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Impacts of STEM Professional Development on Teachers' Knowledge, Self-Efficacy, and Practice

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Research frameworks outline key aspects of STEM (science, technology, engineering, mathematics) integration for teachers, but translating this research into productive changes in teachers' classroom practices remains a challenge, particularly in schools without an emphasis on STEM integration. In this article, we detail how a STEM education descriptive framework was used to design and enact a year-long professional development with eight middle and secondary teachers at non-STEM focused schools in Southeast USA. We examined the professional development impact on teacher content knowledge, self-efficacy, and practice using pre- and post-test scores on a content exam, pre- and post-test scores on a self-efficacy instrument, and self-reported STEM integration efforts. We found teachers improved in their self-efficacy and made productive changes in their classroom practices, though no significant gains in content knowledge was detected. We conclude with how this STEM education descriptive framework can be helpful in designing effective professional development for teachers at non-STEM focused schools.

Keywords: professional development, STEM integration, middle and secondary teachers, mathematics education, science education

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INTRODUCTION

Expansive reform initiatives in science, technology, engineering, and mathematics (STEM) education over the past several decades necessitate advancing the body of research on professional development for STEM education. Professional development (PD) is consistently used as an agency to educate teachers and to effect change in their practices when new standards are implemented and when new national educational initiatives arise. Current national and local educational goals and initiatives focus on engaging more students in STEM learning and activities, in hopes they will persist in STEM coursework and career pathways to meet STEM jobs demands, ultimately advancing societal STEM literacy (Franco and Patel, 2017). Teachers must be properly introduced to the evolving nuances of the STEM reform movement within their subject area as well as gain some familiarity of changes among the other related subjects (Honey et al., 2014). To effectively increase the number of students electing to pursue careers in STEM, research on PD for STEM education will have to delineate not only best practices, but also what constitutes well designed training that effects change in teaching practices, heightens buy-in to new innovations and initiatives, and improves student achievement (Loucks-Horsley et al., 2009). The vital importance of PD to provide teachers with opportunities to continually grow professionally is based on evidentiary findings that show students whose teachers participate in lifelong learning or PD achieve at higher levels than students whose teachers do not (Wojnowski and Pea, 2013).

In the framework of this study, effective features of an implemented PD for grades 6–12 mathematics teachers are defined that contribute to changes in the teachers' practices. Using an established framework, we designed and implemented the PD according to best practices of integrated STEM education (iSTEMed). The goal of the PD was to enhance the participants' mathematics content knowledge and pedagogical content knowledge through an introduction to iSTEMed concepts across various STEM fields. The integration centered training and instruction on making mathematics connections across science, engineering and technological design processes. The anticipated outcomes were to observe changes in participating teachers' perception of iSTEMed and classroom practices, and to increase their pedagogical content knowledge and self-efficacy for implementing at least one iSTEMed lesson plan with their students. By focusing on ways to ensure participants had authentic iSTEMed experiences, the guiding questions for the research were: (1) how did teachers' content and pedagogical content knowledge change from the STEM PD?, (2)how did teachers' self-efficacy change from the STEM PD, and (3) how did teachers' classroom practice change from the STEM PD? We collected data from eight teachers (six mathematics, two science) over the course of a year. Validated instruments were used to measure content knowledge and self-efficacy. A qualitative analysis was used to analyze participant responses to open-ended questions to develop themes to describe the nature of changes in thinking and classroom practice.

RELATED LITERATURE

To provide context for this study, we (1) define STEM education, and (2) identify the descriptive framework used in this study.

Defining STEM Education

One challenge of designing professional training that integrates STEM subjects is ambiguity in defining STEM education. Broad conceptions of STEM education likely result from the United States Department of Education's report on STEM Education Federal Strategies, which states "STEM education refers to teaching and learning in the fields of science, technology, engineering, and mathematics" which includes "educational activities across all grade levels in both formal and informal settings" (Lemoine, 2013, p. 1). Brevity in this STEM education definition is intentional so that pursuit of authentic STEM experiences focus on designing programs to improve curricula and instruction within and across these disciplines.

Characteristics of PD that support changes in teachers' instructional practices emerge through a survey of research on effective programs. Although the list is not intended to be comprehensive, the prevailing findings are that effective PD: (a) focuses on teachers' understanding of content and teaching methods through active learning, (b) models effective practices coherent with previous and future teaching goals of the learning agency, and (c) is sustained and ongoing with coaching or expert support (Maeng and Bell, 2015; Auerbach and Andrews, 2018). These characteristics provide an understanding for defining and studying professional development programs, but unpacking these features for unobstructed transfer to STEM education training for teachers is met with challenges.

When taken as field-specific, STEM education is approached through static isolation of the subjects. PD specific to science, technology, engineering, or mathematics teachers dominate the landscape and have a notable history of success in changing teachers' instructional practices and improving student achievement. However, some argue that STEM education should focus on "an assemblage of practices and processes that transcend disciplinary lines and from which knowledge and learning of a particular kind emerges" (Lemoine, 2013, p. 3). While this conception of STEM education closer aligns to the interdisciplinary nature of problem solving and innovative thinking various corporate and government sectors profess great need and demand for, designing PD for teachers to have authentic STEM experiences is territory educational trainers and researchers have not charted.

Education professionals and researchers who have repositioned their perspective of STEM education toward an interdisciplinary approach distinguish their work from traditional field-specific approaches by defining a domain within the broad field of STEM education called iSTEMed. This domain emphasizes connections between STEM fields through a variety of experiences. Furthermore, according to Honey et al. (2014) continual integrated STEM experiences "may occur in one or several class periods, or throughout a curriculum; they may be reflected in the organization of a single course or an entire school, or they may be presented in after- or out-of-school activity" (p. 31). Conceivably, each method to iSTEMed likely follow different approaches to planning and identifying resource needs, as well as defining different outcomes and implementation challenges.

In this study, we adopted Honey et al. (2014) notion of integrated STEM experiences as applied to a group of teachers within an ongoing PD setting. As we detail in the following sections, aspects of effective PD were considered when we designed and implemented our PD.

An Integrated STEM Education Framework

A review of iSTEMed initiatives, programs, and research uncovered a variety of proposed models of what successful integration requires. The framework determined to be best suited for the PD under design was adapted from a National Academy of Sciences report published in 2014. The integrated STEM education framework (Honey et al., 2014) presents four general features of STEM education initiatives in grades K-12, based on a meta-analysis of STEM education research and program evaluation reports. The components of the framework are: (1) integrated STEM education goals for students and educators, (2) integrated STEM outcomes for students and educators, (3) nature and scope of the STEM integration, and (4) implementation of integrated STEM education. In designing the PD for the study, goals and outcomes for educators were focused on rather than those for students, although goals for students were indirectly addressed.

The Integrated STEM Education Framework (Honey et al., 2014) goals for educators are: (a) increase STEM content knowledge, and (b) increase pedagogical content knowledge for teaching integration of STEM topics. The goals for educators focus on building subject-matter and pedagogical content knowledge in teachers' area of expertise along with STEM subjects for which they have had little exposure. Opportunities for making connections between and among STEM subjects such as reviewing learning standards, understanding sequence and progression, practicing with and becoming comfortable with technology, understanding and valuing the concept of STEM integration, and comfort in exposing students to integrated STEM learning experiences are suggested in facilitating the goals for educators (National Research Council, 2012).

Integrated STEM Education outcomes for educators include: (a) changes in practice, and (b) increased STEM content and pedagogical content knowledge. Outcomes for educators may be evident through increased content and pedagogical content knowledge, increased understanding of STEM integration concepts, and increased self-efficacy in planning and implementing integrated STEM lessons or other activities for students (National Research Council, 2012).

Three elements for defining the nature and scope of integration are identified in the Integrate STEM Education framework: (a) type of STEM connections, (b) interdisciplinary emphasis, and (c) duration, size, and complexity of initiative. The nature of connection may be through bringing together concepts from two or more disciplines, building concepts from one subject through a practice of another, or combining practices from more than one discipline. The type of connections support the interdisciplinary emphasis. Typically, one subject has a dominate role and concepts or practices of other subjects are included to deepen learning in the targeted subject. The scope of an integrated STEM initiative is assessed by its duration, size, and complexity. The duration might be an hour or over several class periods. The size might be a single course, multiple courses, or an entire school. The setting or environment, available resources, and school or state requirements are some components that contribute to the complexity of the nature and scope of the integration.

Although there are many factors to consider in the implementation of integrated STEM education, the framework focused on three: (a) instructional design, (b) educator supports, and (c) adjustments to learning environments. Instructional design encompasses a vast range of approaches to teaching from traditional instruction to student centered, experiential, or open-ended approaches. The instructional design implemented connects practices of the area of interest to the mode of teaching, such as using problem based learning approaches to develop understanding of engineering design. For effective implementation to occur, educators need continued support and engagement that improve STEM content knowledge and change teaching practices, particularly in ways that build self-efficacy for subject-matter integration. Adjustments to learning environments are considered for educators and students. More class time may be needed to experiment or improve a design, lesson planning may need to be extended, team teaching may expand by becoming more interdisciplinary, and professional learning communities specific to STEM integration might be developed.

The description of the goals, outcomes, nature and scope, and implementation of the Integrated STEM Education Framework are not comprehensive, but serve to provide a conceptualization for planning, identifying, or investigating integrated STEM initiatives across educational systems. Recognizing the interdependence of the four features in practice is integral when planning a PD experience for achieving educational change. The framework was integral in discerning the purpose of the study, determining feasible characteristics of the training and how they worked together, and stating the research questions. The Integrated STEM Education framework is used to describe the features of the PD and the interdependence of the features in thoughtfully designing and implementing the program.

METHODOLOGY

The study was conducted in accordance with the recommendations of the Kennesaw State University Office of Research. The study protocol was approved by the Kennesaw State University Institutional Review Board. All participants gave written informed consent in accordance with the Declaration of Helsinki. This section details the eight participants of the study, how we designed and implemented the PD, and the expectations the participants had following the PD. Additionally, we detail how we collected and analyzed data to answer our three research questions.

Participants and Setting

Grades 6–12 teachers were recruited through announcements at professional learning workshops and by school district mathematics and science coordinators. The participants were eight teachers (6 secondary mathematics, 1 secondary science, 1 middle grades science). Three of the teachers reported having 10 or more years of teaching experience, another three had 3 to 5 years of experience, and two had taught less than three years. Additionally, five teachers had level T-5 certification (master's degree) and three had level T-6 certification (specialist degree) in their respective teaching fields. On the registration application, teachers' interests in the workshop ranged from wanting to incorporate more STEM activities in their instruction, learning more about forming collaborative STEM teams and partnerships, and integrating technology in their instruction.

Professional Development Design

The PD was designed by a collaboration between three academic faculty from mathematics education, statistics, and engineering disciplines. Some planning meetings consisted of reviewing the state's 6–12 grades mathematics curriculum, reviewing documents about STEM college/career readiness, and discussion of each member's habits of practice in their respective professions. Iteratively, the content focus was narrowed to geometry, statistics and advanced algebra. With respect to the nature of integration sought, these topics were deemed to be the most encompassing in their flexible application across the other STEM subjects. Honey et al. (2014, p. 4) supports this approach, citing the ability to "represent the same concept within and across disciplines in multiple ways…can facilitate learning."

Each facilitator selected tasks used in his or her own classes or workshops, and revised them so that they explicitly defined how the tasks met the iSTEMed criteria the participants were expected to use in their own task selections. The criteria allowed us to select high quality tasks using iSTEMed in ways aligned to content standards across at least two different STEM disciplines. We then detailed how the different tasks supported principles in iSTEMed as well as overall themes throughout the PD, such as design processes, environmental sustainability, and critical thinking and problem-solving skills in the Twenty-First century. For example, making real-world connections was emphasized as well as including discussion between participants. The culminating product from the PD was a STEM lesson the teachers implemented in their classroom (see the **Supplementary Document** entitled PD Implementation Template and Rubric).

Characteristics of some of the tasks and activities used by the facilitators during the workshop are in **Table 1**. Since the Georgia Standards of Excellence (GSE) are very similar to the Common Core State Standards (CCSS) Curriculum, standards typical to each are presented.

Professional Development Implementation

The PD was 50 contact hours comprising of five days during the summer and three follow up sessions during the school year. During the summer session, teachers were: (1) introduced to iSTEMed reform along with its benefits and challenges, (2) engaged in activities carefully selected and adapted to truly meet the targeted nature of the PD integration, (3) exposed to pedagogical methods for iSTEMed instruction, and (4) worked in teams to create lesson plans based on the state's Department of Education STEM Integration Model. Teachers' content and pedagogical content knowledge for teaching mathematics were assessed prior to exposure to the workshop content. Teachers also provided responses to survey questions about their efficacy and attitudes toward STEM, and feedback was provided to facilitators at the end of each day through discussion board posts. The required deliverable from the teachers was an iSTEMed framed lesson plan to be implemented with students. The PD was funded by *Improving Teacher Quality State Grants Program, Elementary and Secondary Education Act, Title II, Part A* from February 2017 to May 2018.

A requirement of the lesson was to teach mathematics concepts integrated with one or more concepts from at least one other STEM discipline. We provided time during the summer sessions for participants to work on lesson plans in groups, share the lesson, and gather feedback from their peers. Additional task analysis requirements for the participants were to list lesson objectives, discuss ways of maintaining a student-centered learning environment, and list anticipated student questions followed by teacher responses. A rubric created by the researchers was used to evaluate the lesson plans for key features of STEM integration. At the end of the implementation process, teachers were asked to respond to a question prompt discussing the influence the PD had on their teaching practices.

Data Collection and Analysis

We used quantitative methods to investigate our first research question regarding how teachers' content and pedagogical content knowledge changed from the STEM PD. To measure teachers' mathematics content and pedagogical knowledge, we administered the Knowledge of Algebra for Teaching (KAT) instrument on the first day of the summer workshop and

TABLE 1 | Alignment of PD activities with CCSS and state standards, and iSTEMed concepts.

Activity	Applicable standard	iSTEMed concepts
Solar car race – K'Nex	Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets. Obtain, evaluate, and communicate information to evaluate types, availability, allocation, and sustainability of energy resources	Connect sustainable energy resources to data collection and analysis
Gears–K'Nex	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. Use research and technology to support writing	Connect technology use to mathematical concepts and research activities
Cabbage juice lab	Construct and compare linear, quadratic, and exponential models and solve problems. Obtain, evaluate, and communicate information about the properties that describe solutions and the nature of acids and bases	Connect chemistry concepts about acids and bases with determination of pH using logarithm functions
Wind powered water pump—K'Nex	Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations Obtain, evaluate, and communicate information about the law of conservation of energy to develop arguments that energy can transform from one form to another within a system	Connects mathematical concepts of ratios and rates to explain transfer of energy principles related to wind and hydro power
"Apple of my eye"—snap circuits	Construct viable arguments and critique the reasoning of others. Look for and make use of structure. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations	Uses mathematical method of equation rearrangement to understand circuitry and its relation to Ohm's Law

nine months later during the last session at the end of the school year. The KAT instrument was developed through research by McCrory et al. (2012). The three subdomains of the KAT assessment are: (1) knowledge of school algebra (middle and secondary), (2) advanced knowledge of mathematics, and (3) knowledge of teaching algebra. The instrument has been validated for use with both pre-service and in-service teachers. Eight participants took the pre-test and five took the post-test administered approximately eight months after the summer session. Paired data of the five teachers were analyzed.

To study research question two, the paired scores on the Teacher Efficacy and Attitudes Toward STEM (T-STEM) Survey (Friday Institute for Educational Innovation, 2012) taken by eight participants were analyzed. This survey asks teachers to report their confidence and self-efficacy about STEM education on seven constructs using a 5-point Likert scale. The subscales were: (1) mathematics teaching efficacy; (2) mathematics teaching outcome expectancy; (3) student technology use; (4) mathematics instruction; (5) Twenty-First century learning attitudes; (6) teacher leadership attitudes; and (7) STEM career awareness.

The purpose of quantitatively analyzing research questions 1 and 2 is to provide information on the nature of within group changes in content knowledge and self-efficacy. There were no intentions of generalizing the findings, especially in the absence of a comparison group. Also due to the size of the sample, no assumptions were made about the underlying distribution of scale scores and paired differences. Hence the non-parametric method, Wilcoxon signed ranked test was used on all quantitative comparisons to determine whether significant changes had occurred within the group. A 5% level of significance was used for all methods. Furthermore, the results of the quantitative analyses complement the thick, rich descriptions of the qualitative results. Synergistically all of the data analyses contribute to the body of knowledge on effective features of STEM PD that foster change in teachers' knowledge and practices.

We used qualitative methods to answer our third research question regarding how teachers' classroom practice changed in relation to their participation in the STEM PD. Data were collected from two sources. The first source was teachers' reflections on iSTEMed concepts, activities, take-aways, and implementation challenges provided at the end of each day during the summer sessions. Eight participants' data were collected from this source. The second source of data collection for research question three was the teachers' iSTEMed lesson implementation reflection coupled with an additional question prompt *Now that you've had a semester with your students, describe any instructional or pedagogical influence the workshop has had on your practices in the classroom or in leadership. Also, let us know in what ways you feel you may best influence or support STEM education/initiatives in your school or district.* Four of the participants contributed data to the second source. We qualitatively analyzed both sets of data by open coding each response. Axial codes were then used to show relationships with the open codes. Finally, selective coding was used. Reflections were re-read to identify core themes across all participant responses.

RESULTS

Overall, we found the STEM PD did not result in statistically significant gains in content knowledge from the teachers. All eight teachers' scores on the T-STEM survey significantly increased, indicating all experienced an increase in self-efficacy. For the five teachers who completed the entire year-long PD, four provided data that produced evidence that their classroom practices were more iSTEMed focused. This section details this development to answer our three research questions.

Research Question 1: Changes in Teacher Knowledge

Based on pre- and post-test measures, all eight teachers had well developed and sufficient content and pedagogical content knowledge of algebra from the PD. From the KAT assessment administered at the beginning of the workshop, five of the eight participants scored above the normed mean of 50 and three of the five participants taking the post-test scored above the normed mean. Mathematics content knowledge was sustained throughout the PD, as no significant changes in the five paired differences was detected. The result suggests that the participants were already strong in mathematics content knowledge such that the magnitude of gains due to the PD was negligible. Research supports that "teacher's subject-matter knowledge is directly correlated with students' learning (e.g., Hill et al., 2007) p. 115," and the teachers' consistent high marks on the KAT likely contributed to their ability to engage in the rigorous PD tasks (medium to high levels of difficulty and cognitive demand). They also actively generated thoughtful, rich dialogue about mathematics content, supported struggling peers, and anticipated students' challenges with the concepts. The KAT ultimately served as a measure of teachers' preparedness to engage in the demanding activities of the workshop.

Research Question 2: Changes in Teacher Self-Efficacy

During the week-long summer session, all eight teachers completed pre- and post- administration of the T-STEM survey. Self-efficacy measures significantly increased on three of the seven T-STEM subscales: Mathematics Teaching Efficacy and Beliefs ($W = 2.328$, $P = 0.001$), Mathematics Teaching Outcome Expectancy ($W = 2.252$, $P = 0.012$), and STEM Career Awareness ($W = 2.388$, $P = 0.008$).

Research Question 3: Changes in Teacher Practice

Five teachers completed the 50 contact hours through the summer sessions and then continued engagement during the school year by attending face-to-face and virtual sessions, and by self-reporting changes in their classroom practice. Due to changes in school, position, or teaching assignment, along with time constraints, only two teachers were able to teach an adaption of the implementation lesson plan they created with students. Two other teachers were able to create, implement, and report other iSTEMed lessons, activities or out-/after- school activities they did with students. The responses to question prompts on what teachers were able to accomplish in their schools, and daily reflections from the summer PD were analyzed.

A total of 17 open codes were developed based on the reflections provided by participants. Since the goal of research question three was to identify changes in teacher practice, open codes centered on classifying the types of activities and practices used in the classroom. **Table 2** shows the open codes that emerged from the analysis, properties that guided how the text was classified within the code, the number of open code references, and examples of participant quotes.

Since the PD was designed for mathematics teachers, it is not surprising that teachers predominantly reported the use of *Math Content* in their practices. However, the change in teacher practice observed centered on the integration of other subjects within the mathematics classroom. Mathematics teacher, Patricia, led an interdisciplinary service learning project to revitalize a park near her school. From what she learned in the PD, she led collaborations across subjects with teachers and tasked her students with applying concepts of sustainability similar to her experience with the K'Nex environmental kit she received during the PD.

The analysis revealed other notable changes in teachers' practices. The *Extra-curricular* open code revealed additional roles teachers took on in their schools as leaders and sources of knowledge in creating clubs, mentoring students conducting STEM research projects, and leading interdisciplinary service learning projects. Nathaniel, a middle grades science teacher reported using integrated STEM knowledge along with various resources he received from the PD to enhance his teaching and mentoring of students doing projects for the science fair. Mathematics teacher, Erica, described the continuation of her momentum from the workshop to start a club at her school to get girls interested in STEM careers and courses.

Once open codes were established, they were axially coded into six categories. From these codes, and a re-read of teacher reflection data, selective coding was done and the results are presented in **Figure 1**. It was determined that an overarching theme from teacher reflections centered on teacher success and optimism in implementation of iSTEMed practices in their classrooms. This success and optimism were met with challenges related to school support and declines in resource allocations, yet the teachers persisted. For example, Leslie and Erica worked together on the implementation plan, but both had to modify their intended lessons due to constraints on school resources. Inspired by her students' enthusiasm and excitement, Leslie considered ways to acquire resources that anchored students' learning in authentic STEM experiences. Erica developed a lesson based on the implementation plan, but encountered unforeseen software restrictions at her school. By applying what she knew about the characteristics of an integrated STEM lesson, Erica made modifications that aligned with achieving her STEM objectives, and she reported that her students were impressed with the alternate ways they used technology to generate and analyze data.

Overall, teachers demonstrated that they knew how to blend ideas of the mathematics standards and iSTEMed concepts with available resources and materials for learning. There are indications that this approach to iSTEMed PD not only changes teachers' classroom practices, but also provides a foundation for how a teacher may teach or support after-/out of- school programs for students, and lead collaborative STEM teams with teachers. The five teachers who completed the PD and reported trying something new, traced their confidence and inspiration back to authentic STEM experiences they had during the PD.

DISCUSSION AND CONCLUSION

In their recommendations, Honey et al. (2014, p. 8) stated "designers of integrated STEM education initiatives need to be explicit about the goals they aim to achieve and design the integrated STEM experience purposefully to achieve these goals." In this study we followed these recommendations by setting goals examining teacher content knowledge, self-efficacy, and integrated STEM lessons in their classroom practice. We designed the professional development experiences in ways to support these goals (**Table 1**) and measured outcomes using both qualitative and quantitative data. In this way, we found the iSTEMed framework was successful in helping us design and implement a PD for teachers.

The first guiding question of the study sought to investigate changes in teachers' mathematics content knowledge in relation to their participation in the STEM PD. There were no significant changes in performance on the instrument used to assess teachers' knowledge. While future use of the instrument will be to measure teachers' preparedness prior to participation in the PD, the result of no negligible gain in content knowledge in relation to participation in the PD is best explained by the lack of alignment between the PD curriculum and the assessment instrument. The KAT subscales measured knowledge for teaching algebra, school algebra knowledge and advanced algebra knowledge. The PD curriculum covered statistics and geometry, in addition to school algebra. Furthermore, the PD integrated rates of change, solving equations and inequalities, factoring and graphing across at least one other STEM concept and discipline. These algebra topics comprised about 50% of the KAT items, and none of the items integrated concepts from other school level STEM curricula. Therefore, the participant's KAT score is a direct measure of algebra content and algebra pedagogical content knowledge, but it did not represent a direct measure of a participant's mathematics content knowledge integrated with other STEM content knowledge and pedagogical content knowledge, which were our primary interests.

Romberg (1992) noted the complexities of aligning curriculum standards to tests. Curriculum standards describe observable outcomes so that items are created to assess them. Items undergo a rigorous validation process, but still may not directly measure an intended trait in the test taker. We note that integration across STEM topics is an approach to teaching and not a content area with a curriculum, and also that process standards are a part of all school STEM curricula. While process standards are useful in developing pedagogical knowledge, designing items to assess mathematical knowledge for teaching is challenging (Hill et al., 2007) and the challenge intensifies

TABLE 2 | Overview of open codes in the qualitative analysis.

Open code	Properties	References	Examples of participants' words
Community	Activities planned that involved individuals outside of the school	4	Southwest section of Atlanta, park located near the school which is in need of care, revitalize the park
Computers	Desktops, laptops and/or tables	5	My school's laptops however are few and antiquated, sufficient number of laptops, I see much room for better technology in our school as well. We are waiting for each student to receive a laptop which was a District wide promise. If that does not happen, we will be remaining at a deficit
Course	Specifically identified courses or classes where lessons were planned	4	Environmental science, geometry, computer science
Excel	A spreadsheet program that features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications	3	Programs like EXCEL, We used EXCEL to analyze the data
Extracurricular	School sponsored activities that do not occur during regular instruction periods	4	I started a girls who Code club at my school, along with robotics, I was able to meet with several teachers to put in place a STEM project
Go Motion	Technology used to collect position, velocity, and acceleration data of moving objects	6	I was able to use Go Motion in a whole group setting, motion detector, when attempting to use my go motions
Grants	A sum of money given by a government or other organization for a particular purpose	2	Learn the art of grant writing, I would like some help on grant writing to develop a STEM lab at my school
K'Nex	STEM Education brand that provides creative building sets for kids to stimulate curiosity and imagination	2	I was able to purchase 2 K'nex sets to add to the set received in class, K'Nex STEM kit
Math content	Mathematical concepts that can be connected to educational standards	15	Difference between fast and slow, constant and various rates of change, and stopping, AVERAGE and ABS functions, Geometry I had the students design a section ground plan using the specifications highlighted in the online Pythagorean Theorem Spiral Project
pH activity	PD activity performed during the Summer Session that reviews logarithms through a pH Activity	2	Is to one on pH, but will not be able to get into logrithms with them as much as we were exposed, There are many clinical applications surrounding pH that they need to understand such as the function of different portions of the digestive system because of the different pHs and how that affects the absorption of different medicines in the different areas
Principal	School administrative representative	3	When I suggest how to use the technology to enhance a lesson, teachers and administrators revert back to their comfort zone of pencil and paper, I also had the pleasure of the principal coming in to do an observation during this class. I'm interested to see her feedback
Renewable project	PD activity performed during the Summer session that utilized solar, wind and hydro power science content to study rates	2	Solar power, wind power, and water power, design a solar powered treadmill for pets
Resources	Related to funds, materials and donations used to execute STEM related activities in the classroom	6	Short on the technology side, Now that I have a sufficient amount of Go Motion devices, sufficient number of laptops, I see much room for better technology in our school as well. We are waiting for each student to receive a laptop which was a District wide promise. If that does not happen, we will be remaining at a deficit
Science content	Scientific concepts that can be connected to educational standards	7	Human water cycle that was relevant to their lives which they [were] about to use as their science fair project, students gain an understanding of the water cycle, how humans use and disposal of water, cost of water, I asked them to think about how math, science, etc. could be incorporated making it a park for not only recreation and fun, but a learning experience for all age groups
Snap Circuit	A line of electronic kits manufactured by Elenco that offers a range of building experience for the user, and may include motors, lamps, and speakers	1	Snap circuit kit
Student response	Perceptions by teachers of student responses to STEM lesson activities	3	They had NEVER seen/experienced anything like that before and to this day, The students were WOWed with the EXCEL portion of the lesson along with playing Kahoot to get our data
Teacher response	Perceptions by teachers of teacher/administrator responses to STEM lesson activities	5	I have learned sooooo much, when I suggest how to use the technology to enhance a lesson, teachers and administrators revert back to their comfort zone of pencil and paper, teachers feel the indirect pressure to conduct business as usual

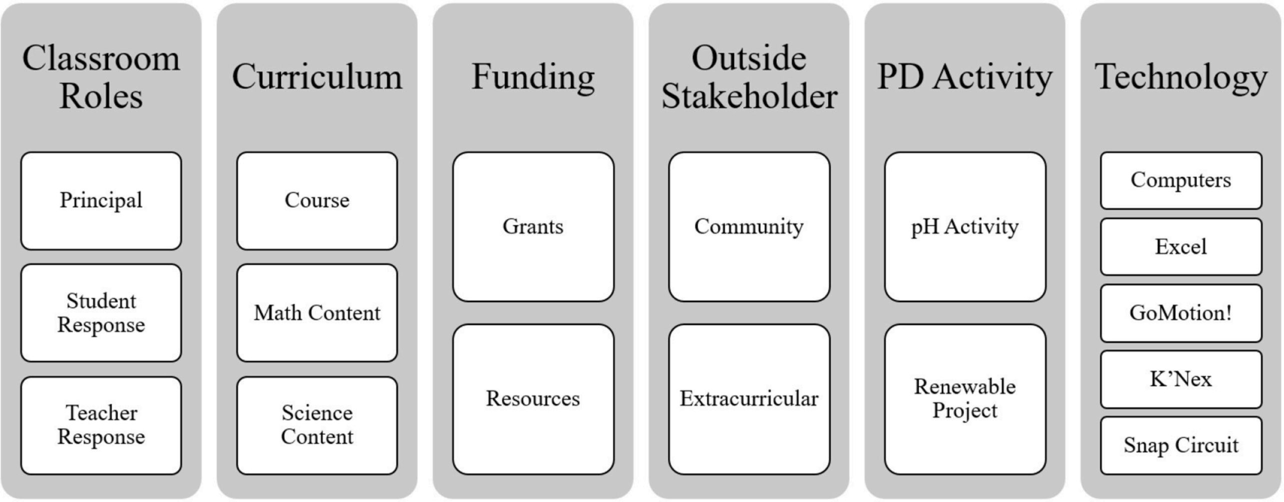

FIGURE 1 | Overview of axial and selective codes in the qualitative analysis.

with the addition of other STEM concepts and disciplines. The misalignment between test and curriculum in the study has led us to explore ways to assess mathematics knowledge needed to teach an integrated STEM lesson. Such an instrument is possible, based on research by Glassmeyer et al. (in press), in which a study assessed in- and pre-service mathematics teachers' content knowledge from their participation in a lesson integrating pH, a chemistry topic and logarithms. The Logarithms and pH Assessment (LPA) consisted of two subscales, 16 items on logarithms (Cronbach's $\alpha = 0.80$) and 16 items on pH (Cronbach's $\alpha = 0.85$). The scores on the LPA after the integrated lesson were significantly higher than those on the pretest [$t_{(28)} = 10.66$, $p < 0.001$]. An assessment designed to target mathematics content within a complementary STEM context would advance understanding of mathematical knowledge needed to teach an integrated STEM lesson.

Regarding our second research question, there were significant gains in teacher self-efficacy, as measured by the T-STEM instrument. Honey et al. (2014, p. 7) stated "one limiting factor to teacher effectiveness and self-efficacy is teachers' content knowledge in the subjects being taught." There is plausible interdependence between research questions one and two in accounting for aspects of the PD that likely contributed to the outcomes observed for research question two. The teachers' high content knowledge as measured by the KAT was a reasonable foundation on which teachers could build a higher self-efficacy. Under support of their sustained, strong content knowledge teachers' self-efficacy increased statistically on three of the T-STEM subscales. The Mathematics Teaching Efficacy and Beliefs subscale measured confidence in teaching mathematics (e.g., continually improving teaching, knowing what it takes to teach effectively, and ability to answer a student's question). The activities the teachers encountered during the PD were rigorous and thoughtfully aligned with concepts of iSTEMed during task facilitation. Achieving success in understanding how various STEM topics relate to mathematics provided meaningful, authentic learning experiences for the teachers that increased confidence in teaching mathematics. Similar findings for STEM PD were found in a study by Green and Kent (2016) in which meaningful PD fellow—classroom teacher relationships were shown to have a positive impact on elementary teachers' confidence to teach mathematics, science, and technology using integrative instructional approaches. The Mathematics Teaching Outcome Expectancy subscale measured the degree to which the participant believes student learning can be impacted by a teacher's actions. The PD positively impacted teachers' perceptions on how their actions and expectations of students transfer to student achievement in mathematics, which has been shown in recent studies (Archambault et al., 2012; Petty et al., 2013; Rubie-Davies et al., 2015; Peterson et al., 2016). The STEM Career Awareness subscale measured awareness of not only STEM careers but where to find resources for further information. Discussions between participants and facilitators along with collaborations on lesson plan implementations afforded ample support and time to identify and experience STEM resources on careers and activities during the PD. Furthermore, a factor contributing to students taking advance mathematics courses is teachers' influence, and students' interest in STEM careers is commonly influenced by parents and teachers when steered toward having high expectations for the future (Ma, 2001). The results of research question two are aligned with other research findings in that supporting teacher's self-efficacy is vital for effective STEM integration (Koirala and Bowman, 2003; Honey et al., 2014), which enhance credibility of using the iSTEMed framework to design and implement the PD model for teachers.

The qualitative results provide evidence in support of the positive impact the PD had on teachers' classroom practices, thereby answering the third research question. These changes to classroom practice are particularly significant because the teachers enacted instruction of mathematics and iSTEMed concepts using integrated STEM activities within schools that were not STEM-focused and had limited supplies and support for integrated STEM activities. Furthermore, some teachers experienced setbacks to their initial plans to implement integrated STEM activities, but they persisted beyond those challenges by adapting lessons they were teaching to focus on iSTEMed concepts and by forging authentic experiences for students by working with the limited resources available to them. Coupled with the results of research question two of increased self-efficacy, this suggests the PD model addressed the challenge of inadequate self-efficacy among the mathematics teachers to implement at least one iSTEMed lesson in their classrooms. The synergy of the results of the three research questions produce greater combined evidence of the positive impact of the PD than when taken separately. The strong foundational knowledge affirmed by the measure of content knowledge used in research question one fostered significant increases in teacher's self-efficacy as measured by the instrument used to answer research question two. The teachers' perseverance in enacting an integrated activity or extra-curricular activity at non-STEM themed schools qualitatively demonstrates how the significant increase in self-efficacy translates into teachers' actions in their schools and changes in teaching practices in their classrooms. In other words, teachers may have been more likely to implement an integrated STEM lesson in their classroom because of the increased self-efficacy. This notion is supported by both the iSTEMed framework (Honey et al., 2014) as well as mathematics education literature more broadly (Tuchman and Isaacs, 2011). In addition to teachers making changes to their own classrooms, we found four of the five teachers who completed the entire year of STEM PD engagement succeeded in efforts to enact STEM integration within the larger school community. This indicates teachers can support and drive iSTEMed culture beyond their classroom or STEM disciplines, even within non-STEM schools. Since the teachers in this study volunteered to participate in the PD, this suggests that early adapters (teachers interested in iSTEMed) may be more likely to influence STEM culture in their schools and communities. Other administrators or PD providers could use this information to encourage teachers to do the same, perhaps through clubs or by creating more informal STEM environments for students to experience, or by adopting a school wide theme such as integrating social justice within STEM efforts (Sahin et al., 2014; Corbera, 2015; Garibay, 2015; Higgins et al., 2018).

From this work, we offer three implications for teacher educators, PD providers, and administrators. First, consider how the Honey et al. (2014) framework could be used to structure PD for teachers, particularly in settings where teachers have little existing support for STEM efforts. This framework could be great for early adapting teachers within a single school or a district interested in STEM initiatives, even if the principal or superintendent is not encouraging STEM initiatives but with some convincing would support it. Second, having multi-disciplinary representation of teachers from mathematics and science enriched the PD experience for the facilitators and the participants. We encourage STEM PD efforts that recruit teachers from at least two or more STEM disciplines, based on the nature of integration and the ability to pair concepts of the dominate STEM discipline with similar concepts from the supporting STEM disciplines (see also Corlu et al., 2014; Lambert et al., 2018).

A third implication is that a support structure should be in place to help teachers make STEM-related changes to their classroom practice. In our PD, we had sustained engagement during the school year, where the teachers, PD facilitators, and STEM experts met and worked beyond the summer workshop. Based on participant feedback, this helped teachers stay accountable to their STEM initiatives. Additionally, keeping open communication between participants and facilitators and iSTEMed experts helped answer questions and resolve concerns that arose. Regular communication through email included accountability check-ins, answering of questions, sharing what each teacher was in their classrooms, discussing resolutions to implementation challenges, and sharing STEM-related information (e.g., teacher and student resources, grants, and conferences) with each other. Also having a learning management system that remains active and available to the participants and facilitators to share and archive STEM articles and materials, and invites feedback from STEM experts across all fields is helpful in supporting continued engagement. We recommend team leaders, district coordinators, and school administrators provide these support structures to teachers, especially those in non-STEM oriented schools.

A clear limitation of the study is the sample size, which prevents us from making generalizations to the larger population. Studies involving small samples however contribute to the body of knowledge particularly for the value of information gained weighed against the void in knowledge that would exist if the study were never conducted. Knowledge advanced from the study contributes to research on designing effective PD models from the STEM framework which can be replicated and evaluated at scale, and the study highlights recommendations for continued education of teachers adapting iSTEMed teaching approaches. Knowledge gained from the study also support a foundation for quasi-experimental studies aiming to compare student achievement between teachers of iSTEMed teams and traditional subject matter teachers to further examine the impact these kinds of PD have.

An additional limitation of the study is the reliability of self-reported data. The participants' positive reflections about changes in their teaching practices due to the PD may have been underlined with their desire to please the researchers. However, site visits to the schools validated the lessons, projects, extra-curricular activities and collaborations the teachers reported creating resulting from their participation in the PD. The teachers' observed actions and enactments provide tangible evidence of their changes in practice and are manifestations of their increased self-efficacy, refuting the likeliness of them responding in ways to solely please the researchers.

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AUTHOR CONTRIBUTIONS

KG designed and directed the study, KG led recruitment, the full team (KG, DG, and RW) led implementation, KG conducted quantitative analyses, RW conducted qualitative analyses, the full team interpreted results, and the full team contributed to and managed the writing and revising process.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2019.00026/full#supplementary-material

Data Sheet 1 | PD Implementation Template and Rubric.

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