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Preservice teachers' experiences of STEM integration: challenges and implications for integrated STEM teacher preparation

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Abstract
In the United States, recent STEM education reform initiatives call for teaching STEM subjects through integration of multiple related subjects. In response to this call, an integrated STEM education methods course was developed for secondary preservice teachers in STEM disciplines. At the conclusion of the course, qualitative data (e.g., interviews, student artifacts) were collected to examine the methods course students' practices and experiences of STEM integration. Teachers' learning was approached from situated perspectives that shed light on contexts in which teaching practices are situated and funds of knowledge that individual teachers bring to bear to their teaching contexts. While the students successfully developed STEM integration lessons and taught them, they faced challenges attributable to current school practices, limited interdisciplinary understandings, and a lack of role models. Acknowledging the numerous constraints in the current educational system and structure, several ways were suggested to mitigate the challenges and build on the strengths that preservice teachers established.

Keywords STEM integration · Interdisciplinary technology education · K-12 education · Teacher Education

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Introduction

Recent STEM (Science, Technology, Engineering, and Mathematics) education reform initiatives in the United States call for integrated STEM education approaches in which students learn how to solve problems by connecting content and practices of various STEM fields (e.g., International Technology Education Association 2007; NGSS Lead States 2013; The National Council for Agricultural Education 2015). To accomplish this vision successfully, it is critical to prepare preservice STEM teachers for teaching STEM-subjects through integrated approaches (Honey et al. 2014). While there are some exceptions (e.g., Adams et al. 2014; Berlin and White 2012; Koirala and Bowman 2003; O’Brien 2010), secondary preservice teachers in STEM-related subjects are typically taught in teaching methods courses that are content-specific and do not attempt to integrated multiple STEM subects (e.g., Ball and Knobloch 2005). Teacher educators face the need to design and provide teacher education programs that prepare teacher candidates to be able to adopt this changing context of STEM education and teach STEM through integrated approaches (Corlu et al. 2014; Stubbs and Myers 2016).

In this backdrop, a secondary teaching methods course for integrated STEM education was designed and taught to students enrolled in science, technology and engineering, and agricultural education programs. Reflective teacher educators and researchers (Cochran-Smith 2003) strive to understand the effectiveness of the teacher education course and draw implications for their own teaching and other educators who share similar interests. To that end, the purpose of this study was to describe how STEM teacher education students enrolled in our integrated STEM teaching methods course experienced teaching STEM in an integrated way. Three research questions guided the study: (1) What strategies did the students in the methods course employ to develop integrated STEM lessons? (2) What funds of knowledge did they draw on and in what ways did the funds of knowledge shape the practice of developing integrated STEM lessons? (3) What were challenges that they faced in developing and implementing integrated STEM lessons?

In the following section, a review of the current literature on integrated STEM education and teacher education is discussed. Then, a theoretical framework is outlined that draws on situative perspectives (Putnam and Borko 2000) and funds of knowledge (Hedges 2012; Moll et al. 1992). Using this theoretical framework, the authors examined the contexts in which the teacher education program was situated, identified strengths that education students brought into the contexts, and proposed ways in which teacher education programs might mitigate current challenges and capitalize on the teacher candidates’ strengths.

Literature review

Integrated STEM education

Over the past decade, STEM integration has received an increasing attention, and growing numbers of teachers and teacher educators have focused on characterizing integrated STEM education. Multiple definitions and approaches of integrated STEM education have been proposed with respect to which traditional subject areas are integrated and to what degree the boundaries are blurred (e.g., Bybee 2013; Honey et al. 2014; Sanders 2009). Different subject areas are integrated (e.g., science and mathematics, mathematics and agriculture, and science and engineering), and the *integration* is used to refer to, for instance, connected, interdisciplinary, multidisciplinary, or transdisciplinary approaches. Recognizing the multiplicity of view in the field, integrated STEM education was conceptualized using a comprehensive definition suggested by Wang et al.'s (2011), as explicit and intentional blendings of science, technology, engineering, mathematics, and agriculture into a learning experience in order to deepen student understanding of each discipline, situate learning in socially and culturally relevant contexts, and increase interests in STEM careers.

Agriculture was purposefully included with the four subjects that STEM acronym typically represents; there were several reasons agriculture was included into STEM integration efforts. Most importantly, "agriculture is intertwined with other disciplines in the natural and social sciences" (National Research Council 2009, p. 4). Thus, agriculture provides a platform for integrating multiple STEM-disciplines (Stubbs and Myers 2016) because abstract ideas of science and mathematics are applied in agricultural contexts (Smith et al. 2015). Furthermore, agriculture can facilitate integrated learning experiences in solving intertwined grand challenges such as climate change, biodiversity, and food security, which depend on and transcend the stand alone disciplines of science and others (Barnosky et al. 2016). Because agriculture grows food, fiber and renewable energy to meet human needs, it provides highly contextualized and complex problems that can help students analyze problems and solutions using a variety of considerations (Agunga et al. 2005) such as social, economic, ecological, political, scientific, technological, and risk factors (Ozturk and Yilmaz-Tuzun 2017), and facilitate transdisciplinary learning and systems thinking (Francis et al. 2011; Schneider and Rist 2014; Scott et al. 2015).

Finally, the authors and present study are situated in a land-grant university. A land-grant university is an institution of higher education that was established in the U.S. through federal legislation and funds to provide citizens of the working class a liberal and practical education (Association of Public and Land-grant Universities [APLU] 2012). The original land-grant university curriculum consisted of agriculture, military tactics, mechanical arts, and classical studies. Today, land-grant universities provide comprehensive curricula and are well-established public universities that focus on fulfilling "their democratic mandate for openness, accessibility, and service to people" (APLU 2012, p. 1). Committed to the roles of land-grant institutions (National Research Council 2009) and Boyer's (1990) scholarly pursuits of discovery, integration, application and teaching, agricultural education leads the efforts to cultivate new approaches to interdisciplinary learning by providing students with learning experiences that connect them to solving real-world challenges.

Educators have attempted to make connections between subject areas since early 1990s (Drake and Burns 2004). In these integrated approaches, students are encouraged to bring knowledge from several disciplines together around a central theme, and in doing so, they learn content of individual subject areas and interdisciplinary skills, such as literacy, critical thinking skills, and numeracy. Students are also encouraged to metacognitively assess the strengths and limitations of different perspectives offered by each discipline to solve complex problems (Hargreaves and Moore 2000; Ivanitskaya et al. 2002). More recently, the idea of integration has further expanded among STEM educators. Scholars argue that STEM education should transcend disciplinary boundaries in order to advance students' STEM literacy, twenty-first century skills, and capability to understand and address STEM-related global issues (Bybee 2013; Honey et al. 2014). A curricular approach that integrates STEM learning provides students with opportunities to engage in real-world problems while learning STEM disciplinary ideas and practices, rather than to learn abstract and fragmented bits and pieces of knowledge and then have to assimilate them at a later time.

Several research studies demonstrated benefits of integrated approaches in achieving several critical goals of STEM education (Honey et al. 2014). Integrated STEM teaching approaches improved science content knowledge (Becker and Park 2011), sophisticated scientific understandings (Fortus et al. 2004), and higher-order (i.e., schematic and strategic) thinking skills (Wells 2016). These approaches also benefited historically underserved students more than students from a White middle class (Mehalik et al. 2008). Despite these promises, Honey et al. (2014) showed inconsistency among reports about students' performances in integrated STEM courses and called for a caution that strong evidence has not been documented to support effectiveness of integrated STEM education in students' achievement.

One factor to explain this discrepancy may be teacher preparedness. For successful integrated STEM education, preparation of quality teacher candidates is critical (Stohlmann et al. 2012). Honey et al. (2014) identified teachers' content knowledge and pedagogical content knowledge, self-efficacy in STEM disciplines, and collaboration among educators as key components of successful STEM integration and argued that the lack thereof is a current challenge. Indeed, surveys conducted in 2012 showed relatively low levels of STEM content knowledge of STEM teachers (Banilower et al. 2013). Only 52 percent of high school mathematics teachers and 61 percent of high school science teachers have majored in the subject areas that they teach. Middle and elementary teachers have taken an even smaller number of science courses and a smaller number has majored in STEM disciplines. These data indicate weak content preparation for teaching science, mathematics, and engineering in general, let alone integration. In addition, only 14 percent of high school science teachers and 6 percent of middle school science teachers have taken one or more engineering courses. Considering that teaching self-efficacy is highly intertwined with their content knowledge and positive experiences (e.g., Leader-Janssen and Rankin-Ericksons 2013; Swackhamer et al. 2009; Woolfolk Hoy and Spero 2005), it is not surprising that teachers are often fearful about teaching engineering design to their students (Cunningham 2009).

Several studies have been designed to support inservice teachers for STEM integration. These studies designed and implemented intensive summer and/or year-long professional development programs for improving integrated STEM education. Nadelson et al. (2012) invited inservice teachers of Grades 4 through 9 to four-day long summer residential institute composed of lectures and exploration of selected themes (e.g., energy, space, and human body) that provide potential for STEM integration. The findings suggested an increase in teachers' comfort with integrated STEM teaching, STEM knowledge, and peer collaboration. Roehrig et al. (2012) conducted a year-long professional development program for inservice teachers. In their program, teachers participated in 5 days of summer professional development, and joined professional learning community sessions and implemented an integrated STEM unit throughout the school year. Teachers in this study reported increased beliefs about benefits of STEM integration as they experienced natural connections between disciplines and observed students' enhanced engagement in integrated STEM activities.

Other studies sought to design innovative preservice teacher education programs and courses to prepare teachers for integrated STEM teaching. Examples include math-science integrated teaching methods courses for middle school preservice teachers (Koirala and Bowman 2003) and integrated MSAT (Mathematics, Science, and Technology) education program for Grade 7–12 mathematics, science, and technology preservice teachers (Berlin and White 2012). In elementary teacher preparation programs, efforts have been made to provide preservice elementary teachers with content learning experiences that integrate STEM disciplines (Adams et al. 2014; O'Brien 2010). Educators of these programs argued that this learning experience would help preservice teachers learn STEM contents *and* prepare them to teach STEM in an integrated manner.

These studies provide insights into what are key elements for successful STEM integration teacher preparation programs, which include content knowledge across all STEM disciplines, experiences of STEM integration as a learner, collaboration among teachers or teacher candidates within and across content areas, and collaboration among faculty instructors across content areas. While programs incorporating these elements demonstrate a certain level of success, they also reported challenges. For instance, teachers from different content areas demonstrated different perspectives on what should be the key learning practice for STEM integration and faced different degrees of pressure to meet content standards (Roehrig et al. 2012; Stubbs and Myers 2016). In addition, tensions arose when preservice teachers noted an inconsistency between use of concepts/ideas in two different disciplines (e.g., variable in mathematics vs. science) or specific ideas that are important in one discipline and are not relevant another other discipline (e.g., integers; Koirala and Bowman 2003). In addition, despite their strong beliefs about STEM integration, preservice teachers reported an increased feeling of difficulty in implementing STEM integration units after completion of a teacher preparation program (Berlin and White 2012).

Preservice teachers' learning experiences from a situative perspectives

To address and negotiate these challenges in teacher education for STEM integration, the authors were theoretically informed by a *situative perspective* on teacher learning (Putnam and Borko 2000) and teachers' *funds of knowledge* (Hedges 2012). These frameworks were chosen to consider strengths and resources that teacher candidates bring to teacher education programs while taking into consideration unique challenges that they face. A better understanding of strengths, resources, and challenges could provide insight into what can be done within a given context to improve current practices of preparing teachers to facilitate integrated STEM learning.

Putnam and Borko's review (2000) showed how preservice teacher education program and inservice teacher professional development programs have been influenced by recent advancement in cognitive sciences that focuses on social and situated nature of learning and cognition. In this perspective, knowing and learning how to teach is not individual teachers' acquisition and implementation of strategies, skills, and curricula that are known to be successful. Rather, learning to teach is situated in contexts in which the act of teaching occurs (Greeno and Middle School Mathematics Through Applications Project Group 1998), achieved through participation in practice and discourse of a community of teachers (Lave and Wenger 1991), and distributed across and mediated by individuals, time, and tools (Hutchins 1995). This perspective has been applied to preservice teacher education programs, by combining university-based course work and classroom experiences, engaging preservice teachers in discourse communities of teachers (e.g., mini discourse community between preservice teachers and cooperating teachers), and active use of various tools to transform teachers' work and support their learning.

Along the same line, it has been argued that learning should be perceived as occurring in and shaped by contexts of individual learners' living that go beyond school and classroom

(Moll et al. 1992). Teachers then should actively identify and engage learners' funds of knowledge that are constructed in their daily lives as valuable assets for further learning rather than obstacles to learning. While this notion has primarily focused on students, particularly underserved and underrepresented students, several scholars expanded this construct to apply to teachers' learning and professional development. Teachers and teacher candidates develop their funds of knowledge from personal and family experiences, childhood experiences, experiences as a learner and a teacher, and interactions with local communities (Andrews et al. 2005; Gupta 2006; Hedges 2012). Funds of knowledge play an important role in sense-making of educational theories and shape moment-to-moment curricular and pedagogical decisions. This perspective encourages teacher educators to perceive inservice and preservice teachers' "intuitive, subjective and experience-based knowledge" (Hedges 2012, p. 9) not as barriers to good teaching, but as key elements in understanding teachers' decision-making and engaging them in new pedagogical practices and reflection about their practices.

These two frameworks share a core assumption that learning and development of preservice teachers is mediated by multiple social actors, environments, and experiences that they bring to the learning setting (Hammersley 2005). Teacher educators should consider in what contexts preservice teachers' knowledge and learning is situated (Putnam and Borko 2000) and what funds of knowledge preservice teachers use to make sense of pedagogical practices introduced to them in educational courses (Hedges 2012). Inspired by these premises, the purpose of the study was to describe preservice teachers' practices of pedagogical decision-makings and how contexts and funds of knowledge shape their decision-making throughout the process of lesson planning, teaching, and reflecting. This approach was chosen to move beyond evaluating preservice teachers' performance with research-based standards that are stripped from specific contexts of their teaching and learning and gain insights into resources that preservice teachers and teacher educators can utilize within the complex contexts in which integrated STEM education programs are situated.

Research design and methods

An integrated STEM teaching methods course at a large land-grant university served as the research site of the study. Data were collected through student-generated artifacts and semi-structured interviews of students enrolled in the course. The authors utilized principles and techniques of grounded theory (Miles and Huberman 1994), such as open coding, axial coding, graphing, and tabulation. Grounded theory was chosen as the methodological approach because the researchers hoped to describe preservice teachers' approaches to integrated STEM education while minimizing reduction of the meaning of data. The study began with an overarching question as to how students enrolled in an integrated STEM methods course experienced teaching STEM in an integrated way; yet, specific research questions and coding scheme emerged "clearly only gradually" (p. 17, ibid) as the authors delved into data collection and analysis. As stated earlier, we examined strategies students in the methods course employed in developing integrated STEM lessons, the funds of knowledge they brought to the STEM lesson development, and the challenges experienced. In the following section, research contexts, data collection, and analysis methods are explained in greater depth.

Research contexts and participants

The integrated STEM teaching methods course was a 3-credit, semester-long course designed for undergraduate and graduate students who seek to attain teaching certificate in science, mathematics, technology and engineering, or agriculture. The second and third authors in two different disciplines (technology and engineering education and agricultural education) co-taught the course. The first author (science education) participated in the course as an participant observer who voluntarily joined the course, participated in course discussions, and provided resources for science instruction with a minimal role in the instruction. Students were engaged in learning and practicing: (1) foundational learning theories (Bransford et al. 2000); (2) reform-oriented discipline-general pedagogical approaches, in particular learner-centered teaching (Weimer 2002), problem-based learning (Hmelo-Silver 2004), and backward design lesson planning (Wiggins and McTighe 2005); and, (3) discipline-specific instructional approaches (e.g., mathematical modeling, scientific inquiry, engineering/technology design). Field experience was another component, which helped students in the course observe inservice teachers and younger students in school-based contexts. Observations helped students in the course consider ways in which they would practice as a teacher, and have opportunities to practice lessons in an authentic teaching setting (Hancock and Gallard 2004).

Throughout the semester, students were guided gradually to integrate multiple STEM subjects through lesson plan development and micro-teaching practices (Remesh 2013). They developed and taught a series of three lessons in front of the peers and instructors that increasingly more integrate multiple STEM subjects. After each teaching practice, students submitted a reflection paper that addressed general questions (e.g., "Did the students learn what you wanted them to learn?" "Were the teaching methods, learning, activities, and materials/resources effective?") and questions specific to integrated STEM teaching, such as "How was this lesson different from the previous lesson with respect to types and extent of integration?" Concurrently, students visited and observed a classroom in a partnership school that served Grades 7–12. Toward the end of the semester, based on the three micro-teaching practices in class, students delivered an integrated STEM lesson at the partner school and submitted a reflection paper. Finally, students wrote a paper as their final assignment. Undergraduate students defined integrated STEM education and discussed how it could be implemented in a secondary school setting, and graduate students outlined a conceptual framework of integrated STEM teaching and learning that was supported by literature.

Participants of the study were six students enrolled in the course (Table 1). Although the course was designed for teacher preparation, two Ph.D. students (S2 and S3) did not plan to teach K-12 students upon completion of the degree. They opted to take the course because of their research interests and prepare for future teaching in higher education settings.

Data collection and analysis

Data sources were 1-h long semi-structured interviews that the first author conducted with the six participants and artifacts that they generated to complete the course (e.g., lesson plans, reflection papers, final paper). After completion of the course, the first author invited all student participants to an interview and individually interviewed them. Interview questions were designed to inquire about the procedure of integrated STEM lesson

Table 1 Participants of the study

	Degree program and purpose	Career goal
S1	M.S. Teaching certificate in Technology and Engineering Education	Teaching high school technology and engineering
S2	Ph.D. in Youth Development and Agriculture Education	Teaching to prepare science teachers in university
S3	Ph.D. in Science Education	Teaching undergraduate physics course
S4	M.S. in Youth Development and Agriculture Education	Teaching in informal settings
S5	B.S. Teaching certificate in Technology and Engineering Education	Teaching high school technology and engineering
S6	B.S. Teaching certificate in Technology and Engineering Education	Teaching high school technology and engineering

development and challenges the participants faced in the planning and teaching of the lesson at the partnership school. Example questions included: "How did you end up with your lesson topic?" "What are a few moments that you vividly remember in teaching your integrated STEM lesson?" "Can you describe what an ideal or perfect integrated STEM lesson/unit looks like?" All interviews were audio-recorded.

After the interviews, audio recordings were transcribed verbatim. Then, three authors of this paper individually conducted open coding which included reading the transcripts multiple times while listening to the audio recordings and identifying emerging themes with respect to the overarching question—how students in an integrated STEM education methods course experienced teaching STEM subjects in an integrated way. As specific research questions came to be clearer, the researchers' sense-making also came to be more focused around the three research questions (Miles and Huberman 1994). The authors first generated categories that corresponded to each research question (i.e., strategies, funds of knowledge, and challenges) and individual codes in each category. Examples of codes identified in this stage included "Challenges: Limited experiences in integrated STEM" and "Challenges: Finding possible connections between disciplines." After this initial coding was completed, the authors conducted axial coding to identify upper level codes, for instance, "Challenges: Absence of role models." While analyzing the interview data, the authors also read student-generated artifacts. The participants' artifacts provided critical insights into what the participants may have meant in the interviews. This allowed the researchers to triangulate and validate their sense-making of the interview data (Miles and Huberman 1994).

The data analysis process was iterative and dialogic (Miles and Huberman 1994). The three authors met regularly during the data analysis phase for peer-debriefing and extensive discussions of the themes that each author noticed individually in the interview data. After meeting four times (2 h per meeting), we worked through the sense-making process of the data and reached consensus of the data analysis process and findings. Based on discussion in each meeting, we generated a working coding scheme, coded the data using the coding schemes, and reorganized and revised the emergent coding schemes. Through this process, we revisited our sense-making of the data and codes to negotiate meanings.

Findings

Research Question 1: Strategies for developing integrated STEM lessons

The participants demonstrated a variety of approaches in designing their lesson plans that included selection of curricular topics for STEM integration and developing engineering design tasks and other instructional materials. Participants drew upon resources and ideas from their own experiences, classroom observations, and the Internet. Below, participants' unique and common strategies that were employed in developing integrated STEM lessons are briefly described.

The three technology education students chose a roller coaster and car as objects for their integrated STEM lessons. S1 and S6 first chose a roller coaster activity as their engineering design task and then developed their lessons around the selected design task. S1 and S6 remembered making a roller coaster in high school and recalled it was fun, and thus decided to develop a lesson around this particular activity. While they both chose the roller coaster as the main design task of their lesson, content foci of the lessons differed. Student 1 connected it to ideas around user-centered design whereas S6 developed it into projectile motion. Furthermore, S5 chose to do a lesson related to a car because he was interested in cars and thought many teenagers would be interested in cars as well. After choosing cars as main topic area, S5 explored various ideas that could be discussed in car designs and narrowed down to friction and tire design.

The other three students in agriculture (S2 and S4) and life sciences (S3) took somewhat different approaches. They first carefully reviewed the curriculum and curricular topics covered in the class that they had observed prior to the teaching practice. Based on the review, they chose topics that were more directly related to the curriculum of the class. For instance, S3 found a potential opportunity for expanding students' experiences of scientific experiments during his observation of his cooperating teacher. A question from a student as to how to figure out the length of DNA in the class triggered S3 to recall a lab activity extracting DNA from strawberries. With the DNA extraction at the center, he built his lesson about genetic engineering and social ethical issues related to genetic engineering. Next, S4 reviewed curricular topics to be taught during her teaching at the partnership school and chose the topic that would fit in the existing course plan. She also considered her own interests, comfort level for teaching, and topics that could easily integrate an engineering design. Then, she decided to engage her students in designing a garden landscape for their school. Finally, S2 made a substantial amount of effort to find out contexts that might be relevant to her students' lives with a hope to stimulate their interest and curiosity. She investigated the local community, such as geographic location of the community of which her students are part and issues faced by the local community. After identifying the problem that she wanted to address in her lesson (i.e., a decrease of bass population in a local lake and its environmental and economic impacts), she conducted an online literature research to design the storyline of her lesson.

Importantly, most students employed an extensive Internet search, but with various purposes in mind. They used the Internet to identify useful hands-on science experiments and/or design challenges (S1, S3, S6), existing integrated STEM lesson plans (S3), scholarly research relevant to the selected lesson topics (S2), and contexts that may intrigue their students (S2, S5). Specifically, S2 read local newspaper articles to identify "controversial issues" the local community faced, and S5 searched for stories to situate his automobile tire friction problem that might be interesting to teenage students. S3 and S5 searched for potentially interesting episodes from popular culture and movie to introduce the problem in which their students would engage.

The participants' entry points to the development of integrated STEM lesson varied (e.g., their own experiences, interests, curriculum, and local contexts). However, through extensive research, in particular that occurred online, they strived to incorporate various aspects of STEM integration that they believed to be critical to adolescents, such as hands-on activities, relevant contexts, and real-world stories that would be of interest to youth. This implies that the participants understood and applied their understanding about the situatedness of learning and importance of learning contexts. In addition, as evidenced in that S1 and S6 developed different lessons starting from the same engineering design activity (designing a roller coaster), the participants considered content standards and deliberately tried to identify aspects relevant to content standards in the selected hands-on activity. S2 took into consideration the existing curriculum, local contexts, and science research to converge various demands that are pulling toward several different directions, such as state-mandated content standards, relevance to and interests of young students, and authenticity to the expert science communities. The participants were aware of the complexity in designing integrated STEM lessons and employed strategies to incorporate various facets of STEM integration.

Research Question 2: Funds of knowledge for developing integrated STEM lessons

Participants in this study drew upon various kinds of funds of knowledge in designing their lessons, such as their experiences as a student, personal interests, and disciplinary identities. As mentioned earlier, S1 and S6 did the roller coaster activity as a high school student. They remembered the activity was fun but did not know what science or engineering content they learned from the activity. As a preservice teacher, they recognized opportunities to turn it into a more meaningful learning experience for their students, as opposed to a fun craft or hands-on activity. S4 and S5 explicitly mentioned that they chose their lesson topic partly based on their own interests. S5 was interested in cars and S4 wanted to become an educator in zoo or public garden settings. Car industry and gardening served as contexts in which the engineering design was situated in S5 and S4's lessons, respectively.

Among identified funds of knowledge, it is notable how the participants' disciplinary identities influenced their views on the relationship between STEM disciplines, and in turn, shaped how they organized subject areas to integrate them as they connected to their home disciplines. In all participants' lesson planning, their own discipline was centerpiece in framing the lesson. The participants added other subject areas by identifying how other subjects were related to their subjects. Not just in developing a lesson, but they indeed believed a central role of their respective discipline in STEM integration—a disciplinary way of knowing. For instance, S4, majoring in agricultural education, believed that agriculture plays a key role in STEM integration:

> You put all the knowledge that you learn from different fields to make sure you get the products that you want um to help survive the process of transportation. You can enjoy eating a fresh product… So for me that's the beauty of agriculture. Agriculture gives you opportunity to integrate many disciplines. (S4)

To S4, agriculture by its disciplinary nature draws on knowledge in various other disciplines such as science, technology, and business, and provides good contexts to learn other disciplines.

S3, in science education, tried to identify opportunities for scientific inquiry, which he defined as "manipulate the variables and see how things are gonna change and make predictions." Starting from scientific inquiry, he added other subject areas, engineering and math, to the lesson:

> Then making it a sci[science]- er now I want it to be an inquiry activity. DNA extraction the, the steps that you can just find online are the steps that work. Ahm, if you are trying to think of this as a way for students to be able to play around with variables and what not. (S3)

Therefore, "The science is being the topics, the content knowledge of that science is the base and then we're using technology and math to look at that." To S3, STEM integration is part of science:

> To me that's all part of my science project. Yes I use the engineering and the math. … To me that's all I was doing a science, it's still, [I] have a hard time separating. (S3)

S3 believed that doing science requires mathematical knowledge and technology by nature. To S3, integrated STEM was not new, but is part of doing science in a broader sense. In K-12 schools as well, scientific inquiry can easily integrate other disciplines because good scientific investigation needs mathematics and technology.

On the other hand, technology and engineering education students perceived technology as an "anchor" discipline that can bring all disciplines to enable technological endeavors. For instance, S6 and S5 said,

> Technology is never going to be just using one tool to do a specific project. It is a process and if you're actually wanting to design something specific you're going to want to bring in the calculations. The physics and the math in it as well. So when you move to an integrated STEM approach. Technology can definitely be a good anchor for that, for incorporating the other fields. (S6)
>
> If you don't know the laws of physics and you create a product like a car, it's not going to work properly because you have not taken into account the laws of physics. If you make the car too heavy and don't give it enough power, you can't overcome inertia, and therefore physics, if you would have known that, used your physics content you could have designed something appropriate. (S5)

For S6 and S5, a technology and engineering task serves as an end goal and provides a reason and rationale for learning science and mathematics. In the process of designing a better solution for a technology and engineering problem, K-12 students could learn science and mathematics.

As shown in several examples above, students in the teacher education program positioned their own disciplinary questions, ideas, and activities as main foci and used other disciplines in order to better accomplish learning and doing of their discipline. Thus, the process of developing integrated STEM lesson plans and resulting lesson plans looked different across six participants' lessons. These differences were considered a strength of the STEM integration approach because it can draw upon participants' funds of knowledge as experts, relatively speaking, in their own disciplines.

Research Question 3: Challenges in STEM integration education

While excited about the idea of integration, the participants faced or foresaw several challenges in implementing integrated STEM. In this section, challenges attributable to three main factors in current educational contexts are discussed: existing school structure and instructional practices, limited interdisciplinary understandings, and absence of role models.

Existing school structure and instructional practices

Participants found existing school structure, curriculum, and instructional approaches that were more or less rigid as a salient impediment to STEM integration, which is similar to findings from LaPorte and Sanders (1995). When asked what was challenging in the development and implementation of integrated STEM lessons, several participants mentioned "time" that was required to develop and implement integrated STEM lessons. The participants believed that integrated STEM lessons cannot be done in one class period. For instance, S4 asserted,

> I think to get the full effect of the activity having multiple days where we can actually create models and go through more of the engineering design process would have been more beneficial for this unit. (S4)

Similarly, S2 said that although she wanted to have her students design a prototype of their design, she could not do so because "It's too time consuming." Because many integrated STEM lessons require students to design and build prototypes, it requires at least several class periods to implement them. Participants recognized that the tight curricular structure does not allow room for trying this new instructional approach. "Time" also meant the efforts that teachers need to devote to designing integrated STEM lessons. S6 reported,

> It takes a very long time to develop an integrated STEM lesson effectively… This cannot always be done when in a real school due to time and busyness of many of the teachers. (S6)

The participants perceived a tight schedule and heavy workload diminished their motivation and opportunities to even develop and try to implement integrated STEM lessons.

Another aspect was an existing culture in the school building that encompasses teachers' pedagogical approaches and students' expectations about classes and schoolwork. Many teachers at the partnership school appeared to teach using a traditional lecturing approach, in which teachers' monological speech dominates and students passively listened to the teacher's lecture. S2 pointed out that because students in her class were used to this teaching method, it was hard for her to incorporate collaborative and interactive teaching strategies. She bemoaned, "I was not able to, of course, in one class to change the way they work. They [were assigned to] work in teams but [worked] individually, and you can't break that structure." S6 anticipated potential pushback from teachers as well. When he teaches in the year following graduation, he would like to implement integrated STEM lessons. Although he was worried the lessons may not go the way he expected, he still wanted "to be able to go out of my comfort zone." Then, he added, "It's going to be hard because coming in as a young teacher and wanting to make waves and all these changes. I don't think people will respect that right away." S6 appeared to call for a need for a school-wide initiative to accomplish a successful integrated STEM education.

Limited interdisciplinary understandings

Participants' competence was limited in terms of content knowledge, practices, nature of reasoning in disciplines other than their own as well as relations among STEM disciplines. Certainly, they were not trained in various STEM disciplines and did not develop equal expertise in diverse subject areas. What we want to shed light on is not the deficits that the participants demonstrated in implementing integrated STEM education, but *how* the limited understandings of other disciplines may affect the participants' development and implementation of integrated STEM lessons.

First, participants integrated mathematics as an algebraic "tool" to provide numeric reality to their design problems. On one hand, this notion encouraged them to see mathematics as easily integratable, as S1 said, "I've always thought math, like that's very important and I feel like that can be used in any subject pretty much." On the other, mathematics was used only in relatively simple algebraic manipulations. For instance, participants incorporated mathematics to calculate how many fish would be affected by a certain number of fishermen within a certain period of time (S2) or calculate to find potential and kinetic energy at certain points in a roller coaster (S1 and S6). In the interviews, participants acknowledged that they used mathematics as a "tool" and did not provide opportunities for mathematical reasoning and modeling. However, they were not equipped with sufficient knowledge and experiences to do otherwise.

Second, in the context in which students did not develop sophisticated understandings of STEM-related disciplines, the acronym STEM was misleading. One way they used the acronym was to check if their lesson has all components of STEM. Thus S, T, E, and M in STEM served as a simple checkmark to evaluate their lessons. The participants thought that their lessons were successful if they "hit them (science, technology, engineering, and mathematics) all evenly" (S1). The assumption seems to be made that each discipline of science, technology, engineering and mathematics was a self-contained unit of disciplines: within each discipline, the nature of content is unitary and among disciplines the boundaries are rigid and clear. However, as a school subject in secondary education, science was divided into several different disciplines (e.g., biology, physical science, and earth science, according to NGSS) that addressed natural phenomena different from each other and engaged different ways to approach those natural phenomena. Our participants, however, did not recognize the relationships among science sub-fields of biology, chemistry and physics, and the simplistic STEM acronym did not help them notice the relations.

The limited understanding of the relations between STEM subjects restricted the scope of integrated STEM lessons. In particular, participants believed that certain topics and subject areas provided easy STEM integration opportunities. S1 specifically named chemistry as not easy to integrate with engineering design. In addition, S1 and other participants did not seem to be concerned about what specific content areas were connected and how they were integrated. As long as their lesson "hits" four domains (i.e., science, technology, engineering, and mathematics), the participants assumed that integrated STEM lessons were successfully designed. Therefore, rather than examining interdisciplinary connections between *and* within subject areas, participants gravitated toward curricular connections that were widely available and/or adopted by other educators (e.g., physics and mechanical engineering exemplified in roller coaster lessons). Participants did not seem to recognize the complex and flexible relationships among subject areas.

Finally, participants who were not in agricultural education had a limited understanding of agriculture. While agriculture encompasses diverse sub-disciplines that are relevant to science and engineering, some participants appeared to narrowly see it as a study about "farming." Thus, the instructors' explicit attempt to bring agriculture to the table was frequently missed by four participants who did not have experiences in agriculture. The fact that the STEM acronym does not include agriculture in it was confusing to some participants and did not recognize agriculture as part of integrated STEM learning. For instance, S1 did not recognize how and why agriculture should be integrated with STEM and explained the reason:

> So that's [agriculture] not something I've really thought about just because that's not technically included in the STEM acronym. … I kinda ignored that throughout the semester just because I see it as STEM and not STEAM. (S1)

Indeed, agriculture students were concerned about the underrepresentation of agriculture in STEM integration and how to position agriculture in STEM integration efforts:

> I wish maybe there would have been more of a focus on agriculture in STEM. I have been doing some reading and there was not a whole lot out there about agriculture in integrated STEM. (S4)

These two views of a student in technology/engineering and agriculture were consistent with the concern shown in the literature and a lack of efforts to connect agriculture and technology curricula (Smith et al. 2015; Stubbs and Myers 2016).

These findings imply that the acronym obscured nuanced understandings of STEM. In particular, when STEM preservice teachers have limited disciplinary understandings, the acronyms may be misleading. For instance, mathematics was viewed as a subject area to be incorporated, yet in most cases, it was employed at a rudimentary level. The STEM acronym did not encourage participants to consider a broader scope of science in K-12 school curricula. Finally, opportunities that agriculture can bring to STEM integration were frequently missed. It is important to note that through taking the course, S1 realized that agriculture has "a lot of great real-world application" and S4 realized that "all of the science technology, engineering, and math are a part of agriculture and where agriculture fits into STEM." However, these new understandings of agricultural STEM connections were not adequately transferred to their lesson plans.

Absence of role models

Participants experienced another challenge—a lack of, or limited number of, role models, which was manifested in several different ways. On one hand, because STEM integration has not been implemented widely in schools, the participants did not seem to have enough experiences of integrated STEM learning as a K-12 student. The lack of experience as a student disadvantaged the participants because they had limited experiential knowledge resources in thinking of what integrated STEM lessons should and could look like. While S1 and S6 said that some high school technology courses were taught in "a little bit" or "kind of" integrated way, which they realized when they reflected on high school experiences in the STEM methods course, those memories were not salient to them to serve as useful resources for teaching.

The topic of integration of STEM disciplines has been a national concern for more than 30 years, including early projects such as the Technology, Science, Mathematics (TSM) Integration Project and the Integrated Mathematics, Science and Technology Project (IMaST) (LaPorte and Sanders 1995). Despite these efforts, preservice teachers in the STEM methods course perceived a relatively short history of integrated STEM education, which led to another challenge. Participants did not have the luxury of model teachers who served as experienced members of a community of integrated STEM teachers. As such, participants could not observe classes taught by teachers who used integrated methods. Furthermore, most participants reported the feedback from their cooperating teachers was minimal. While various factors might explain why the cooperating teachers did not provide adequate feedback, a reason might have been that the cooperating teachers did not assume their expertise in STEM integration. S4 pointed out the lack of role model as a challenge and provided a suggestion for integrated STEM teacher preparation program:

> I think some agriculture teachers do teach in an integrated way without realizing it. I observed a classroom for my other integrated STEM class and the teacher had no idea that she was doing integrated STEM but she totally was, which was really awesome to see. So I think there is an opportunity to maybe provide agricultural educators inservice trainings on how they can show students they are doing integrated STEM (S4).

This excerpt is consistent with Stubbs and Myers' (2016) finding that agriculture teachers shared they taught STEM, but were not explicit about STEM connections. In this context, S4 was concerned about underrepresentation of agriculture in integrated STEM and hoped to see more good teaching examples that integrate agriculture with other STEM subjects.

Finally, a lack of model curricula was another challenge. To compensate for limited curricular resources, S3 conducted online research to find exemplar lessons. While use of available tools (e.g., the Internet) and drawing on collective knowledge sources are useful practices for teachers, they were challenged because they did not know what a good integrated STEM curriculum would look like. They were doubly burdened in developing a lesson and implementing it without a teacher and/or curricular role model. This aligns with Stohlmann (2012) recommendation for further research and development of curriculum resources and instructional models for STEM integration. Further, the challenge of understanding and implementing quality integrated STEM learning was compounded by emergent state of this educational approach as "very little is known about how to organize curriculum and instruction so that emerging knowledge in different disciplines will mesh smoothly and at the right time to yield the kind of integration that supports coherent learning" (Honey et al. 2014, p. 53).

Discussion and implications

STEM education students used various approaches to develop integrated STEM lessons. The processes were different depending on the STEM education students' previous experiences, personal interests, and disciplinary backgrounds. In selecting curricular topics and activities, some participants were motivated by their own experiences as a student (S1, S2, S5, S6), their students' authentic questions (S3), topics covered in existing curriculum (S4), and local contexts (S2). While their entry points differed, they all considered critical factors for developing successful STEM integration lessons, such as students' interests, curricular standards, and local contexts. In doing so, participants extensively employed the Internet to draw from existing resources. As Putnam and Borko (2000) argued, preservice teachers' pedagogical decision making and practices were mediated by technology tools. In our study, the Internet was a major technology tool. Participants' use of the Internet reiterates that pedagogical practices are not an individual endeavor, but selection and coordination of extensive information shared and distributed across multiple experienced educators and people (Hutchins 1995).

Despite a deliberate coordination of existing resources, technology, and funds of knowledge, participants faced or foresaw challenges in implementing integrated STEM education. Challenges were attributable to existing school culture and structure, limited knowledge in STEM fields, and an absence of role models. Findings from this study resonated with previous research in the field that reported challenges in integrated STEM teaching, such as teachers' limited content knowledge, accountability to meet content area standard, and limited self-efficacy in implementing integrated STEM teaching (e.g., Berlin and White 2012; Honey et al. 2014; Roehrig et al. 2012; Stubbs and Myers 2016). Putnam and Borko (2000) asserted that the existing powerful discourse communities of schools could easily "enculturate" preservice teachers into the community of traditional teaching practices and may discourage teaching in new ways. The findings from this study resonated with Putnam and Borko's arguments and showed how the contexts in which teacher preparation program was situated—encompassing early schooling experiences, university coursework, practicum, and practicum school environment—can be a hurdle to teaching STEM in an integrated way.

Based on the findings, we suggest implications for teacher education program for successful STEM integration. Inspired by ideas of funds of knowledge (Moll et al. 1992), these suggestions are intended to encourage teacher educators to actively utilize existing local resources and capitalize on the strengths of preservice teachers. First, in response to challenges related to limited role models, strategic partnership with schools and teachers to support integrated STEM education should be established and cultivated. Strong partnerships should be developed with schools that strive to teach in innovative ways, have experienced reform-oriented instructional methods, and are more flexible and resilient to changes. In addition, a collaboration between a STEM integration preservice teacher education program and inservice teachers' professional development program could generate synergistic impacts. Through this collaboration, instructors of STEM integration methods courses may be able to identify schools and teachers who are committed to STEM integration and can mentor preservice teachers. Given a short history of integrated STEM education, practicing teachers might be still in the beginning stage of STEM integration wherein they also may try out this new instructional method. Nonetheless, as experienced members in the community of teachers, they may know how to navigate rigid structure and culture of schools and curricula. Practicing teachers learn innovative ideas for STEM integration from preservice teachers who are informed by university methods courses. As they teach STEM subjects using integrated approaches, they would grow their expertise in STEM integration gradually and serve as STEM integration experts. This would further facilitate development of a community of integrated STEM teachers.

Second, participants' extensive use of online resources should be considered as a means to accessing educational resources that support STEM integration. This implies that a successful lesson planning can be mediated by effective and critical use of the online resources. Participants in this study searched for curricula materials which they can build on or adapt for integrated STEM learning. Online resources may include video clips, images, and newspaper articles. In the preliminary planning stage, preservice teachers make various pedagogical decisions, such as what resources to search online, how to evaluate them, and how to modify to meet the needs of their students. Their decision making hinges upon information literacy (American Library Association 2006), multimodal literacy (Jewitt and Kress 2003), and critical analysis of existing curricula. Teaching methods courses should explicitly address how to select, modify, interpret and use multimodal texts for teaching. For instance, preservice teachers should learn how to critically analyze, modify existing online curricular materials, and use in developmentally appropriate ways for their students. To address this academic need, preservice teachers may be asked to develop a rubric of criteria to analyze existing STEM integration curricula that are supported by research evidence, locate curricular materials online, and analyze the materials with the rubric.

Third, teaching methods courses should use examples of interdisciplinary work in the professional fields to demonstrate how STEM fields are integrated in reality. Although participants hoped to design their lessons to be authentic to professional fields, not all participants had experienced or knew what interdisciplinary work looks like in the various professions that represented agriculture and STEM disciplines. Examples can be introduced from interdisciplinary research teams that examine and attempt to solve grand challenges (e.g., food security; bioenergy; climate change) and case studies of interdisciplinary work found in industry (McLaughlin 2014). This approach can also support understanding of complex relations among STEM disciplines that a simplistic STEM acronym cannot achieve. These highly contextualized and dynamic problems lie in a complex system that involves various kinds of expertise and requires professionals to work in interdisciplinary teams (National Research Council 2009) and possibly develop transdisciplinary and systems thinking (Francis et al. 2011; Schneider and Rist 2014; Scott et al. 2015). Furthermore, these topics can bring another important aspect of STEM education, to educate students to be aware of socioscientific issues (Ozturk and Yilmaz-Tuzun 2017) and become an informed citizens and decision makers (Knobloch et al. 2007).

Finally, it is important that preservice teachers' reflect on their experiences as students and future teachers. Employing reflection of prior experiences as useful resources for teaching is not a novel or new approach, but engages preservice teachers to actively self-regulate their ideas of STEM integration. Experiential knowledge resources gained from being a K-12 student or by observing K-12 classrooms engages preservice teachers to reflect and consider their beliefs about teaching and learning (Hancock and Gallard 2004). Some participants in the study reflected that their high school technology classes incorporated other STEM disciplines or observed teachers who were integrating multiple subject areas. Methods course instructors should facilitate students' reflection and strive to draw those experiences out to help them realize and employ the experiential knowledge. Hancock and Gallard (2004) found that teachers recalled their own experiences as a student when engaged in reflection about their beliefs after field experiences. Efficacy of reflection activities can be maximized when the timing of these activities is carefully aligned with field experiences. Reflective practices are important for teachers in any context and are particularly important when teachers develop new curriculum without prior experiences. The results from this study showed that preservice teachers do have *some* experiences and can and should draw on such experiences through thoughtful reflection. Instructors of methods courses should play a key role in engaging preservice teachers in careful reflection and encouraging them to utilize resources from their experiences.

Conclusion

As other scholars have shown, this study revealed several challenges that preservice teachers experienced or anticipated in teaching STEM subjects through integrated approaches. Despite the challenges, preservice teachers saw possibilities and values of STEM integration. The research approach, as reflective practitioners, allowed the authors to recognize potential resources to utilize in helping preservice teachers develop integrated STEM teaching skills. It is important to consider an incremental approach with small changes to gradually mitigate the challenges preservice teachers experienced in designing and implementing intregrated STEM lessons. Establishing partnerships with teachers and schools committed to integrated STEM education, drawing on existing interdisciplinary work, and supporting preservice teachers' funds of knowledge may be a small step toward resolving those challenges and meeting the needs for STEM education in the twenty-first century.

References

Adams, A. E., Miller, B. G., Saul, M., & Pegg, J. (2014). Supporting elementary pre-service teachers to teach STEM through place-based teaching and learning experiences. *Electronic Journal of Science Education, 18*(5), 1–22.

Agunga, R., Connors, J. J., & Chen, H. Y. (2005). A study of The Ohio State University College of Food, Agricultural, and Environmental Sciences' ecological-paradigm model. *NACTA Journal, 49*(3), 2–10.

American Library Association. (2006). *Information literacy competency standards for higher education*. Retrieved from http://www.ala.org/acrl/standards/informationliteracycompetency.

Andrews, J., Yee, W. C., Greenhough, P., Hughes, M., & Winter, J. (2005). Teachers' funds of knowledge and the teaching and learning of mathematics in multi-ethnic primary schools: Two teachers' views of linking home and school. *ZDM Mathematics Education, 37*(2), 72–80.

Association of Public and Land-grant Universities. (2012). *The land-grant tradition*. Washington, DC: Author.

Ball, A. L., & Knobloch, N. A. (2005). A document analysis of the pedagogical knowledge espoused in agriculture teaching methods courses. *Journal of Agricultural Education, 46*(2), 47–57. https://doi.org/10.5032/jae.2005.02047.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 National Survey of Science and Mathematics Education*. Chapel Hill, NC: Horizon Research Inc.

Barnosky, A. D., Ehrlich, P. R., & Hadly, E. A. (2016). Avoiding collapse: Grand challenges for science and society to solve by 2050. *Elementa: Science of the Anthropocene, 4*(1), 000094.

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

Berlin, D. F., & White, A. L. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science and Mathematics, 112*(1), 20–30.

Boyer, E. L. (1990). *Scholarship reconsidered*. Princeton, NJ: Carnegie Institute for the Advancement of Teaching.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn*. Washington, DC: National Academy Press.

Bybee, R. W. (2013). *STEM education: Challenges and opportunities*. Arlington, VA: National Science Teachers Association Press.

Cochran-Smith, M. (2003). Learning and unlearning: The education of teacher educators. *Teaching and Teacher Education, 19*(1), 5–28.

Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers in the age of innovation. *Education and Science, 39*(171), 74–85.

Cunningham, C. M. (2009). Engineering is elementary. *The Bridge, 30*(3), 11–17.

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. Alexandria, VA: Association for Supervision and Curriculum Development.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081.

Francis, C. A., Jordan, J., Porter, P., Breland, T. A., Lieblein, G., Salomonsson, L., et al. (2011). Innovative education in agroecology: Experiential learning for a sustainable agriculture. *Critical Reviews in Plant Sciences, 30*(1–2), 226–237.

Greeno, J. G., & Middle School Mathematics Through Applications Project Group. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*(1), 5–26.

Gupta, A. (2006). Early experiences and personal funds of knowledge and beliefs of immigrant and minority teacher candidates dialog with theories of child development in a teacher education classroom. *Journal of Early Childhood Teacher Education, 27*(1), 3–18.

Hammersley, M. (2005). The myth of research-based practice: The critical case of educational inquiry. *International Journal of Social Research Methodology, 8*(4), 317–330.

Hancock, E. S., & Gallard, A. J. (2004). Preservice science teachers' beliefs about teaching and learning: The influence of K-12 field experiences. *Journal of Science Teacher Education, 15*(4), 281–291.

Hargreaves, A., & Moore, S. (2000). Curriculum integration and classroom relevance: A study of teachers' practice. *Journal of Curriculum and Supervision, 15,* 89–112.

Hedges, H. (2012). Teachers' funds of knowledge: A challenge to evidence-based practice. *Teachers and Teaching, 18*(1), 7–24. https://doi.org/10.1080/13540602.2011.622548.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Committee on Integrated STEM Education; National Academy of Engineering; National Research Council. Washington, DC: The National Academies Press.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science, 19*(3), 265–288.

International Technology Education Association (ITEA/ITEEA). (2007). *Standards for technological literacy: Content for the study of technology*. Retrieved from https://www.iteea.org/File.aspx?id=67767&v=b26b7852.

Ivanitskaya, L., Clark, D., Montgomery, G., & Primeau, R. (2002). Interdisciplinary learning: Process and outcomes. *Innovative Higher Education, 27*(2), 95–111.

Jewitt, C., & Kress, G. R. (2003). *Multimodal literacy*. New York, NY: Peter Lang.

Knobloch, N. A., Ball, A. L., & Allen, C. A. (2007). The benefits of teaching and learning about agriculture in elementary and junior high schools. *Journal of Agricultural Education, 48*(3), 25–36.

Koirala, H. P., & Bowman, J. K. (2003). Preparing middle level preservice teachers to integrate mathematics and science: Problems and possibilities. *School Science and Mathematics, 103*(3), 145–154.

LaPorte, J., & Sanders, M. (1995). Integrating technology, science and mathematics education. In G. E. Martin (Ed.), *Foundations of technology education* (pp. 179–219). New York: Glencoe.

Lave, W., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Leader-Janssen, E. M., & Rankin-Erickson, J. L. (2013). Preservice teachers' content knowledge and self-efficacy for teaching reading. *Literacy Research and Instruction, 52*(3), 204–229.

McLaughlin, T. D. (2014). *Support for interdisciplinary engineering education through application of industry-focused case studies.* Paper presented at the American Society of Engineering Education annual conference & exposition, Indianapolis, IN.

Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71–85.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage.

Moll, L. C., Amanti, C., Neff, D., & González, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31,* 132–141.

Nadelson, L. S., Seifert, A., Moll, A. J., & Coats, B. (2012). i-STEM summer institute: An integrated approach to teacher professional development in STEM. *Journal of STEM Education: Innovations and Research, 13*(2), 69.

National Research Council. (2009). *Transforming agricultural education for a changing world*. Washington, DC: National Academies.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Retrieved from https://www.nextgenscience.org/search-standards.

O'Brien, S. (2010). *A unique multidisciplinary STEM K-5 teacher preparation program.* Paper presented at the American Society for Engineering Education. Retrieved from http://assess.pages.tcnj.edu/files/2011/07/OQA_TechEd_09.pdf.

Ozturk, N., & Yilmaz-Tuzun, O. (2017). Preservice science teachers' epistemological beliefs and informal reasoning regarding socioscientific issues. *Research in Science Education, 47*(6), 1275–1304.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4–15.

Remesh, A. (2013). Microteaching, an efficient technique for learning effective teaching. *Journal of Research in Medical Sciences: The Official Journal of Isfahan University of Medical Sciences, 18*(2), 158–163.
Roehrig, G. H., Wang, H.-H., Moore, T. J., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31–44.
Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, December/January, 2009,* 20–26.
Schneider, F., & Rist, S. (2014). Envisioning sustainable water futures in a transdisciplinary learning process: Combining normative, explorative, and participatory scenario approaches. *Sustainability Science, 9*(4), 463–481.
Scott, C. A., Kurian, M., & Wescoat, J. L., Jr. (2015). The water-energy-food nexus: Enhancing adaptive capacity to complex global challenges. In M. Kurian & R. Ardakanian (Eds.), *Governing the nexus* (pp. 15–38). Cham: Springer.
Smith, K. L., Rayfield, J., & McKim, B. R. (2015). Effective practices in STEM integration: Describing teacher perceptions and instructional method use. *Journal of Agricultural Education, 56*(4), 182–201.
Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research, 2*(1), 28–34.
Stubbs, E. A., & Myers, B. E. (2016). Part of what we do: Teacher perceptions of STEM integration. *Journal of Agricultural Education*, *57*(3), 87–100.
Swackhamer, L. E., Koellner, K., Basile, C., & Kimbrough, D. (2009). Increasing the self-efficacy of inservice teachers through content knowledge. *Teacher Education Quarterly, 36*(2), 63–78.
The National Council for Agricultural Education. (2015). *Agriculture, food, and natural resources career cluster content standards.* Retrieved from https://www.ffa.org/thecouncil/afnr.
Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research, 1*(2), Article 2.
Weimer, M. (2002). *Learner-centered teaching: Five key changes to practice*. San Francisco, CA: Wiley.
Wells, J. G. (2016). Efficacy of the technological/engineering design approach: Imposed cognitive demands within design-based biotechnology instruction. *Journal of Technology Education, 27*(2), 4–20.
Wiggins, G., & McTighe, J. (2005). *Understanding by design* (expanded 2 ed.). Alexandria, VA: Association for Supervision and Curriculum Development.
Woolfolk Hoy, A., & Spero, R. B. (2005). Changes in teacher efficacy during the early years of teaching: A comparison of four measures. *Teaching and Teacher Education, 21*(4), 343–356.