on integrated STEM education if we are still not sure what it means?” From an overarching perspective, questions like this inform the work needed on governmental levels with education policies that facilitate this transitionary, contemporary phenomenon of integrated STEM education.

There are implications for schools that have already acquired STEM/STEAM designation as well as those who are striving towards doing so. For STEM/STEAM designated schools, the factors influencing teachers’ integrated STEM teaching as presented in this study can help school administrators in different ways. Additionally, further research on these factors can inform school principals and administration on effective initiatives and support mechanisms that can encourage teachers’ efforts, as well as the challenges teachers face by way of the shortcomings of schools’ administrations. Conversely, for schools that are considering STEM/STEAM designation, this move is multifaceted, in that conversations must be entertained in terms of the school’s philosophy and policy, funding, and internal structures especially pertaining to teacher support. This study showed that support can take the form of regular professional development, availability of appropriate resources, departmental and grade-level collaboration, planning time, and a whole-school initiative. For principals and school administration to be in a better position to provide effective support to teachers with respect to integrated STEM education, then there needs to be research that seeks to capture these administrators' philosophy and conceptualizations of this phenomenon. Furthermore, future research on administrators' understanding of how discipline integration can be successfully implemented and supported in schools can complement efforts being made by policymakers in rolling out such initiatives.

With respect to implications for policy, there is evidence of the presence of technology within mathematics curricular documents, and technology and engineering practices within science curricular documents. As a future initiative for facilitating integrated STEM education, policymakers need to consider integrated STEM standards. Participants expressed concerns about not having appropriate resources to guide them in enacting integrated STEM education. This request along with the findings from this study, in terms of a lack of a clear framework for teaching integrated STEM can be used as a premise for establishing preliminary work on standards for integrated STEM curriculum.

Conclusion

The intent of this study was not to assess mathematics teachers' ability to teach integrated STEM nor was it to determine whether this phenomenon was being implemented in STEM-designated schools. The primary interest of this work was to provide mathematics teachers with an opportunity to comfortably share their conceptions and experiences enacting integrated STEM when teaching. Such opportunities can initiate a desire in them to engage in some retrospective thinking and some thought-provoking moments of their experiences in understanding and using integration among STEM disciplines. In addition, it was also imperative to highlight factors that either encourage or hinder these teachers in enacting STEM integration. The findings, discussion, and recommendations presented here are instructive in addressing integrated STEM initiatives at all levels and assist in highlighting among educators some transformative possibilities to consider in progressing this phenomenon. Although this study suggests that the conversation for integrated STEM education needs to focus on teachers' conceptions, it by no means de-emphasizes the critical role(s) of school administrators, education districts, departments of education, policymakers in education, and any other stakeholder.

Research Journey

> To increase student engagement and ownership of learning, we should give students opportunities to do meaningful work - work that makes a difference locally, nationally, and globally (Eric Williams).

As I undertook this task to delve deeper into an area of interest to me as a mathematics teacher educator, little did I realize it would heighten my desire even more. Throughout my career as a mathematics teacher, I was always bothered by the lack of enthusiasm and confidence shown by many students in mathematics classes. They expressed disinterest in most topics being done as they felt that, in addition to being routine and formula-driven, they often failed to see its relevance to them. This outlook on the subject often affected their performance. As a result, I was compelled to seek out innovative and attractive ways to teach mathematics in a way that was meaningful and engaging to my students.

This drive transitioned with me as I entered the realm of teacher education, striving to increase individuals' interest and motivation but now in both learning and teaching mathematics. This in part led me to grasp the opportunity to embark on this topic for my dissertation. A combination of exploring a more meaningful way to engage students in learning mathematics through its integration with other disciplines and experiencing it from mathematics teachers' perspectives.

I experienced some mixed emotions from the onset and throughout this journey. My first dichotomy of emotions came with the fact that I was extremely excited to learn about how mathematics teachers understood and enacted integrated STEM teaching in their classrooms. On the other hand, I had a sense of apprehension, because I was seeking to examine individuals' conceptions of a phenomenon, it meant that a phenomenographic methodology was best suited. This would mean that my study would be qualitative in nature. Ironically, I came from a mathematical background, so I felt more comfortable in the quantitative space. A paradigm shift was needed on my part, a move away from the scientific and clinical world of mathematics. I shifted gears, moving from the objectivity of quantitative thinking to the subjectivity of qualitative research - the absence of right or wrong responses, and giving up the exactness of mathematical thinking.

I was up for the challenge, I had to learn new methodologies along this interesting and transformative journey. In my consideration of the intersection of individuals' conceptions of and perspectives on integrated STEM, I was exposed to the philosophical idea of intersubjectivity. This would best be accomplished if all other variables were kept as constant or as similar as possible, leaving only variability for these individuals' conceptions.

On one front, I felt like I could connect to this study on so many levels: a mathematics teacher who taught for several years in grades K-8, a mathematics teacher educator for approximately ten years, a quest for knowledge in the evolving field of integrated STEM education, a desire to contribute to this field by helping to create an awareness in teachers to its elements and benefits to enhancing student learning. There were two major inner challenges I faced throughout the data collection; bracketing and being selective in what to include in the data analysis and what to omit. Having done some research on integrated STEM before conducting this study, there were so many edifying moments for me. For example, the use of technology in integrated STEM as beyond just an instructional tool for teachers or its use by students to perform mathematical calculations, but a move to view it as a tool for research, modeling, and data collection by students (Ellis et al., 2020). Hence, during the data collection and analysis phases, I had to intentionally bracket this knowledge and proceed based on the participants' descriptions of their incorporation of technology use in their integrated STEM teaching. Another challenge I had was determining what and how much of the participants' quotes should be included in the study. I came to that realization when I was advised that I included too many lengthy quotes. Although some of their points were important and interestingly valuable, on numerous occasions I had to force myself to be selective and constantly guided by my research questions. I felt that there were so many aspects of teachers' voices that needed to be documented and highlighted. The decision was then to determine despite being critical, what was directly related to the objectives of my study.

All in all, this journey was filled with ambiguity and uncertainty as to the complexity of this phenomenon and the concern that coining a definition or distinct understanding of it has eluded researchers and educators alike. Despite the uneasiness and questioning moments, it was unforgettably fulfilling. I should note that the more I engaged in this research the more I felt confident and convinced that it is an area of study that needs more focus. I believe that adopting integrated STEM approaches within mathematics teaching can yield significant success for student learning. Even after having completed this dissertation, the feeling that resides in me is that there is still so much more to explore based on the responses from the interviewees and the unanswered questions on integrated STEM education, especially in mathematics teaching.

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APPENDIX A

PARTICIPANT RECRUITMENT EMAIL

Subject: Research Study on Integrated STEM education

Good day M_______,

Hope all is well with you at this time.

My name is Elizabeth Forde and I am a Ph.D. student at Florida International University (FIU). For my dissertation, I am conducting a study examining K-8 teachers' conceptualizations and enactment of integrated STEM (science, technology, engineering, and mathematics) education. Integrated STEM education is increasing in interest, but there is little research that specifically captures the perspectives of teachers who teach mathematics, like yourself. The findings of this study will help me gain a deeper understanding of teachers' approaches to discipline integration in their teaching and its benefits to mathematics instructions.

I am interested in learning about your experiences, ideas, and approaches to this integration of disciplines and would like to conduct a 45–60 minute brief interview with you at a time that is most convenient to you.

Should you choose to participate in this study, please review the attached consent form which provides more details about the study and about how your information will be kept confidential. Please complete the form and return it to me via email. We can then make arrangements to meet via Zoom (or any other web-based platform) so we can conduct the interview. If you have questions, you may email me or contact me via phone at (*Email and phone contact given*).

Your participation in this study is voluntary and all efforts to protect your identity and keep the information confidential will be taken seriously.

I truly look forward to learning about your experiences and ideas. Your participation will be greatly appreciated.

Kindest regards,

Elizabeth Forde
Ph.D. Candidate
Florida International University

APPENDIX B

PROTOCOL: RESEARCH QUESTIONS AND INTERVIEW QUESTIONS

Research Question	Interview Questions	Follow-up Questions
Background Information	Q1: (a) Can you please tell me about your experiences teaching math? (b) What is your background in math?	
Research Question 1: In what ways do K-8 mathematics teachers conceptualize integrated STEM education?	Q2: In your own words how would you describe integrated STEM education? / What does Integrated STEM education mean to you? Q3: Do you incorporate other disciplines when teaching mathematics?	Yes → Q3F: In what ways have you done this? / Can you give example(s)? No → Q3F: Are there any reasons why you do not incorporate other disciplines?
Research Question 2: What are K-8 mathematics teachers' accounts of enacting integrated STEM education in their classroom teaching?	Q4: How often do you use this integrated approach in your math teaching?/ Do you do this on a regular basis? Q5: When you use this integrated approach, what would someone walking into your classroom see & hear? Q6: How would you describe your role in the lesson? Q7: What are students usually doing during the lesson?/ What are the students' roles? Q8: What are your expectations of students during the lesson? Q9: How are students typically allowed to solve/work on mathematics problems during the	

	lesson? (e.g., individually/ pairs/ small groups/whole class) Q10: In what ways, if at all, do you incorporate students' everyday or personal experiences into your mathematics lessons? Q11: How does this differ from teaching a more traditional (single discipline) mathematics lesson? Q12: Are students required to work on mathematics-related projects throughout the quarter/school year?	→ Q11F: For example, before you mentioned you do _________ when you are teaching an integrated lesson, how is this different from the way you would do a traditional math lesson? Yes → Q12F: Can you describe one of these for me? No → Q12F: Any competitions (district/school)?
Research Question 3: What factors did these mathematics teachers identify as influencing their enactment of integrated STEM education?	Q13: You mentioned previously that you implement integrated lessons ______ times. I also know that you are at a STEM-designated school. Can you tell me a little bit about what are the administration's goals or expectations for teaching integrated STEM lessons? Q14: Have you participated in any formal training or workshops related to integrated STEM education?	→ Q14F: Was it a mandated PD or did you opt into attending?

	If they integrate: Q15: You also mentioned before that _________________. (a) Why do you integrate other disciplines when teaching mathematics? (b) What are the benefits of using an integrated approach? (c) How do you get ideas for these integrated lessons? (d) Are there any particular resources that you find useful? (e) Do you plan with other members of your department?	Q14F: What is your general impression of these PD experiences? → If they don't integrate (STEM disciplines): Q15F: You mentioned before that you do not incorporate other disciplines when you teach - Does anyone else at your school do integrated STEM? - Can you describe what you have seen them done? - Did what you witness encourage/ discourage you into thinking about using integration in your teaching? / Why or why not?
Barriers	Q16: What barriers do you encounter/foresee in using integration of disciplines when teaching?	→ Q16F: "What other barriers do you see?"
Recommendations	Q17: What recommendations will you suggest to assist teachers/ schools/ administrators/ districts in facilitating discipline integration when teaching mathematics?	
Questions/comments	Q18: Do you have any additional questions/comments?	
Additional participants	Can you recommend any other math teachers who work at a STEM center in South Florida? (at least 1 more)	

APPENDIX C

IRB ADULT CONSENT FORM

ADULT CONSENT TO PARTICIPATE IN A RESEARCH STUDY

A Phenomenographic Study of K-8 Mathematics Teachers' Conceptualizations
and Their Accounts of Enacting Integrated STEM Education

SUMMARY INFORMATION
Things you should know about this study:

- **Purpose:** The purpose of the study is to investigate K-8 mathematics teachers' conceptualizations of integrated STEM education.
- **Procedures**: If you choose to participate, you will be asked to engage in one semi-structured interview.
- **Duration:** This will take about 45-60 minutes.
- **Risks**: The risk or discomfort from this research is minimal.
- **Benefits:** There are no benefits from this research.
- **Alternatives:** There are no known alternatives available to you other than not taking part in this study.
- **Participation:** Taking part in this research project is voluntary.

Please carefully read the entire document before agreeing to participate.

PURPOSE OF THE STUDY

The purpose of this study is to develop a deeper understanding of the different ways mathematics teachers in the K-8 grades conceptualize and enact integrated STEM education.

NUMBER OF STUDY PARTICIPANTS

If you choose to participate in this study, you will be one of ten to twenty people in this research study.

DURATION OF THE STUDY

Your participation will involve one interview which takes approximately 45 to 60 minutes.

PROCEDURES

If you agree to be in the study, we will ask you to do the following things:

1. You will be asked to participate in one 45- to 60-minute semi-structured interview.
   The interview will include background information about yourself and your understanding of integrated STEM education. It will then seek to elicit from you how your understanding relates to your approaches to teaching mathematics. Additionally, some questions will attempt to identify the factors which influence your conceptualization of integrated STEM education.
2. This interview will be conducted on a web-based platform (e.g., Zoom, Google Meet, etc.) and will be audio and video recorded with your permission. The interview will be transcribed without referencing any individuals. Once the transcriptions are completed, the recordings will be deleted immediately.

RISKS AND/OR DISCOMFORTS
There are no foreseeable risks for your participation in this research study.

BENEFITS
There are no foreseeable benefits for your participation in this research study. However, it is expected that this study will benefit education, and society in general, by developing a greater understanding of mathematics teachers' conceptualization and effective use of an interdisciplinary approach to classroom practice.

ALTERNATIVES
There are no known alternatives available to you other than not taking part in this study.

CONFIDENTIALITY
The records of this study will be kept private and will be protected to the fullest extent provided by law. In any sort of report we might publish, we will not include any information that will make it possible to identify you as a participant. Research records will be stored securely and only the researcher team will have access to the records. However, your records may be reviewed for audit purposes by authorized University or other agents who will be bound by the same provisions of confidentiality.

COMPENSATION & COSTS
There are no costs to you for participating in this study.

RIGHT TO DECLINE OR WITHDRAW
Your participation in this study is voluntary. You are free to participate in the study or withdraw your consent at any time during the study. You will not lose any benefits if you decide not to participate or if you quit the study early. The investigator reserves the right to remove you without your consent at such time that he/she feels it is in the best interest.

RESEARCHER CONTACT INFORMATION

If you have any questions about the purpose, procedures, or any other issues relating to this research study you may contact Barbara King at Florida International University by email at bking@fiu.edu or by phone (305) 348-3215.

IRB CONTACT INFORMATION

If you would like to talk with someone about your rights of being a subject in this research study or about ethical issues with this research study, you may contact the FIU Office of Research Integrity by phone at 305-348-2494 or by email at ori@fiu.edu.

PARTICIPANT AGREEMENT

I have read the information in this consent form and agree to participate in this study. I have had a chance to ask any questions I have about this study, and they have been answered for me. I understand that I will be given a copy of this form for my records.

______________________________	__________________
Signature of Participant	Date
______________________________	
Printed Name of Participant	
______________________________	__________________
Signature of Person Obtaining Consent	Date

APPENDIX D

CODEBOOK: INTEGRATED STEM ENACTMENT THEMES

Main Themes	Description	Subthemes (from codes)	Example Quotes
Contextualizing the Learning	Use of pedagogical approaches to contextualize student learning within integrated STEM teaching	- Project-Based - Problem-Based - Thematic	- "they [students] need to put all these things together to create this project or whatever invention they decide to come up with and to test things that they need to know a little bit of Science, Math and Technology" (Ida) - "With the integration, you present a problem… And even now, in my math curriculum, at the end of each chapter, there's a section called STEM, so there, we have problems that are more oriented with the STEM style." (Dan) - "A lot of times we're doing STEM, we're doing engineering projects… I try to make it local, like stuff on the Everglades [Theme] at my school… some of the animals we see in our local environment." (Fiona) - "Yeah, when doing my STEM projects, I work with whatever theme I have happening." (Kim)
Teacher as Facilitator	Role of the teacher during integrated	- coaches - guides - facilitates	- "I'm facilitating, I'm walking around, you know, I explain what

	STEM lessons/activities	- helps students; ‘holds their hands’; checking in on weak/quiet/lost students - answers questions/ allows for students’ questions - makes suggestions to students - makes connections (among disciplines) for students - advances students’ knowledge, shows them how to apply knowledge (different disciplines), extends students’ knowledge - explains - emphasizes process over product - models - clearing up misconceptions/ confusion/ mistakes - changes roles - emphasizing the important stuff, reinforcing/highlighting skills/ concepts, main points - provides feedback (positive, critiquing) - provides the experience - walks around; moves from group to group/stations; circulating; traveling - ensures that students stay at task; classroom management; safe environment - listens	we're doing, then they're doing it on their own… I'm facilitating it. I'm supervising it… after we discuss and learn about the topic… I'm mostly a facilitator.” (Fiona) - “Because teaching right now, is to be more of a facilitating thing. You let the children do.” (Mya) - “So it was more for me to be able to do more one-to-one coaching or tutoring or more like ‘the help’ in the classroom.” (Dan) - “at the beginning of the lesson, of course, I'm the facilitator… by the end of the lesson, I would like to be way more hands-off, I would like to be more the guide… just kind of guiding you [students] in a direction instead of leading you in the right direction… I'm just clearing up some misconceptions.” (Beth)

Cooperative Learning	Opportunities presented for students to work collectively and collaboratively in small groups		- “Definitely group work, when we're doing a STEM/STEAM lesson, and they work a lot better because they can bounce ideas off of each other in groups.” (Celia) - “I would consider a small group, a group of four when they're doing engineering and STEM projects, they work in groups of four a lot.” (Fiona) - “I would allow them to work in groups as much as possible for them to learn amongst themselves…There's only so much, right, that they're going to be able to get from me, they would learn much better through their peers.” (Pat) - “Ideally, they would be grouped together, where each of their strengths could show where they can become a teacher, and a learner at the same time.” (Kim) - “So when I put them in small groups, sometimes I try to do it on ability… I just want them to cooperate, work together.” (Julia)
Formative Assessment	Students are assessed throughout	- Teacher observations -Teacher asked questions	- “When I get that observation, I will see where you know, data

	integrated STEM lessons/activities rather than at the end		comes in analyzing, see where I need to meet them… The assessment is observation at that point… And I question them, and I'm taking notes. Of course, this is all observational, but I'm giving them grades for that.” (Mya) - “Well I will walk around and you know… use oral questioning and use observation, ask them question” (Racquel)

APPENDIX E

CATEGORIES OF CONCEPTUALIZATIONS

Categories	Description	Participants	Example Quotes
Mathematics & Science Integrators	participants' understandings reflected integration of only mathematics and science	Beth, Kim, Mya	“You're teaching math through science and teaching science through math.” (Beth) “I mostly incorporate math in science. Just because I found it an easier connection with the kids that way. (Kim) “I am putting all these subjects together to get the kids to see where math and science go together. And so we don't teach in isolation.” (Mya)
Mathematics, Science, & Technology Integrators	participants' understandings reflected integration of mathematics, science, and technology	Ann, Dan, Racquel	“mostly, you know, pulling in from other subject areas and connecting them. And so obviously, the science, the math, the technology is, you know, obvious for the STEM.” (Ann) “you know, math is the language of science. And, and that technology has been there ever since I started teaching math.” (Dan) “Science and Mathematics and a little bit of technology” (Racquel)
STEM Integrators	participants' understandings reflected integration of science, technology, engineering, and mathematics	Eve, Fiona, Gary, Hazel, Pat	“Integrating, focusing on science, technology, engineering, and math, putting in critical thinking.” (Eve) “There's a way to rope that in some way, shape or form, the engineering is where the math comes in, when they're doing engineering and

			STEM projects they work in groups of four a lot of the technology things we do they'll do in pairs with their programming." (Fiona) "And to incorporate all subject areas, we're going to create what they call the science, technology, engineering, once you're in mathematics." (Gary) "So, I would take it as you know, being able to involve, obviously, science, technology, right, the engineering and the math process in my case, each portion having its own job, let's say, in the integration process, and then it kind of coming together." (Hazel) "really touching upon content from all parts of the STEM. So, from science, technology, the children would be really focused on, like, using computers, discussing like careers and engineering, and then just doing math… in their projects." (Pat)
STEAM Integrators	participants' understandings reflected integration of science, technology, engineering, arts, and mathematics	Celia, Ida, Julia, Leah, Olivia	"When you're integrating the science, technology, engineering, the arts and the math. Integration to me, it has to do with not specifically stopping what you're doing to go into teaching STEM. It's part of how they're learning, do feel like the kids ended up doing a STEAM project." (Celia)

			"show them [students] how they need to put all these things together, they need to know a little bit of science, math, technology and art, creating and drawing things." (Ida) "I would describe it as just a curriculum that stems across all curriculums, we do STEAM instead of STEM… so, with engineering, we'd have to get very creative. But it's usually a way to kind of bring all subjects and give them some sort of connection, like they're all completely different, but they all seem connect in one way or another… the best way to put it. It's one thing, but it's a lot of things all in one." (Julia) "To me is STEAM, ask you to do something. Let's say use all the arts and all the science and technology and all that in the project. I always ask them to do math, with connection with science and technology. And if I can with engineering" (Leah) "Science, technology, engineering, engineering, math, and they added the arts too, a curriculum for reading language arts, math, science, social studies." (Olivia)

VITA

ELIZABETH NATASHA FORDE

	Born, San Fernando, Trinidad and Tobago
	B.S. Mathematical Sciences Florida International University Miami, FL
2007-2008	M.S. Mathematical Sciences Florida International University Miami, FL
2018-2022	Graduate Assistant Department of Teaching and Learning Florida International University Miami, Florida
2018-2020	Education Specialist – Teaching and Learning Florida International University Miami, Florida
2021-2022	Doctoral Candidate Florida International University Miami, Florida

PUBLICATIONS AND PRESENTATIONS

Faruqi, F., Keratithamkul, K., Roehrig, G. H., Hiwatig, B. M., Forde, E., & Ozturk, N. (June, 2022) *Manifestation of Integration into Practice: A Single Case Study of an Elementary Science Teacher in Action*. 2022 American Society for Engineering Education (ASEE) Annual Conference. Minneapolis, Minnesota.

Forde, E., Robinson, L., Ellis, J., & Dare, E. (2022, March) *Yes, math is there, but ….: Examining mathematical content in integrated STEM education.* 2022 National Association for Research in Science Teaching (NARST) International Conference. Vancouver, Canada.

Hiwatig, B. M., Ellis, J. A., Dare, E. A., Ring-Whalen, E. A., Forde, E., & Roehrig, G. H. (2022, January) *Relationship between Context Integration and Content Integration in the implementation of integrated STEM*. 2022 Association for Science Teacher Education (ASTE). Greenville, SC.

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