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Tackling Integrated STEM in Elementary Education: A Collaborative Approach

Laura Robertson

ASSISTANT PROFESSOR OF SCIENCE EDUCATION, EAST TENNESSEE STATE UNIVERSITY

Ryan Andrew Nivens

ASSOCIATE PROFESSOR OF MATHEMATICS EDUCATION, EAST TENNESSEE STATE UNIVERSITY

Alissa Lange

ASSOCIATE PROFESSOR OF EARLY CHILDHOOD EDUCATION AND DIRECTOR OF THE EARLY CHILDHOOD STEM LAB, EAST TENNESSEE STATE UNIVERSITY

Introduction

We must improve the quality of Science, Technology, Engineering, and Mathematics (STEM) education in elementary school and early childhood classrooms. In order to address this issue, we recommend improving the frequency and quality of experiential opportunities offered through teacher preparation programs. Pre-service teachers in early childhood and elementary education benefit from applied experiences, but highly involved placements typically come only at the end of their programs. Graduates may leave teacher preparation programs with varied levels of ability to teach STEM disciplines in a way that integrates skills and knowledge across the domains (i.e., Lamberg & Trzynadlowski, 2015). As a result, elementary teachers often enter service without the knowledge and skills necessary to support the inclusion of early elementary STEM lessons and units (DeCoito & Myszkal, 2018).

Once in the classroom, elementary teachers are under immense pressure to meet standards and prepare students for state tests, resulting in a variety of content covered (Polikoff, 2012). This problem is compounded when teaching standards are updated, as the STEM standards recently have been in many states under *Next Generation Science Standards* ([NGSS]; NGSS Lead States, 2013), *Common Core State Standards for Mathematics* ([CCSS]; National Governors Association, 2010), or similar revisions. Such changes are rarely paired with quality training that enables teachers to meet these new and rigorous standards, especially with a focus on integration. Our project sought to address these issues by using an innovative, collaborative approach to support the growth and learning of pre-service teachers in early childhood education (ages 5-8) and elementary education (ages 5-10) while simultaneously providing elementary teachers with materials and resources for implementing integrated STEM.

Review of Literature

Importance of STEM for Young Learners

STEM concepts are critical domains in early childhood and elementary education. Early mathematics and science skills are predictive of student performance later in elementary school and even into high school (Grissmer et al., 2010; Watts et al., 2014). In order to address the current and future challenges of our world, we will need teachers who are ready to teach STEM to young learners and who can better prepare the future workforce (McClure et al., 2017). Science, in particular, is often under-taught in the early childhood and early elementary grades (Marco-Bujosa & Levy, 2016; Poland, Colburn, & Long, 2017; Spodek & Saracho, 2014). When pre-service teachers are not involved with designing and implementing STEM lessons during the teacher preparation process, we risk continuing the cycle of marginalizing science in the early grades (Berg & Mensah, 2014; Goldston, 2005; Maulucci, 2010) which is especially concerning in current times when the culture at large expects STEM to be prominent (Freeman et al., 2014).

Challenges of Integrated STEM

One challenge of integrated STEM is lack of consensus regarding its definition. For the purposes of this project, we use the term *integrated STEM* to designate situations in which two or more STEM subject areas are integrated. Teachers and administrators cite numerous challenges to the implementation of integrated STEM in K-12 classrooms which include time for planning and implementation, preparation through pre-service education and professional development, school organization, state testing, and access to resources (Shernoff, Sinha, Bressler, & Ginsburg, 2017). These challenges have been specifically noted for implementing these types of lessons effectively with young learners (Paolucci & Wessels, 2017) and the general lack of preparedness regarding implementing integrated STEM content (Stohlmann, Moore, & Roehrig, 2012).

Bybee (2014) strongly recommends forging a connection between the NGSS and the CCSS for mathematics with an emphasis on development of these connections during pre-service teacher education; however, pre-service teachers often need support to develop an understanding of strategies that can be used to implement learning opportunities that involve authentic integration, rather than surface-level integration (Heimer & Winokur, 2015). Supporting teachers in the field to teach STEM concepts individually or in an integrated way are two possible ways to address this, but high-quality professional learning opportunities are less common and those that do exist tend to be expensive. Integrated STEM teaching for teacher preparation programs is also a challenge because it demands collaboration across domains and possibly across the notoriously siloed departments of academia. As Gardner and Tillotson (2018) wrote, "integrated STEM instruction remains ill-defined with many gaps evident in the existing research of how implementation explicitly works" (p. 1).

Pre-Service Teacher Education

Teacher education focuses on both the practical and the theoretical aspects of education. Smith and Lev-Ari (2005) reported findings that demonstrate the value of practicum in teacher preparation programs; however, science is not often linked to practicum experience in early childhood programs (Lobman, Ryan & McLaughlin, 2005). Content knowledge (CK) and pedagogical content knowledge (PCK) are both critical in effective teaching, and field experiences are conducive to developing pre-service teachers in both of these areas. Donna and Hick (2017) showed that gains in pre-service teacher CK were achieved through their efforts to implement lessons in their field placements, particularly when those lessons were modeled after best practices. Similarly, Hume and Berry (2011) found evidence that a lack of practicum experiences can be a limiting factor in pre-service teacher development of PCK.

One approach method of advancing the CK and PCK of pre-service teachers during practicum experiences is the practice of microteaching (Cinici, 2016; He & Yan, 2011). In microteaching, the pre-service teacher plans a very short lesson, often on only a single concept, and implements that lesson with a small group. Following the lesson, the pre-service teacher then receives immediate feedback, adjusts the lesson plan, and, ideally, implements the adjusted lesson plan with another small group. This has been found to be a useful way to engage pre-service teachers in experiential learning while also making a positive impact on the students that receive the lessons (Cinici, 2016; He & Yan, 2011).

Attitudes towards teaching STEM, beliefs about the value of STEM, and self-efficacy influence teaching practice (Pajares, 1992; Greenfield et al. 2009), and as Ng, Nicholas, and Williams (2010) discussed, initial beliefs can be changed throughout the course of effective teacher preparation programs. Bedel (2015) documents the importance of self-efficacy among pre-service teachers and its impact on their academic motivation, and Kazempour and Sadler (2015) found that science methods course could have a positive impact on beliefs, attitudes, and self-efficacy. Because these aspects of a pre-service teacher are important to their science teaching practice and because they are malleable, we should ensure that pre-service teacher education programs address these as part of the curriculum.

Collaborations in STEM Education

One vehicle for addressing authentic experiences, PCK and CK, and attitudes and beliefs is taking advantage of collaborations. Collaborations in education offer opportunities and experiences that can advance STEM teaching and learning by reaching across pre-service, teacher, departmental, content, and other divides to take advantage of diverse areas of expertise; however, in an extensive review of literature, Willegems, Consuegra, Struyven, and Engels (2017) found that "few studies have actively investigated the roles of other actors, such as [in-service teachers] and teacher educators" (p. 242). At the university level, faculty across departments rarely collaborate in coursework, which means that pre-service teachers (and faculty) miss opportunities to learn from exposure to different philosophies and approaches. For the educational collaborations that do exist, many operate on a small scale and are "often unknown beyond the area in which they are operating" (Clark, Tytler, & Symington, 2014, p. 29).

One documented example of collaboration in STEM education is the Preparation for Industrial Careers in Mathematical Sciences (PIC Math) program which partners higher education with industry in order to solve real-world problems offered by the industrial partners. The PIC Math program is funded by the National Science Foundation in collaboration with the Mathematical Association of America and Society for Industrial and Applied Mathematics. During a semester long course, professors work with small teams of college undergraduates who analyze data and present solutions to issues identified by industrial partners. In the process, undergraduates gain skills which better prepare them for careers in their chosen industry (Joyner, 2017).

Purpose of the Project

Solutions to the challenges of implementing integrated STEM with elementary students are difficult to find. New standards and other demands place practicing teachers with already severely limited time constraints under further strain. Pre-service teachers feel the strain as well. This unease can be due to a variety of factors, beginning with their own prior experience coming up through K-12 education under a system that devalued integration in STEM areas. Later, this may continue with a resulting lack of familiarity with early/elementary STEM integrated activities, and culminating with their current potentially negative attitudes, beliefs, and self-efficacy. These problems are exacerbated by departmental isolation.

In order to address the challenges of implementing integrated STEM, we initiated a collaboration between our laboratory school elementary teachers, pre-service teachers, and education professors (Figure 1). Similar to the way that the PIC Math partnership connects industry with STEM content majors, we asked the elementary teachers to identify authentic problems involved with the teaching of new science standards and then we supported pre-service teachers in solving those problems through plans for integrated STEM activities. The following question guided our work: *How can collaboration between elementary teachers, pre-service teachers, and education professors solve problems related to the implementation of integrated STEM education?*

This collaboration was intended to alleviate several of the difficulties discussed previously. Through the collaboration we sought to: 1) leverage the time and energy of pre-service teachers to assist elementary teachers in the integration of science and mathematics; 2) provide additional hands-on experience through microteaching for pre-service teachers by engaging them in solving authentic problems related to elementary STEM teaching and learning; and 3) increase professionalization of the workforce through collaboration across departments and by fostering relationships between pre-service teachers and practicing teachers. What follows is a detailed description of the methods we employed and the initial outcomes from this development phase. In the conclusion, we identify key features of the collaboration that emerged that contributed to the advancement of integrated STEM in elementary education, implications of this approach, and our plans for the future.

Project Overview

General Organization

The project described below has evolved over multiple years. In Year 1, the project was conceived by elementary education professors as a way to help elementary teachers at a partner laboratory school as they transitioned to a new and challenging set of state science standards. Furthermore, it was intended to benefit pre-service teachers through authentic and challenging experiences planning hands-on science learning activities and professors by enhancing the program in which they served, while positively impacting elementary students in science. In Year 2, the project expanded to address integrated STEM and added professors and pre-service teachers in the early childhood education program. At the time of writing, the team was planning and beginning implementation of Year 3. Unless otherwise noted, this paper focuses on Year 2 of the project. Table 1 summarizes the contributions by each group of collaborators during the project.

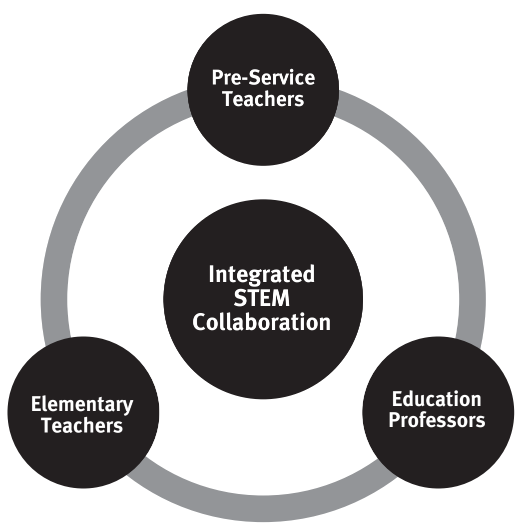

Figure 1. Collaboration to Implement Integrated STEM in Elementary Education

	Pre-service Teachers	Elementary Teachers	Professors
Contributions	Completed in-depth analysis of the standards Identified integration points Designed learning experiences Implemented microteaching of one hands-on learning activity Shared created materials with elementary teachers	Identified "problem" standards Shared exemplary science examples and tips Gave feedback on the projects at two points Scheduled time and brought elementary students for microteaching	Initiated the collaboration Designed project requirements for pre-service teachers Developed timeline for collaboration Modeled best practices Supported pre-service teachers in project development Facilitated logistics and communication Evaluated pre-service teachers' work and provided feedback

Table 1. Summary of Contributions by Each Group of Collaborators

Timeline. The collaborative project for Year 2 took place over the course of one semester during which the pre-service teachers were enrolled in a course related to STEM in either an elementary education program or an early childhood education program. Table 2 is a timeline of the major events of the project during the semester. The semester at our institution includes 14 weeks of coursework and one week for finals.

Week of Instruction	Major Events
2	Elementary teachers provided a list of the most difficult science standards which they would like pre-service teachers to address. Professors created a shared spreadsheet to organize the list of standards. Collaborators finalized and coordinated dates and times for microteaching experience during finals week (week 15)
4	Pre-service teachers selected their preferences for a grade level and Disciplinary Core Idea (DCI) for the project.
5	Professors coordinated standard selection by pre-service teachers using a shared spreadsheet. Pre-service teachers finalized the grade level science standard for their projects.
6-14	Pre-service teachers worked on projects. Required elements included integrating mathematics (and other subjects in early childhood program), reviewing relevant STEM content, and planning learning activities. Professors, in their respective courses, modeled and provided instruction on best practices in STEM, helped pre-service teachers identify mathematics standards for integration, reviewed projects, and provided feedback.
11	Elementary teachers met with pre-service teachers that were working on a standard for their grade level to share an exemplar science unit and to offer tips and suggestions for student projects. Pre-service teachers had a work session for their projects and could ask questions of the visiting elementary teachers. Pre-service teachers from elementary education and early childhood education discussed their projects comparing different approaches.
15	Pre-service teachers led hands-on learning activities for elementary students and reflected on their experiences. Elementary teachers observed projects, shared feedback, and facilitated safety and management of elementary students. Professors facilitated safety and timing of microteaching and collected reflections from pre-service teachers and interviewed elementary teachers.

Table 2. Timeline of Major Events

Participants. The project included four elementary teachers, four professors, 59 undergraduate pre-service teachers, and six graduate pre-service teachers for a total of 73 collaborators in a university setting in the southeast United States. The elementary teachers were from grades kindergarten (five years of age) through three (eight years of age). The pre-service teachers were enrolled in one of three courses related to STEM education: *STEM Content for Elementary Educators* (undergraduate elementary education), *Constructivist Inquiry Approach to Science/Mathematics for Young Children* (undergraduate early childhood education), or *Constructivist Inquiry Approach to Science and Mathematics for PreK-3* (graduate early childhood education). The elementary teachers were employed by the university's K-12 laboratory school. The lab school culture embraced collaborations with pre-service teachers, but elementary science collaborations had been on a smaller scale and not in such an integrated fashion.

Description of the Process

Identifying authentic problems. The problem faced by elementary teachers in this collaboration was the adoption of new and challenging science standards. Although the state did not formally adopt *NGSS Science Standards* (NGSS Lead States, 2013), the same guiding document, *A Framework for K-12 Science Education* (National Research Council, 2012) was used to develop the state science standards. The new science standards (15-25 standards per grade level) required changes in planning, instruction, and assessment, and the elementary teachers had little time available to commit to re-designing their curriculum. As a part of the collaboration, elementary teachers reviewed the new standards and selected the standards about which they felt the most concerned. This list was primarily composed of physical science and engineering standards, but all of the disciplines were represented on the list. The identified standards were then used as the basis of the projects created by the pre-service teachers.

Structure of projects by pre-service teachers. Each pre-service teacher was tasked with designing an integrated STEM unit of instruction that focused on one of the science standards identified by the elementary teachers. The projects for both elementary and early childhood education were based on prior semesters' assignments and differed in their specific requirements; however, it was possible to address the needs of the elementary teachers through both formats. Small changes to the structure of the projects were made without re-designing the projects. In the elementary education program, the project requirements were to create a 5E Learning Cycle (Bybee, 2015) that integrated one mathematics and one science standard. The final product also had to be organized into an interactive notebook format (Marcarelli, 2010) that included two Claim Evidence and Reasoning ([CER]; Zembal-Saul, McNeill, & Hershberger, 2013) writing activities and assessments for mathematics and science. Pre-service teachers created electronic and hard copies of the interactive notebooks to share with elementary teachers.

In the early childhood education program, the project requirements were to create a two-week integrated unit plan, with the selected science standard at the center. Pre-service teachers had to create a curriculum web, two full lesson plans, descriptions of activities across the day and across the two weeks, an assessment plan, and to discuss how activities were connected to one another. Pre-service teachers had to link the activities to standards in a number of other domains, including mathematics. A critical element of this assignment was to identify how the activities would allow for elementary students to engage in inquiry or scientific practices and to be active in their learning (rather than a focus on direct instruction), for example, through using the 5E cycle as a framework. Early childhood educators provided the integrated unit plans for the collaborating teachers.

Supports during project development. To support the pre-service teachers in the development of their projects, the professors scheduled multiple points for feedback and revision throughout the semester. In an effort to provide maximum feedback, up to three people (two professors, one graduate assistant) would review submitted work to provide focused feedback. Smaller assignments helped break the projects into manageable pieces over the semester to encourage pre-service teachers to avoid procrastinating until the end of the semester. Pre-service teachers learned to "unpack" standards (Table 3) using a template adapted from a local school system (Sullivan County Schools, n.d.). Significant time for support and feedback was provided during the weeks when pre-service teachers were trying to find a mathematics standard that fit well with their assigned science standard. To locate points for integration, pre-service teachers created concept maps of math topics, and they discussed the difference between surface level and deep integration.

STEP 1	Standard as it appears in the Standards (copy/paste):		
STEP 2	Initial Gist:		
STEP 3	**A** Nouns / Noun Phrases:	**A** Verbs / Verb Phrases:	**B** Webb's DOK levels:
STEP 4	Key Academic Vocabulary: (indicate those that need to be clarified or directly taught)		
STEP 5	Discussion notes: (What comes before/after this standard? What prior knowledge/skills are needed to master this standard?)		
STEP 6	New Understanding: (May write this as an "I Can" statement)		
STEP 7	**A** Instructional Implications (i.e., activities/strategies/writing):	**B** Assessment Implications (formative and summative):	
STEP 8	How will you differentiate to meet the needs of your students?		

Table 3. Unpacking Standards Guide (Sullivan County Schools, n.d.)

Built into the projects early in the semester were opportunities for the pre-service teachers to review and extend their CK related to the mathematics and science of their project standards. The pre-service teachers researched their topics and created concept maps of the major science ideas. Some of the mathematics and science concept maps were incorporated into the final project while others were only used as reference tools during planning. In the early childhood education program, pre-service teachers reviewed the state standards and the NGSS, and then prepared, presented, and received peer feedback on hands-on science activities delivered during class that covered the major disciplinary core ideas. These in-class ideas supported pre-service teachers' CK and PCK, while also preparing them for the teaching experiences to come.

The pre-service teachers also received support through examples of best practices shared by the professors and the elementary teachers. The professors, in their respective classes, modeled integrated STEM teaching and assessment regularly with projects such as pancake engineering (Chizek, VanMeeteren, McDermott & Uhlenberg, 2018; Flynn, 2017) and explorations of sinking and floating (Merritt, Jimenez-Silva, Rillero & Chavez-Thibault, 2018). Assigned readings from practitioner journals such as *Science and Children* and *Teaching Children Mathematics* also provided examples of high-quality STEM for elementary students. Additionally, the early childhood pre-service teachers had a guest lecture from a mathematics professor in the elementary education program.

Later in the semester, special class meetings were arranged so that pre-service teachers of both programs could meet for one hour with the elementary teacher for whom they were designing a project. The elementary teachers each brought one exemplar science unit to share with the pre-service teachers and shared tips and recommendations. For example, the second grade teacher discussed how she looked at both the first and third grade standards in her planning to understand what prior experience students were likely to have and what she needed to prepare them for in the third grade. The kindergarten teacher shared that she did not hesitate to use content vocabulary with her students because they were ready for, and enjoyed using, the terms that described science phenomena. While the elementary teachers visited, there was also time for the pre-service teachers to work on their projects, discuss their projects with peers from the other education program, and ask the elementary teachers for feedback.

Microteaching of hands-on activities. The project culminated with the pre-service teachers implementing one of the hands-on learning activities from their projects with elementary students in a microteaching format. This occurred at the end of the semester during the two-hour final exam period. Pre-service teachers worked with a peer that had a standard from the same grade level. The first 30 minutes of the period were for preparing materials and activity setup, and the last 30 minutes were for clean up and reflections (Table 4). The elementary students and teachers arrived for the hour in the middle. During the hour, small groups of elementary students rotated through activities for their grade level every 15 minutes. Each pre-service teacher taught an activity two times and served as an assistant for a peer two times. This allowed the pre-service teachers the opportunity to receive immediate feedback and make small revisions the second time they taught, and it allowed them to get a different perspective as an observer/assistant. Pairing up the pre-service teachers also meant that someone was available to support the teaching experience if there were management or materials issues. During this time, the professors and elementary teachers provided assistance as needed.

Time	Events
30 minutes	Pre-service teachers prepare materials.
60 minutes	One pre-service teacher leads an activity while a peer assists (15 min). The pre-service teachers switch roles (15 min). Elementary students rotate to a new group, and the pre-service teachers repeat their activities with new students (30 min).
30 minutes	Pre-service teachers clean up and complete reflections.

Table 4. Schedule for Microteaching with Elementary Students

Logistics and communication. A flexible logistical plan was used to coordinate the work of 73 people. Prior to the start of the semester, the elementary teachers and professors met to discuss the project, set action items, and plan the days and times for elementary students to visit for the microteaching experience. The college final exam periods were used for microteaching hands-on activities with small groups of elementary students; the culmination of the project. These dates and times were scheduled five months in advance in order to ensure that they would work for the elementary teachers and students. This was also necessary in order to determine which course sections of pre-service teachers addressed which standards and reserve classroom space during final exams. With the most important dates set, other parts of the timeline such as due dates for smaller assignments, class activities, and project work time could be modified during the semester as needed.

An online survey was used to determine the grade level and DCI preferences of the pre-service teachers. Pre-service teachers were assigned to a small group based on a grade level and discipline (i.e., 3rd grade physical science), and then each student selected one of the identified problem standards to address. A shared, cloud-based spreadsheet was used to organize which pre-service teachers were addressing which standards across the different education classes.

Email was the primary method of communication used between the professors and elementary teachers. Communication was on-going, but there were planned methods for collecting feedback from the pre-service teachers and elementary teachers at the end of the project. On the day of microteaching, the pre-service teachers completed a short, written reflection about what they learned from working with the elementary students and what they learned from the project as a whole. On the same day, one of the professors conducted a short interview with each elementary teacher for feedback on the projects created by the pre-service teachers and the collaboration.

Outcomes

The collaboration to implement integrated STEM resulted in observable benefits to each group of participants which fall into two categories, 1) materials (physical products) and 2) experiences and opportunities (see Table 5). Year 2 of the project provided initial pilot data collected primarily through anecdotal observation and informal feedback.

	Pre-service Teachers	Elementary Teachers	Professors
Materials	Shared projects of peers	Integrated unit with materials New hands-on teaching ideas to address standards integration	Improved course content due to authenticity and feedback from elementary teachers
Experiences and Opportun-ities	Authentic, challenging experiences Opportunity to work with elementary students Exposure to integrated STEM, best practices, and high quality resources Opportunity to observe and assist a peer during microteaching Opportunities to engage in the profession through publications, presentations, and sharing of ideas	Opportunity to observe hands-on activities during microteaching Opportunity to present at professional conference and co-author publications Participation can count toward tenure requirements	Ability to provide opportunities for pre-service teachers to work with elementary students Participation may help with tenure and promotion criteria Exposure to philosophies of other pre-service programs serving same grades

Table 5. Summary of Benefits to Each Group of Collaborators

Materials

This collaboration resulted in the production of 65 integrated STEM units for grades kindergarten through three. By grade level, this amounted to 14-18 units, in electronic and hardcopy formats, for each of the four elementary teachers. In addition to materials that were specific to the project requirements of each department, each unit addressed a science standard that had been identified as challenging by the elementary teachers and included at least two hands-on learning activities (one of which was field tested during the microteaching), materials lists, activity directions, assessments, and reference lists. The materials were shared with the elementary teachers and among the pre-service teachers. The collaboration also led to revised teaching materials and projects for STEM courses in pre-service teacher programs; the professors made changes to their course materials and the progression of the collaboration based on feedback from the elementary pre-service teachers.

Experiences and Opportunities

The experiences working with elementary teachers and elementary students were valuable for the pre-service teachers. Anecdotal evidence from written pre-service teacher feedback indicated that some pre-service teachers learned that their hands-on activities were not as engaging as they had imagined, while others learned that they had underestimated the capabilities of elementary students. The microteaching component was also valuable for the elementary teachers, because they were able to see all of the projects that had been created to address their standards carried out consecutively, which is a more engaging and time-saving experience than only receiving a packet of printed unit plans that they would need to visualize, prepare, test, and adapt on their own. One teacher noted, "I liked the cloud in a jar activity for the water cycle and the severe weather marshmallow activity. I'd known about that standard, but hadn't thought to try a hands on activity like that."

As stated in Table 5, a benefit to the professors was that the Early Childhood Education (ECE) and Elementary Education programs were able to bridge a departmental and programmatic divide that is rarely breached. Indeed, university faculty from the early childhood department reported learning about approaches in elementary education, such as the claims, evidence, reasoning approach (Zembal-Saul, McNeill, & Hershberger, 2013), and the faculty intend to integrate this approach in future classes. In addition, the elementary professors learned that pre-service teachers in the early childhood program used more hands-on approaches to learning and more frequently integrated subjects. There was also crossover learning for the professors in other disciplines. For example, the mathematics professor in elementary education learned new theories and approaches to teaching science, while the science professor was exposed to new strategies for teaching mathematics.

Both groups of pre-service teachers also learned from one another. The ECE pre-service teachers appeared more comfortable with planning and implementing hands-on materials and activities during the culminating teaching experience, while some of the elementary school pre-service teachers were surprised by the less-than-ideal level of engagement of the children with lessons that were focused heavily on paper-and-pencil activities. The elementary group used more written documentation in their teaching experiences than did the ECE group, and the ECE pre-service teachers noticed this and discussed including more documentation in future work with elementary students. Both groups took away something valuable from this experience of working side-by-side with peers from another program.

Sharing the projects with the elementary teachers of the laboratory school was a requirement of the project; however, there were several other opportunities for pre-service teachers to share their projects with a broader audience. All of the pre-service teachers were invited to share their projects with classmates and others through the university website. With their permission, pre-service teachers' projects were organized by grade level and standard and posted online for others to download. Additionally, 10 pre-service teachers were invited to co-present their projects at education conferences. As a result, three pre-service teachers presented at a regional conference, and one pre-service teacher presented at a state conference. Two of our pre-service teachers were co-authors on manuscripts, based on their projects, that were published in practitioner journals (Lange, Lodien, & Lowe, 2019; Robertson, Dunlap, Nivens, & Barnett, 2019).

Discussion

The intent of this project was to address the challenges of implementing integrated STEM in elementary education through an innovative collaboration between pre-service teachers, elementary teachers, and education professors. As a result, we created new materials and provided all parties with opportunities to increase knowledge and experiences with integrated STEM in elementary education. When we started, the specific details of the Integrated STEM Collaboration (Figure 1) were not fully developed, but upon its completion, we identified five key components of our approach that were essential to its success (Figure 2). Accordingly, the key components align most closely with the implementation features of the Descriptive Framework for Integrated STEM Education (NRC, 2014). We theorize that the key features of our collaboration led to impacts on the attitudes, beliefs, self-efficacy, knowledge, and practice of the three groups of collaborators, and we plan to formally investigate these impacts in the future.

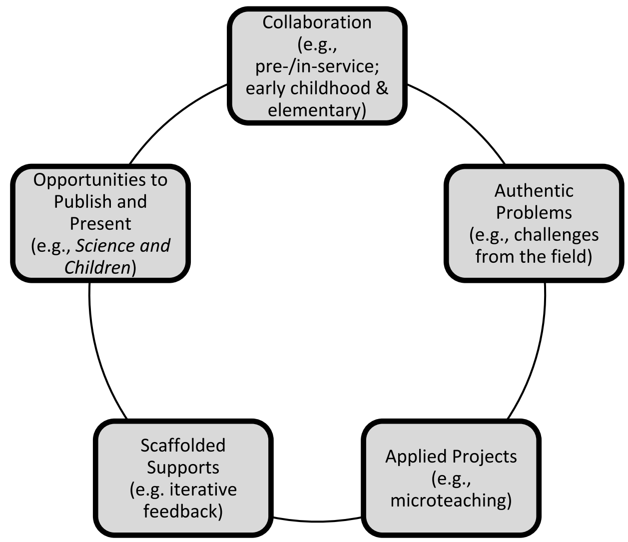

Figure 2. Key features of the Integrated STEM Collaboration

The first key feature of our project was collaboration among different types of STEM educators. The NRC describes this as adjustments to the learning environment (2014). The challenges of planning and implementing integrated learning activities have been documented (Paolucci & Wessels, 2017; Shernoff, Sinha, Bressler, & Ginsburg, 2017; Stohlmann, Moore, & Roehrig, 2012) and with new standards being adopted in our state, teachers were under more pressure to develop new learning activities. Each group of collaborators in the project made specific contributions to the project. Similar to the PIC Math collaboration, elementary teachers that served as our "industry" partners in the present project identified challenging standards from the newly adopted state science standards, and the pre-service teachers were tasked with finding sound and previously unknown approaches to teaching the standards in an integrated way. The pre-service teachers provided time to the collaboration addressing one of the primary barriers cited by teachers and administrators to the implementation of integrated STEM (Shernoff, Sinha, Bressler, & Ginsburg, 2017). Opportunities for the collaborators to interact during the project expanded their understanding of educational philosophies and practices. For example, File and Guillo (2002) found that pre-service teachers in ECE programs tended to report beliefs that were more in line with the National Association for the Education of Young Children's (NAEYC) guidelines, which are heavily constructivist, than did the elementary education pre-service teachers.

Using the concept of microteaching (Cinici, 2016; He & Yan, 2011), pre-service teachers applied their learning and were able to make gains in their own CK, as evidenced from their self-reported feedback at the end of the semester. While Donna and Hick (2017) showed CK gains among pre-service teachers while in their field placements, our project provided opportunities for pre-service teachers to gain knowledge by bringing elementary students to the university classroom. As an anecdotal example, our pre-service teachers expressed confusion about "pictographs" (a 2nd grade common core mathematics standard) and "scaled-pictographs" (a 3rd grade common core mathematics standard). Such nuances in standards become much more evident when pre-service teachers have to apply and teach activities they envision to be aligned with the standards. Although this was an effective technique for many pre-service teachers, we also found evidence that not all of them learned the underlying content, mirroring findings by others that it is critical that STEM instruction include information about the generic or abstract concept in addition to the more perceptually-rich version (NRC, 2014).

There were multiple scaffolds provided to help pre-service teachers succeed with the challenges of designing and teaching integrated STEM. Throughout the semester, pre-service teachers had opportunities to receive and respond to feedback from their professors, peers, and elementary teachers. Likewise, instructional design, a key factor that contributes to implementation of integrated STEM (NRC, 2014) was scaffolded in the structure and required components of the projects. Best practices such as the 5E learning cycle (Bybee, 2015) were modeled for pre-service teachers in class sessions to address common mistakes in integrated instruction such as only connecting concepts in a superficial way (Heimer & Winokur, 2015). In the case of the pre-service teachers, the entire experience of planning and teaching integrated STEM in their preparation is a form of educator support, and it may result in an openness to integrated STEM once they are in their own classrooms.

This collaboration resulted in pre-service teacher presentations at state and regional conferences and publications in practitioner journals. Prior to this project, opportunities for pre-service teachers to publish or present were extremely limited. Professionalization of the teaching workforce is lacking, especially in early childhood education (Boyd, 2013). As participants engage in aspects of the profession, the engagement has long-ranging effects. These opportunities may increase the self-efficacy of the pre-service teachers and how they see their role as professionals (Pajares, 1992; Greenfield et al. 2009), and may make them stronger job candidates. Future work will formally evaluate the extent to which our approach led to changes for pre-service teachers in knowledge, PCK, attitudes, beliefs, self-efficacy, and teaching practice.

Conclusion

Limitations

The limitations of this project include the setting of the collaboration and the lack of formal data collection. The project was conducted with a small number of elementary classrooms at a K-12 laboratory school located on the campus of a university. The elementary teachers and professors had existing relationships and levels of professional trust prior to the start of the collaboration. Furthermore, the elementary teachers at the laboratory school have greater autonomy over their curriculum and schedules than typical elementary teachers. Additionally, this project was implemented with data collection limited to informal interviews and anecdotal records. Future work will formally measure the extent to which the described project can impact collaborators. We will also consider how a collaboration such as ours might function in other settings or educational contexts.

Implications and Next Steps

Due to the challenges of integrated STEM, collaborations between elementary teachers and higher education offer a path toward large-scale problem solving. In the course of this collaboration, all groups benefited from the contributions of others because of a focus on authentic problems. For maximum impact, collaborations should be structured in such a way as to strengthen relationships and trust while efficiently managing resources, especially time. It is our belief that this model could be adapted for any context that a teacher or set of teachers faces. For example, this model could extend to other areas within education, such as literacy, or outside of education, such as psychology. Potentially, participation in these types of opportunities for collaboration could be extended to professional development for in-service educators.

The next steps for this program include designing and carrying out a research study that quantitatively evaluates the effects of this intervention. We will evaluate immediate impacts on collaborators, such as changes in pre-service teacher attitudes towards teaching science, as well as longer-term outcomes, such as continued use of the lesson plans developed by the pre-service teachers in the mentor-teacher classrooms in subsequent years. In the future, it would be beneficial to explore the collaboration in more inclusive school settings, including schools that are racially and ethnically diverse and schools with challenging socio-economic demographics. The age range of the student participants could be extended, as well, for example by including pre-school classes, and the scope of the concepts addressed could be extended by allowing university staff to come up with additional lesson topics. Other ideas for further development of this type of collaboration include: the addition of book club style discussions of readings based on STEM content or teaching and learning theories, encouraging or requiring additional use of shared materials, and having pre-service teachers conduct a second or third iteration of their teaching activity after allowing them additional time to revise their microteaching lesson following the initial field test.

In closing, we are encouraged by the early rollout of this innovative, collaborative endeavor. All groups of contributors reported benefitting from the collaborative experience, and observations indicated that the elementary students benefited from the microteaching experience. We have plans to further develop this model in the coming years, because we strongly believe that this style of multi-level collaboration has the potential to influence large-scale change in the way that pre-service teacher programs function and in the ways that STEM standards are taught in early childhood and elementary classrooms.

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Author's Biographies

Laura Robertson is an Assistant Professor of Science Education at East Tennessee State University. She teaches science content and methods courses for pre-service teachers, leads professional development workshops, and is the program coordinator for the STEM K-12 Education Certificate. Her research interests include teacher autonomy, professional learning communities, and the integration of science and English Language Arts. Prior to her current position, Laura was a middle school science teacher for 11 years. Robertson holds a B.S. of Biology and M.S. of Elementary Education from the University of Tennessee, Knoxville and a Ph.D. of Science Education from North Carolina State University.

Ryan A. Nivens is an Associate Professor of Mathematics Education and is extensively involved in undergraduate and graduate STEM education. He is the coordinator of secondary education at East Tennessee State University and an instructor in Eastman Chemical Company's Scholar MathElites Program. He has served as president of two mathematics education organizations and has published several articles on innovative ways to teach mathematics. He edits the award winning *UETCTM Newsletter* where he shares the writings of northeast Tennessee mathematics teachers. He started his career as a secondary mathematics teacher in Missouri and holds a B.S. in Mathematics from Evangel College, an M.Ed in Secondary Education from Drury University, and a Ph.D in Mathematics Education from the University of Missouri – Columbia.

Alissa A. Lange is an Associate Professor of Early Childhood Education and Director of the Early Childhood STEM Lab at East Tennessee State University. Her work focuses on early science, technology, engineering, and math (STEM) professional development for preschool educators and innovative approaches to enhancing the quality of pre-service teacher preparation in early childhood STEM from Pre-K through 3rd grade. Prior to joining ETSU, Dr. Lange worked at the National Institute for Early Education Research (NIEER) at Rutgers University. She was also a U.S. Fulbright Scholar in Bogotá, Colombia, and a U.S. Department of Education, Institute of Educational Sciences Postdoctoral Fellow. She has led or co-led grant-funded studies of early childhood STEM teaching and learning amounting to over $2.8 million, and she has presented and published extensively on the topic. . She received her Ph.D. in Psychology from Queen's University Belfast.