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What STEM Teachers Need to Know and Do to Engage Families of Emergent Multilingual Students (English Language Learners)

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Abstract

STEM teacher educators are aware that we teach far more than content-specific methodology. Educators need to guide STEM teachers in the knowledge and skills to support emergent multilingual students (English language learners, or ELLs) by simultaneously developing their STEM content learning and scaffolding their language acquisition (Hoffman & Zollman, 2016; Suh, Hoffman, & Zollman, 2020). Research identifies the family unit having a profound effect upon student learning and educational choices. Educators, educational researchers, and policymakers alike recognize the importance of family involvement in education (Grant & Ray, 2019). Although previous family engagement initiatives have focused on teaching families from a school-based perspective (Bush & Cook, 2016), we advocate for a STEM family engagement model which honors and grows out of families' existing funds of knowledge. This article lays out an argument for STEM teacher educators explicitly addressing multilingual family engagement as a key part of STEM education. We explain purposes, pitfalls, and practical steps STEM teacher educators can utilize that have a positive impact on diverse students' STEM learning. We also encourage STEM educators to address "STEM mindset" in addition to STEM literacy skills and interdisciplinary STEM content knowledge.

Keywords: English language learners, ELL, cultural and linguistic diversity, CLD, family engagement, parental involvement, STEM mindset

"STEM Education" has hit the mainstream—not just as a buzzword in education but also in retail and marketing. Walk through any bookstore, toy store, or even large supermarket and you will see a wide range of activity kits and toy sets marketed as promoting STEM (Science, Technology, Engineering, and Mathematics) skills. This trend suggests families' investment in building their children's STEM knowledge through purchasing products or experiences, such as summer camps. Families of school-aged children can influence their children's pursuit of STEM careers (Nugent et al., 2015), and the nationwide shortage of highly skilled STEM workers has received increasing public attention. STEM educators can build upon this cultural trend as an opportunity to engage with family interest in STEM as an interdisciplinary approach extending beyond traditional disciplinary boundaries.

Previous research on family engagement shows us what efforts are more successful as well as which families are sometimes left out (Evans, 2013). Even though we know that families play a key role in casting a wide vision for their children in STEM careers, educators sometimes have trouble connecting to families from different linguistic or cultural backgrounds (Goldsmith & Kurpius, 2018; Colegrove & Krause, 2017; Evans, 2013; Lawrence-Lightfoot, 2003). This article builds upon earlier research on supporting STEM education among English language learners or ELLs (Hoffman & Zollman, 2016), to whom we refer as "emergent multilingual students" (Canagarajah & Wurr, 2011; Catalano et al., 2018). In this article, we summarize research on family engagement in STEM education, literature on culturally relevant and culturally sustaining pedagogy (Gay, 2002; Paris, 2012), as well as our own family involvement outreach work with families of emerging multilingual students (Zollman, Hoffman, & Suh, 2020; Hoffman, 2014). We use an integrated approach to STEM literacy (Zollman, 2012) and introduce the concept of "STEM mindset" to outline some information STEM educators need to know for engaging families of emergent multilingual students. We also infuse some examples from our own experiences with engaging multilingual families with STEM.

Why STEM Educators Need to Think about Family Engagement with Linguistically Diverse Families

Significant linguistic and cultural differences can exist between home and school (Shanahan & Echevarria, n.d; Tarasawa & Waggoner, 2015). Family engagement efforts especially are important for multilingual students and connecting between home and school language and knowledge. Family engagement is critical for incorporating academic language into conversations in the home language and supporting students' academic English skills (Philadelphia Education Research Consortium, 2016; Shanahan, & Echevarria, n.d.). Higher levels of family engagement at the K-12 level are attributed to increases in graduation and postsecondary enrollment, positive regard for school, placement accuracy, and attendance for students from a variety of linguistic backgrounds (Henderson & Mapp, 2002). Strategic school-family-community partnerships have been linked to increased academic achievement and positive attitudes towards school, among other advantages (Philadelphia Education Research Consortium, 2016). Research also has documented the benefits of family engagement in STEM disciplines. Family members can play central roles in encouraging students' STEM career pursuits (Archer et al., 2012). In their study of 480 primary students in Nigeria, Olatoye and Olajumoke (2009) found parental involvement to be a significant predictor of science and mathematics achievement, and family engagement was shown to positively impact emergent multilingual preschool students' mathematical problem-solving skills as well as students' language acquisition (Naughton, 2004). Family engagement was identified as an essential component to teaching science to emergent multilingual students (Valadez & Moineau, 2010).

Supporting multilingual students' content language acquisition in both English and the home language requires that STEM teachers recognize the importance of families' funds of knowledge—in other words, the knowledge and skills essential for functioning in the home or community which family members have acquired over time and through interactions with others (Moll et al., 1992). Family funds of knowledge are considered to be central to students' learning, and current models of family engagement position family funds of knowledge as central to student learning. STEM educators can incorporate the funds of knowledge outside the school that are valued by families and communities into STEM learning. WIDA (2017), a consortium which provides assessment and pedagogical professional development for K-12 teachers of emergent multilingual students, outlines three essential components to effective family engagement: (a) Awareness and advocacy, (b) brokering and building trust, and (c) communicating and connecting to learning. Additionally, STEM educators should learn from and incorporate families' goals or aspirations for engaging with the school—and how families' aspirations and needs alike are infused with the local context and families' experiences therein (Coady, 2019).

When STEM teachers honor families' funds of knowledge as a component of meaningful engagement to learn, they are enacting culturally responsive (Gay, 2002) and culturally sustaining (Paris, 2012) pedagogy. Gay (2002) explains that a culturally responsive educator is one who uses students' "cultural orientations, background experiences, [and] ethnic identities as conduits to facilitate their learning" (p. 614). Culturally sustaining pedagogy reaches even further by working to promote and sustain aspects of a student's culture that might be stifled in the midst of other dominant cultures. STEM educators can play a role in sustaining the cultural wealth of communities of color and linguistic diversity. We encourage STEM educators to adapt a critical theory perspective to family engagement: They must acknowledge the possible rift between families and schools within the current system and be open to hearing from families how to restore families' epistemic content knowledge (Booker & Goldman, 2016). Ishimaru et al. (2015) argue that STEM educators need to learn directly from family perspectives on both how the current system has failed to engage them as well as how mathematics (and STEM as an integrated discipline) are routine aspects of their daily and cultural practices. Culturally sensitive and contextually rich teaching strategies are dependent upon strong family-school relationships. Family engagement strategies must be responsive to cultural and community backgrounds (Grant & Ray, 2019).

The importance of family involvement in children's learning has received increased focus from a growing number of professional organizations focused on STEM or language acquisition (i.e., National Association for the Education of Young Children, n.d.; National Academies of Sciences, Engineering, and Medicine, 2018; WIDA 2017). Table 1 shows STEM learning shares many commonalities with both English language learning and learning with families.

Organizing family engagement initiatives is intimidating for many teachers and may seem especially overwhelming for STEM educators who frequently have received limited training in family engagement (Zollman et al., 2020). We believe that all STEM teachers—and their students—can benefit greatly from knowing some basic information about engaging the families of emergent multilingual students.

What STEM Teachers Need to Know

Culturally-sensitive and contextually-rich STEM teaching strategies are dependent upon strong family-school relationships, and family engagement strategies must be responsive to cultural and community backgrounds (Grant & Ray, 2019). The following are suggestions of what STEM teachers need to know about engaging the families of emergent multilingual students in order to facilitate learning for all students.

Cultural Understandings of School and Family Roles in Education Vary

When working with students and families from linguistically diverse backgrounds, STEM educators first need to know that family engagement varies across cultural contexts and that parents from different cultural backgrounds may have divergent expectations about their roles in children's formal schooling (Georgis et al., 2014; Huntsinger & Jose, 2009). For example, in some cultures it is common to confer a great deal of respect on teachers as the source of all knowledge. Families from these cultural contexts may not be accustomed to being invited to collaborate in educational endeavors (Goldsmith & Kurpius, 2018). Some schooling systems rely more on learning through rote memorization rather than inquiry-based or project-based approaches. Some schooling systems promote competition more than collaboration. Although we offer up these examples here, we caution against generalizations that suggest parents from particular backgrounds will share an assigned set of expectations, because culture is dynamic and families each have specific histories and experiences (Poza, Cantu, & Tedrake, 2014).

Table 1
Examples of Connections Among STEM, ELL, and Family Learning Opportunities

Opportunities for STEM Learning	Opportunities for English Language Learning	Opportunities for Learning with Families
Multiple opportunities to hear and use language to express STEM understandings	Multiple opportunities to hear and use both social and academic English	Multiple opportunities to hear, use, and value home languages for academic purpose
Rich contexts to help illustrate STEM concepts, and the opportunity to engage and contribute to the classroom STEM learning community	Rich contexts to help language comprehension, and the opportunity to engage and contribute to the interactive learning community	Authentic contexts for multilingual learning and communication between home and school
Appropriate supports for STEM concepts — e.g., hands-on student engagement, multiple representations, scaffolding strategies for STEM -specific vocabulary	Instructional supports for written and spoken language — e.g., intentional student grouping, multiple representations, scaffolding strategies for different tiers of English vocabulary	Supporting connections between school and community knowledge and ways of knowing — e.g., inviting parents and community members to share how they use STEM concepts to solve problems or in their everyday or professional lives
Promoting inquiry and ideas over concern for precise discipline-specific terminology	Promoting authentic communication over concern for perceived standard academic English	Promoting authentic communication and collaborative exploration e.g., encouraging risk-taking, problem-solving, and cooperation rather than competing to finding "the right answer"

Note. Adapted from Hoffman & Zollman (2016); adapted from Riley & Figgins (2015)

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An example of common generalizations is the assumption that parents from Asian backgrounds value STEM achievement but that families from Latin American backgrounds tend to know little about STEM and are more likely to value fields such as musical achievement. This stereotype is not supported by research (Gonzales & Gabel, 2017). In our own research on multilingual family engagement with STEM, event attendance, survey responses, and administrator feedback all indicate that multilingual parents from a range of cultural backgrounds see a need for strong STEM education and are interested and engaged in supporting their children's learning.

Families are Equitable Partners and Experts in the Educating of Their Children

One common response to such cultural differences is to acculturate parents to school expectations. This approach can be unintentionally alienating to families by belittling their cultural values and assigning value instead to a narrow set of school expectations. Families who are not part of the socially dominant U.S. culture may have different types of cultural capital that is not valued in U.S. schools, and educators can unwittingly pressure families to gain the types of cultural capital valued by dominant U.S. society. Pressure to assimilate to (often White, middle class, English-only) norms and to teach their children particular forms of cultural capital can make parents feel unwelcome in schools (Gonzales & Gabel, 2017). We urge STEM educators to avoid the common pitfall of building family engagement efforts from a "deficit ideology" that focuses on individual student shortcomings rather than recognizing the systemic inequities the students face (Hoffman, 2014; Valencia, 2010; Gorski, 2008). Such approaches to family involvement, that are still prevalent in many schools and communities, attempt to "improve" parents in order to "save" their children from the shortcomings of their local community (Flores, 2007). Additionally, deficit ideology is reflected in assumptions that all parents' school involvement should mirror the preferences of dominant middle class families (Brantlinger, 2003) and that family engagement necessitates parents be physically present at school events and able to help children keep up with their schoolwork by providing technology and extra resources (Hoffman, 2014). For example, we have previously experienced family engagement attempts that assumed most parents could attend events at particular times of the day, necessitated purchasing materials from a book fair, or consisted only of prescriptive programming such as instructing parents how to help their children with mathematics at home.

What is the alternative? In contrast to a deficit ideology, a culturally sustaining approach to family engagement positions families as "equitable partners" and "fellow experts in the teaching and learning of their children" (Ishimaru et al., 2015, p. 4). For linguistically diverse families especially, educators particularly must support students "in sustaining the cultural and linguistic competence of their communities while simultaneously offering access to dominant cultural competence" (Paris, 2012, p. 95). This culturally sustaining approach to family engagement focuses on "how families might collaborate with educators to build more empowered and holistic disciplinary identities across students' home, school, and community learning contexts" (Ishimaru et al., 2015, p. 2). Such practices necessarily recognize and seek to develop family engagement in STEM learning. These partnerships open the door to respectful and collaborative family STEM engagement.

What STEM Teachers Need to Do

STEM educators should value and form relationships with family and community partners whose STEM experiences are both relevant to their children's learning and valued by the school. Although parents (from a variety of backgrounds) may believe that they have a passive role supporting their students' STEM development, STEM learning (and all learning) is most effective when it occurs within a partnership between engaged families and the school (Weyer, 2018). Culturally sustaining practices invite family members to view themselves as valued collaborators in teaching their children.

Engage Parents as Allies in Promoting "STEM Mindset"

Comprehensive STEM education includes content area knowledge, STEM literacy skills, (Zollman, 2012), and "STEM mindset." These three aspects of STEM education mirror key aspects of teacher education: knowledge, skills, and dispositions (Danielson, 2007; Council for the Accreditation of Educator Preparation [CAEP], 2019). We consider a STEM mindset as a cognitive perspective focused on the value of inquiry, problem-posing, questioning, and risk-taking. STEM mindset includes the dispositions required for successful inquiry-based approaches to STEM education as well as the value of welcoming failure as a natural part of learning and development (Boaler, 2015). For example, STEM educators can focus on the importance of risk-taking rather than right answers to relieve STEM anxiety. As one administrator noted from our work, "If the families can get on board with STEM activities and the mindset, then the kids will be more willing to try" (Zollman et al., 2020; p. 22).

Assure Parents that STEM Expertise is not a Prerequisite for Partnerships

Given parents' differing exposure to STEM, an important task for STEM educators is to convey to parents that they do not need to be content or language experts in order to be equitable partners in their students' STEM learning. Parents do not need to (re)learn all the content that their children will learn in order to support their children's STEM development. Similarly, parents do not need proficiency in English in order to support student learning. Instead, STEM educators can encourage family members to view themselves as partners in encouraging students' questioning and discovery—in whatever culturally appropriate form that takes. STEM educators can communicate to families the value of fostering a shared understanding of STEM learning as a form of inquiry rather than simply a set of prescriptive knowledge or skills. For example, parents can model problem-posing and sense-making in STEM environments (Weiland, 2015) or communicate the value of STEM understanding in civic education.

Cast a Broad Vision for Students' STEM Potential

Considering the increase in STEM discipline careers, STEM teachers can provide families with information about STEM as an area of study, including applications in lesser-known careers that involve "STEM mindset" and skills. By actively modeling a broader view of STEM and dispelling stereotypes of computer geeks and lab coats, STEM educators can help parents understand the importance of providing students with a strong STEM foundation for later discipline-specific learning in both the traditional fields of science, technology, engineering, or mathematics as well as areas such as finance and entrepreneurship.

A STEM-Based Engagement Activity with Multilingual Families

Family STEM engagement promotes active learning and can serve challenging curriculum, multiple learning approaches, and an inclusive school environment (Suh, Hoffman, Hughes, & Zollman, 2020). We recommend four STEM-based family engagement considerations for building from families' linguistic and cultural funds of knowledge. We frame these recommendations in an experience that represents one possible approach to a family engagement event. This was an evening "Family STEM Night" event hosted at three elementary schools with high numbers of multilingual families. Although we recognize that "family engagement nights" may not reflect the most current forms of family engagement presented in the literature (Baker et al., 2016; Mahmood, 2020), these events are typical in the areas where we work. Such engagement events are one of many ways to honor existing community STEM knowledge and support English language development while simultaneously encouraging students' academic language, conceptual understanding, and meaningful skills.

Center the Event in Existing Community Relationships

Relationships with students are keys to learning families' "funds of knowledge" and finding natural community partners (Moll et al., 1992; Rios-Aguilar et al., 2011). For instance, your community may be home to a particular industry and therefore you may have access to STEM professionals from that field. Keep in mind also that community resources can be outside of commonly "aspirational" STEM fields such as engineering or medicine. For example, a parent working in supply chain or logistics can explain the mathematical calculations involved with determining how far and how much freight can be carried to maximize profit. Sharing such knowledge could inspire an open-ended STEM challenge activity where groups have to move an object from one area of the room to another given specified limitations. In our previous events, university educators served as guest facilitators, but ideally such events could be hosted "in house" by local teachers and community members in order to capitalize on existing family relationships, cultural knowledge, and community partnerships.

Choose a High-Interest, Integrated STEM Exploration Activity

Effective STEM exploration activities for family engagement are ones which encourage hands-on problem-solving but which do not end in one "correct answer." Instead, these activities focus on the process of exploring STEM concepts. Furthermore, an open-ended activity removes some pressure for participants and attempts to avoid "teaching parents." Because these family engagement events occur outside of the regular academic day, they can more easily apply an integrated approach to STEM learning than what may fit into a traditional school schedule. Although students receive instruction in both mathematics and science as a part of their general curriculum, many students have few opportunities to engage in interdisciplinary STEM learning.

In one study, we found that teachers showed interest in interdisciplinary STEM education, but few ventured outside of separate discrete mathematics and science time to plan or implement interdisciplinary STEM learning activities (Zollman, 2012). Nevertheless, teachers and administrators were interested in increasing students' exposure to STEM and recognized family interest in STEM learning (Zollman et al., 2020).

Make the Activity Hands-On and Challenging

A STEM activity we often used is a variation of the "marshmallow challenge." We outlined minimal rules and prompted participants to determine what questions to ask within their groups as to what they were to accomplish. The marshmallow challenge has participants receive 20 pieces of spaghetti, 1 meter of masking tape, 1 meter of string, and 1 regular-size marshmallow. The expectation is to build the tallest freestanding tower out of the spaghetti, masking tape, and string, with a marshmallow on top. Regardless of which activity is used for such an event, we would recommend choosing an activity with a kinesthetic component that invites participants to stand but does not require a great deal of physical movement so that participants of multiple ages and abilities can participate successfully.

As families enter we suggest assigning parents to sit with other parents and students to sit with other students. Similarly, school administrators are assigned to sit as a separate group as are the teachers. We made this choice deliberately as some parents defer to teachers and especially school administrators if they are put in the same group. Each group receives a packet of the same materials.

We found students, in particular, enjoy "competing" with the adult groups. The parents enjoyed working separately from their children. Putting parents in an adults-only group removed the pressure or tendency for the parents to spend time directing or redirecting their children. When placed at a table with other parents, the adults seemed less self-conscious about making mistakes and more likely to laugh with their group members. (Incidentally, in each of the three schools where we did this particular challenge, the student groups outperformed the adult groups.) While we have interpreters on site, we deliberately grouped parents to mix language backgrounds to model that STEM learning can be accomplished with limited verbal communication.

Focus on STEM as Inquiry...for *All* Participants

While facilitating we used a language of inquiry and growth mindset instead of our traditional language of instruction and content delivery. Positioning family members as learners with their students also removes incorrect assumptions that parents need to be English language or content experts in order to support their students' STEM learning. Letting family members be learners as well creates a space for everyone to be silly, make—and learn from—mistakes, and engage in hands-on exploration. Furthermore, it allows adults to participate in STEM inquiry activities themselves without having to be a parent, e.g., to focusing on guiding their child to the "right answer."

After the hands-on activity, we suggest all participants join a large-group reflection discussion to talk about what science, technology, engineering, and mathematics are and are not. For example, solving a real-world problem, such as using geometry to build a tower, connects mathematics to science and to engineering. However, timed basic-fact tests—one activity of a traditional mathematics class that commonly causes anxiety among students—is not an end mathematics goal. Application of the mathematics is a goal.

As a “takeaways” from such our STEM event we included a bilingual handout with advice for reducing STEM anxiety and supporting a growth mindset for learning (see Appendix A). In our own experience, parents expressed appreciation for such take-home reminders of the event in their anonymous surveys.

Our post-event surveys reported parents and guardians seeing STEM education as more hands-on, enjoyable, and problem-based than expected. For example, one parent reported, “I think my children have viewed it differently because I think they view it funner.” Additional parent feedback included mentioning that the learning process was as important as the “answer.” Parents also valued communicating in a team, allowing mistakes, and persevering as important aspects of learning STEM (Zollman et al., 2020).

Welcome All Forms of Language

As families and students undertook the cooperative STEM task, we encouraged communication within groups. We assured families that they can complete this activity in any language. We accepted non-technical language or emergent English for concept development. Most importantly, we engaged with the groups to answer questions or offer encouragement. Families appreciated when teachers and administrators circulated around the room during the challenge, particularly when the educators introduced themselves to parents and greeted students by name.

Some of our family engagement events concluded with a brief introduction of age-appropriate technical STEM language corresponding to the activities the families just completed. This debriefing provided an explicit connection between social and academic language and supported students’ English development. We recommend such debriefing be relatively brief. Remember that family STEM engagement activities are intended to be collaborative and engaging. Technical lectures would be counterproductive to this goal.

Family nights held at a school may not be new or innovative—indeed, family engagement literature offers many other, newer models—yet the parents who participated in the multilingual STEM events reported the types of activities as new and interesting. No parents in our surveys reported having previous experience in school-based learning that involves communication, problem solving, perseverance, or modelling**.** They liked the various role models for the students in the room, in terms of gender and ethnic diversity of presenters. Finally, they enjoyed being able to participate fully even as adults. Our STEM activity presented adults with a non-standard problem that they could tackle. Rather than interpreting procedures or focusing on word walls, parents—and their children—could directly and immediately engage with real-world STEM content through hands-on activities.

Discussion

In this article, we presented suggestions for STEM educators to partner with families of emergent multilingual students through family engagement events. Our suggestions are not meant to be interpreted prescriptively, neither do we claim to have presented an exhaustive introduction to the critical pedagogies informing our recommendations. In the future, we hope to develop a sustained partnership with the schools to collaborate on future STEM family engagement activities. Ideally, STEM educators who already have established relationships with their students’ families build off of existing partnerships. Educators welcome families into seeing STEM education as hands-on learning involving making, learning from mistakes, while simultaneously supporting students' acquisition of academic vocabulary.

Closing Thoughts

As teacher-educators, we have observed how important "intangibles" such as family engagement for emergent multilingual students are often overlooked in teacher education and professional development. We encourage teachers and parents to practice a STEM mindset, avoiding the pitfalls of reductionist thinking about the content or deficit stereotypes of families. STEM educators can expand the whole family's understanding of STEM as an integrated field of inquiry rather than standalone subjects that are composed of procedures and memorized vocabulary. Moreover, STEM educators can reconceptualize family involvement in students' STEM learning to recognize the relevance of family's linguistic resources and the possibilities of school-family partnerships in linguistically diverse communities.

All students benefit from strengthening the connections between home and school—this is particularly true for those whose families do not share a cultural and linguistic background with the school. We know that students achieve more and are more engaged when educators value students' home language and community ways of knowing. We also know that concrete examples, such as the activity from a family engagement night, give context to an integrated approach to STEM learning based in hands-on inquiry rather than technical disciplinary language. This approach to STEM helps not only linguistically diverse STEM students but all STEM students—using family engagement to learn is good for all (Zollman et al, 2020).

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Appendix A: Supporting a STEM Mindset Handout

Supporting a STEM Learning Mindset at Home

***"STEM"* = *S*cience, *T*echnology, *E*ngineering, and *M*athematics**

TRY: Encourage children to play with puzzles, build with blocks, and play strategy games.
WHY: Problem-solving play helps children develop a STEM mindset.

TRY: Praise children when they show a desire to solve challenging problems, when they try something difficult, and when they try again after failing.
WHY: Curiosity is the key to a strong STEM mindset. Persistence results in achievement. Productive struggle with difficult tasks is enjoyable.

TRY: Encourage children to use any language to talk about STEM ideas.
WHY: Learning is a process, not a product. Children are learning STEM in whatever language they speak – even when they don't know technical vocabulary.

TRY: Avoid sharing negative mathematics or science experiences from your own childhood.
WHY: Research has shown that children's achievement can be negatively affected when they hear parents say they are "bad at math" or "hated science." Instead, say something encouraging: "That might be hard sometimes. But it will feel good to accomplish it!"

TRY: When children get a wrong answer in STEM schoolwork, find the logic in their thinking. For example, "I can see why you thought 3 times 4 equals 7. Let's use beans to look at it in a different way."
WHY: Children hear encouragement of their logical thinking instead of discouragement for not reaching the right answer on the first try. We don't want children to be afraid of mistakes. We want to teach them that mistakes are learning opportunities!

TRY: Don't worry about speed in solving problems.
WHY: Forcing children to work quickly can cause anxiety. Children can build a stronger STEM mindset without pressure to work quickly or solve problems in their head.

TRY: Look for STEM all around us.
WHY: Children learn science and math skills from baking, gardening, auto maintenance, nature walks, and other daily experiences. Children develop their STEM mindset when families talk positively about science, technology, engineering, and math in daily life.

Note: Adapted from Zollman, Hoffman, & Suh (2020); Adapted from Boaler (2008).

Ayudando al Aprendizaje de STEM en el Hogar

¨STEM¨ = Ciencia, Tecnología, Ingeniería, y Matemáticas

PRUEBA: Animen a los niños a jugar con rompecabezas, a construir con bloques, y a elegir juegos de estrategia.
PORQUÉ: Juegos que resuelven problemas ayudan a desarrollar una actitud de STEM.

PRUEBA: Alabar a los niños cuando demuestran un deseo de resolver problemas, cuando intentan algo difícil y cuándo vuelven a intentar algo después de fallar.
PORQUÉ: La curiosidad es la clave para una mentalidad para STEM. La persistencia resulta en exits. La lucha productiva con una tarea difícil es agradable.

PRUEBA: Animar a los niños a usar cualquier idioma para tratar de ideas de STEM.
PORQUÉ: El aprender es un proceso, no un producto. Se aprende STEM en cualquier idioma, aun cuando no conocen el vocabulario técnico.

PRUEBA: Evite compartir experiencias negativas de vuestra propia niñez.
PORQUÉ: Hay prueba que el éxito de los estudiantes puede ser afectado negativamente Cuando oyen que los padres fallan en ciencia o en matemática. Es mejor decir algo alentador cómo: Quizá parece difícil ahora pero cuando lo logras te sentirás bien!

PRUEBA: Cuando los niños se equivocan en el trabajo escolar, busca su lógica. Por ejemplo ¨Veo porque pensabas que 3 por 4 igualaban a 7. Vamos a volver a verlo.¨
PORQUÉ: Los niños oyen el animo por su lógica de en vez del desaliento por no llegar a la respuesta correcta la primera vez. No queremos que los niños temen a los errores. Queremos enseñarles qué los errores son oportunidades de aprendizaje.

PRUEBA: No se preocupe por la rapidez en resolviendo problemas.
PORQUÉ: Forzando el trabajo rápido puede causar ansiedad. Se puede construir una mentalidad de STEM sin presión por resolver problemas rápidamente o en la cabeza.

PRUEBA: Busca a STEM a nuestro alrededor.
PORQUÉ: Los niños aprenden aptitudes de la ciencia y la matemática con la jardinería, el mantenimiento automóvil, el paseo de la naturaleza y otras experiencias diarias.

Note: Adapted from Zollman, Hoffman, & Suh (2020); Adapted from Boaler (2008).

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Preservice science and mathematics teachers' acculturation into communities of practice: A call for incorporation of undergraduate research into teacher preparation

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Abstract

Current mathematics and science standards, namely the Common Core State Standards of Mathematics (CCSSM) and the Next Generation Science Standards (NGSS), emphasize engaging students in mathematical and scientific practices. This review article is driven by the question: How can we expect science and mathematics teachers to appropriately engage students in the practices of the scientific and mathematical disciplines, when most teachers themselves lack experience practicing as scientists and mathematicians? To address this question, we review the literature on teachers' understanding of their discipline's practices, disciplinary practices as means to engage in inquiry, and how preservice teacher engagement in undergraduate research experiences may contribute to fostering desirable understandings of their disciplines' practices. We further posit that the communities of practice framework allows teacher educators to conceptualize how undergraduate research can foster understandings of inquiry through engagement in science and mathematical practices, thereby enabling science and mathematics teachers to construct communities of scientific and mathematical practice, respectively, in their own classrooms. We conclude with a call to both provide undergraduate research experiences to preservice science and mathematics teachers as well as an exploration of research that is needed to fully conceptualize the benefits of undergraduate research for preservice science and mathematics teachers.

Keywords: preservice teachers, undergraduate research, communities of practice, inquiry, science and engineering practices (SEPs), standards of mathematical practice

With widespread adoption of the Common Core State Standards of Mathematics (CCSSM) and the Next Generation Science Standards (NGSS), curricular goals within the STEM fields have shifted. These standards emphasize understanding scientific and mathematics concepts, in addition to engagement in science and mathematics as processes of inquiry (NGSS Lead States, 2013; National Governors Association Center for Best Practices [NGA] & Council for Chief State Officers [CCSO], 2010). However, teachers' lack of experience with and knowledge about these practices limit how well they are taught in classrooms (Ricketts, 2014).

The practices described in the standards portray scientists' and mathematicians' actions and behaviors as they engage in inquiry within their disciplines; inquiry builds skills, including the ability to analyze large data sets, collaborate with peers, and design experiments (Marshall, 2013). To prepare their students for the future, teachers need to allow students to construct their own understandings, work collaboratively, and engage in inquiry to identify solutions to real-world, complex problems (Marshall, 2013). To enable inquiry learning, the new mathematics and science standards highlight the importance of problem-based, interdisciplinary lessons that engage students in authentic problem-solving (Mayes & Koballa, 2012).

Inquiry learning persists throughout both mathematics and science classroom content and learning goals (Blanchard et al., 2010; Laursen et al., 2016; O'Brien et al., 2015; Wilson et al., 2010). Inquiry learning can reduce the achievement gap between high- and low-achieving students, increase interest in the content, and deepen understanding (Laursen et al., 2016). Inquiry also creates positive learning opportunities for students (Blanchard et al., 2010; Laursen et al., 2016; Wilson et al., 2010). For example, inquiry learning can increase a student's ability to understand core ideas, learn in more dynamic ways, and collaborate with fellow students (Marshall, 2013).

Inquiry learning is at the heart of STEM education, so effective teachers need to experience how inquiry enables learning. Undergraduate research experiences (UREs) likely provide preservice teachers with opportunities to engage in the inquiry of their discipline, so they build their knowledge of inquiry firsthand. UREs have improved student interest in science and helped students build robust understanding of scientific inquiry (Hunter et al., 2007). UREs provide opportunities for students from all backgrounds to engage in research practices and collaboration (National Academies of Sciences, Engineering, and Medicine [NASEM], 2017), as well as a likely avenue to build skills and motivate preservice teachers to teach inquiry by incorporating the practices of their respective disciplines into their pedagogy. There has been limited research on preservice teacher understanding and intention to integrate the practices of their disciplines into future teaching. Also, to our knowledge, no research has investigated preservice teachers' engagement in the practices of their disciplines outlined in their standards.

Since the development and adoption of the CCSSM and NGSS, mathematics and science teachers are expected to teach inquiry through standards of mathematical practice (SfMP) and scientific and engineering practices (SEPs), respectively. In this article, we collectively refer to these practices, as defined by their respective standards, as disciplinary practices. As mentioned above, potential benefits of UREs include increased interest, understanding, and knowledge within scientific and mathematics disciplines (NASEM, 2017), but few have considered how preservice science and mathematics teachers develop understanding of their discipline's practices, particularly during research experiences. Currently, a URE is not a standard component of teacher education programs, but UREs could be an effective way to develop knowledge of disciplinary practices, which they will be expected to engage students in as teachers. It is uncertain how UREs embed the foundational skills of how to engage in practices within preservice teachers and how this extends into their teaching. While some studies have considered mentoring relationships within UREs and student experiences, very few studies have considered the culture of UREs and understanding of disciplinary practices, let alone how the unique characteristics of research settings may impact student outcomes (NASEM, 2017). In addition, few studies have considered the long-term understanding and teaching integration of disciplinary practices into classrooms. The purpose of this article is to explore the literature on scientific and mathematics teachers' understandings of the practices of their respective disciplines, how disciplinary practices compel engagement in inquiry, the potential influence of UREs on preservice teachers' understanding of their discipline's practices, and UREs' potential usefulness in preparing science and mathematics teachers. We conclude with a call to expand current knowledge of factors that foster science and mathematics teachers' understanding of the practices of their disciplines, which we claim should include preservice STEM teachers' engagement in UREs as part of their preservice STEM teacher preparation.

Practices of the Scientific and Mathematical Disciplines

The NGSS encompasses three overlapping components of scientific knowledge: disciplinary core ideas, crosscutting concepts, and scientific practices (NGSS Lead States, 2013). Crosscutting concepts are ideas that bridge the scientific disciplines and between science and engineering (e.g., structure and function); disciplinary core ideas are specific ideas unique to each scientific discipline; and scientific and engineering practices are the behaviors used to investigate natural phenomena and build theories (NGSS Lead States, 2013). Each standard within the NGSS combines these three elements to define proficient science understanding. Each dimension is equally important for student understanding of science; however, research experiences will likely involve students in the practices outlined by the NGSS. These practices are (1) asking questions and defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations and designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information (National Research Council (NRC), 2012) See Table 1.

The CCSSM were developed in order to create a deeper understanding of mathematics concepts and skills (NGA & CCSSO, 2010). These standards shift mathematics standards to focus on fewer topics, highlight connections between mathematics concepts across grades, and provide rigorous conceptual understanding, procedural skills, and application (NGA & CCSSO, 2010). In addition, these standards include mathematics practices. The Standards for Mathematical Practice (SfMP) describe mathematics skills required for mathematic proficiency (NGA & CCSSO, 2010). SfMP use both procedural and content-based mathematics concepts that enable real-world problems to be solved (NGA & CCSSO, 2010). The SfMP include 1) making sense of problems and persevering in solving them, 2) reasoning abstractly and quantitatively, 3) constructing viable arguments and critique the reasoning of others, 4) modeling with mathematics, 5) using appropriate tools strategically, 6) attending to precision, 7) looking for and making use of structure, 8) looking for and expressing regularity in repeated reasoning (NGA & CCSSO, 2010) See Table 2.

Both SEPs and SfMP are unique to their respective disciplines, but there are areas of overlap. For example, both SEPs and SfMP include developing models that may show the relationships between variables and the real-world (Stage et al., 2013). Also, SEPs and SfMP include justifying claims and evaluating arguments based upon evidence and logic (Mayes & Koballa, 2012). Other potential areas of overlap include constructing arguments, computational thinking, and asking questions and defining problems (Davis et al., 2014; Mayes & Koballa, 2012; Stage et al., 2013). These disciplinary practices are the means through which scientists and mathematicians engage in the inquiry of their discipline.

Table 1
NGSS Scientific and engineering practices and descriptions

Practice	Description
1. Asking questions and defining problems	In science, ask questions to formulate, refine, and evaluate empirically testable questions using models and simulations. In engineering, identify problems and develop designs for useful novel technology.
2. Develop and use models.	In science, use, synthesize, and develop models to predict and explain relationships among variables between systems and their components in the natural world. In engineering, models are utilized to analyze and evaluate technologies.
3. Planning and carrying out investigations.	In science, investigations provide evidence for and test conceptual mathematical, physical, and empirical models. In engineering, investigations are often iterative evaluations of prototypes.
4. Analyzing and interpreting data.	In science, learn more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data of the natural world. In engineering, analysis also includes diverse criteria including scientific and stakeholder requirements.
5. Using mathematics and computational thinking.	Use algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials, and logarithms, and computational tools for statistical analysis to analyze, represent and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Engineering also involves designing concrete items based on real and simulated data.
6. Constructing explanations and design solutions.	Explanations are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. In science, focused on a single “best explanation” for natural phenomena. In engineering, designing solutions involves identifying the “best design solution” based on problem and consideration of tradeoffs (e.g., cost to manufacturer).
7. Engaging in argument from evidence.	Use appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed worlds. Arguments may also come from current scientific or historical episodes in science. In engineering, evidence is utilized to satisfy client needs.
8. Obtaining, evaluating, and communicating information.	Obtain information from multiple sources, evaluate the claims, credibility, and relevance of sources for scientific or engineering enterprise, and communicate findings to the larger scientific community (both verbally and in writing). In engineering, novel ideas are considered proprietary legally and the information is guarded.

Note: Modified from NGSS Lead States (2013) and Cunningham & Carlson (2014), Schwarz et al. (2017).

Table 2
CCSSM standards for mathematical practice and descriptions

Standard	Description
1. Make sense of problems and persevere in solving them.	Being able to analyze givens, constraints, relationships, and goals through self-monitoring, explanations, and logic.
2. Reason abstractly and quantitatively.	Ability to decontextualize and contextualize during problem solving. Creating representation of the problem, considering the units involved, and attending to the meaning of quantities.
3. Construct viable arguments and critique the reasoning of others.	Understand and use assumptions, definitions, and results in constructing arguments. Make conjectures and build logical progression of statements. Justify conclusions, communicate findings, and respond to critiques.
4. Model with mathematics	Apply mathematics to solve problems in everyday life. Comfort in making approximations and assumptions to simplify complex scenarios.
5. Use appropriate tools strategically.	Consider all tools available to solve problems, including simple tools like paper and pencil and more complex tools like calculators and computer modeling software. Understand both the advantages and limits of tools as well as functions and solutions generated. Able to detect possible errors within tools.
6. Attend to precision.	Communicate precisely to others with clear definitions. Describing meanings of symbols, providing units, and label axis. Able to calculate accurately and efficiently.
7. Look for and make use of structure.	Discern a pattern or structure and note complicated things as being single objects or several components.
8. Look for and express regularity in repeated reasoning.	Notice when calculations are repeated and consider general methods and shortcuts.

Note: Modified from NGA & CCSSO (2010).

Inquiry-based Pedagogy and Disciplinary Practices

Inquiry-based pedagogies have been introduced within science and mathematics reform documents (Capps & Crawford, 2013). While there are many definitions of inquiry, three definitions are worth noting: 1) inquiry as content (e.g., the nature and epistemologies of the science and mathematics disciplines); 2) inquiry as action (e.g., engagement in disciplinary practices); and 3) inquiry as pedagogy (e.g., utilizing guided or open inquiry instructional methods) (Capps & Crawford, 2013). This paper focuses primarily on the second aspect of inquiry. Preservice teachers should be able to deliver inquiry-based teaching that parallels the work of practicing scientists (Capps & Crawford, 2013) and mathematicians, so preservice teachers need to come to understand the inquiry practices of their discipline and be active members in the research process in order to be able to do so.

Inquiry-based pedagogy has been connected to many learning goals in both mathematics and science classrooms. Inquiry-based pedagogy enhances student levels of reasoning and argumentation, a key component of the disciplinary practices defined by the standards (Laursen et al., 2016; Wilson et al., 2010). In addition, students receiving inquiry-based pedagogy, which engages them in the disciplinary practices, are better able to persist in problem-solving (e.g., understanding of multiple solutions and pathways to solve problems), learn from the criticism of others, and experience increased interest in the content (Flores et al., 2017; O'Brien et al., 2015; Pudwell, 2017). These benefits extend beyond learning experiences. Inquiry-based pedagogy enables disciplinary practices; engaging in inquiry-based lessons enhances students' interest and provides an avenue to stronger understanding of the disciplinary practices.

Preservice Teacher Understanding of Disciplinary Practices

Science and mathematics practices are interwoven into the framework of the NGSS and CCSSM; therefore, an understanding of these disciplinary practices is essential for science and mathematics teachers to be effective. Disciplinary practices understanding has been explored to a limited degree within secondary preservice and in-service teachers, as elementary teachers are the primary focus of research on disciplinary practices understanding. We synthesize these findings, nonetheless, because they provide a basis for understanding how teachers conceptualize the practices.

Science practices. Developing and using models (SEP2), constructing explanations (SEP6), and engaging in argument from evidence (SEP7) were often absent from in-service and preservice teacher lesson planning and portfolios (Brownstein & Horvath, 2016; Merritt et al., 2018). Therefore, it is unsurprising that literature has primarily focused on interventions to improve preservice and in-service teachers' understanding and classroom implementation of argumentation (SEP7), explanation (SEP6), and modeling (SEP2).

Argumentation and explanation. Engaging in argument from evidence (SEP7) and constructing explanations (SEP6) are often conflated; preservice and in-service teachers are unable to separate the purposes of these practices (Aydeniz & Ozdilek, 2015; Osborne & Patterson, 2012; Ricketts, 2014). Constructing explanations develop cause and effect mechanisms for a phenomenon; in contrast, argumentation considers if the explanation is valid or compares competing ideas (Osborne & Patterson, 2012). While these two practices are intertwined, the level of entanglement is under debate in the science education community (Osborne & Patterson, 2011; Berland & McNeill, 2012; Osborne & Patterson, 2012). Nonetheless, more research has been devoted to preservice teachers' development of argumentation skills than has been devoted to their development of explanation construction skills.

Argumentation with evidence (SEP7) takes time and practice to develop (Driver et al., 2000; Zembal-Saul, 2009). Preservice teachers often fail to acknowledge the importance of considering alternative claims, a key element in scientific argumentation (Dalvi et al., 2020; Osborne &

Patterson, 2012; Zembal-Saul, 2009). In addition, argumentation classroom implementation is viewed as teacher-centered and, often, a formal classroom debate (Dalvi et al., 2020). However, interventions focusing on using evidence for arguments have enhanced participant knowledge of argumentation (Brownstein & Horvath, 2016). Incorporating evidence into explanations is a challenge for preservice teachers (Merritt et al., 2018), which is likely due to an inability to separate inference from evidence (Berland & Reiser, 2008).

Scientific modeling. Preservice and in-service teachers were able to describe models as characteristics of phenomena used to identify parts of a system; however, preservice teachers often fail to apply models as sense-making tools to help construct explanations for both the seen and unseen natural world (Carpenter et al., 2019; Dalvi et al., 2020; Louca & Zacharia, 2012; Ricketts 2014; Schwarz, 2009; Wang et al., 2014). Using models for predictions (Ricketts, 2014; Windschitl & Thompson, 2006) and to describe mechanisms and processes is usually not discussed (Louca & Zacharia, 2012; Windschitl & Thompson, 2006). Also, few preservice teachers acknowledge the iterative testing and revision of models based on data (Göhnur & Krell, 2020). Preservice and in-service teachers grappled with what "counts" as a model (Ricketts, 2014; Van Driel & Verloop, 1999). As such, preservice and in-service teachers describe models as hands-on materials for students to learn scientific facts (Dalvi et al., 2020; Ricketts, 2014; Windschitl & Thompson, 2006), or as a way to simplify systems to make them easier for students to understand (Schwarz, 2009). Preservice teachers are able to discuss specific elements of modeling aligned with NGSS; however, nonnormative conceptions are still expressed (Carpenter et al., 2019), and overall, knowledge of modeling is limited and inconsistent (Van Driel & Verloop, 1999).

Less-studied science practices. The specific practices of asking questions (SEP1), planning and carrying out investigations (SEP3), analyzing and interpreting data (SEP4), using mathematics and computational thinking (SEP5), and obtaining, evaluating, and communicating information (SEP8) have been studied less frequently than argumentation (SEP7), modeling (SEP2), and explanation (SEP6). However, research in elementary education preservice teachers has revealed non-normative understandings for each of these practices. Questioning (SEP1) is viewed as students and teachers posing questions; less attention is given to separating out empirical questions from other forms of questioning (Dalvi et al., 2020; Ricketts, 2014). Preservice elementary education teachers equate carrying out step-by-step labs with planning and carrying out investigations (SEP3); discussions of planning investigations and connecting these investigations with research goals and questions is rarely addressed (Dalvi et al., 2020). Also, planning and carrying out investigations is equated with experimentation; preservice teachers do not discuss other forms of investigations (e.g., observational studies) (Ricketts, 2014).

The practice of analyzing and interpreting data (SEP4) has been less common in preservice teacher edTPA portfolios (Brownstein & Horvath, 2016). Preservice teachers tend to conflate analysis and interpretation and are unable to connect organizing and finding patterns as analyzing data and making sense of the patterns as interpreting data (Brownstein & Horvath, 2016). This could be connected to preservice teachers' lacking the ability to structure data (Bowen & Roth, 2005) or limited experience or understanding on how to implement data analysis and interpretation into teaching practice (Ricketts, 2014). Using mathematics and computational thinking (SEP5) has been equated with plugging numbers in formulas, performing statistical analysis, incorporating technology (e.g., computers, tablets, etc.) into classroom activities (Dalvi et al., 2020), and developing graphs and organizing data (Ricketts, 2014). Preservice teachers tend not to consider the deep thinking required to make sense of values and solve problems with mathematical tools

(Dalvi et al., 2020; Brownstein & Horvath, 2016; Wilkerson & Fenwick, 2017). Finally, the practice of obtain, evaluate and communicate (SEP8) seems to be the least informed practice for preservice teachers (Dalvi et al., 2020); preservice teachers saw this practice as a summary of the scientific method in which an individual obtains data from a scientific experiment, evaluates the results through analysis, and then communicates findings to others (Dalvi et al., 2020). We note that all of these practices are commonplace in undergraduate research experiences.

Preservice teachers display a continuum of understanding across each of these practices (Dalvi et al., 2020), encompassing normative and non-normative ideas as well as a failure to recognize elements of the practices. Non-normative ideas are attributed to unfamiliarity with the practice and its importance to scientific inquiry (Bowen & Roth, 2005; Ricketts, 2014; Windschitl & Thompson, 2006), lack of experience with practice (Bowen & Roth, 2005; Brownstein & Horvath, 2016; Windschitl & Thompson, 2006), and inability to make connections between practice and inquiry (Schwarz, 2009). In addition, for science preservice teachers, traditional college level courses tend not to allow for the development of inquiry knowledge (Windschitl, 2004). Capps and Crawford (2013) suggest an increased understanding of research processes would enhance the level of inquiry pedagogy within classrooms. Thus, it seems plausible that engagement of preservice teachers in UREs would serve to alleviate aspects of these challenges.

Standards of Mathematical Practice. The mathematics education community has considered mathematics preservice teachers and SfMP understanding. Professional development of in-service teachers revealed it was inadequate for experienced teachers to understand the differences and connections between each SfMP by only reading through standards (Bostic & Matney, 2014; Bleiler et al., 2015; Olson et al., 2014). Mathematics teachers have surface level understanding of precision (SfMP6) and do not consider attending to the precision of language (Cheng, 2017; Machmer-Wessels, 2015). Further, experienced mathematics teachers have diminished perseverance in problem-solving (SfMP1) (Bostic & Matney, 2014; Machmer-Wessels, 2015) and less than optimal abstract reasoning skills (SfMP2) (Davis & Osler, 2013). Also, modeling with mathematics (SfMP4) was often viewed as a teacher directly modeling how to complete a solution on the board so students could mimic their problem-solving behavior (Olson et al., 2014). Argumentation (SfMP3) was common in mathematics preservice teaching methods coursework; however, Max and Welder (2020) point out that argumentation should focus on exploring inaccurate reasoning of arguments to maximize efficacy. Finally, attending to structure (SfMP7) and repeated reasoning (SfMP8) were often conflated (Bleiler et al., 2015).

Most investigations of SfMP focus on the pedagogical implementation of SfMP instead of teacher understanding. Some studies highlight the variability of teacher views about SfMP practices of reasoning and utilizing proofs within pedagogy (Davis & Osler, 2013; Kotelawala, 2016; Machmer-Wessels, 2015). The SfMP are less clearly interwoven into the CCSSM than the SEPs are to the NGSS; the SfMP are often seen as separate standards of the CCSSM, causing challenges in teacher implementation (Machmer-Wessels, 2015). Teachers were excited about the SfMP and believed they were integrating the practices into their classrooms; however, this integration is often built upon a simplistic understanding of the SfMP (Machmer-Wessels, 2015) and are interpreted as teacher-centered instead of student-centered behaviors (Olson et al., 2014). Interventions have enhanced teacher understanding of SfMP (Cheng, 2017; Graybeal, 2013). Teacher collaboration, textbooks, professional development, and conferences may help teachers develop and integrate SfMP into their classrooms, but interventions have not been successful in enhancing teacher SfMP understanding (Machmer-Wessels, 2015). There is limited research about the influences of SfMP teacher understanding and no known research on how UREs impact participant SfMP understanding.

Understanding of Inquiry-based Pedagogy

In addition to knowledge of disciplinary practices, teachers need to have a robust understanding of inquiry-based pedagogy in order to compel students' engagement in disciplinary practices (Osborne, 2014). Inquiry-based teaching leads to gains in student outcomes and understanding of both mathematics (Laursen, et al., 2016) and science (Stone, 2014). However, many teachers equate inquiry-based pedagogies with hands-on learning, instead of the actions and processes scientists use to complete their work or the disciplinary practices (Capps & Crawford, 2013; Osborne, 2014). Some teachers do not have experience with or an understanding of inquiry as action and thus do not see connections between inquiry and disciplinary practices (Capps & Crawford, 2013; Kang, et al., 2013; Marlow & Stevens, 1999). Many studies have highlighted the need for increased understanding of both scientific and mathematics practices, and some research has demonstrated that teachers at multiple levels gain better understanding of disciplinary practices after an intervention (Ricketts, 2014; Schwarz, 2009; Windschitl & Thompson, 2006). Interventions include activities such as detecting learning cues while reflecting upon video clips (Graybeal, 2013), an elementary scientific practices methods course (Ricketts, 2014), and an inquiry-based graduate course (Flores, et al., 2017). Other studies have suggested engaging in inquiry-based learning increases the likelihood of teaching through inquiry in the future (Capps & Crawford, 2013; Flores, et al., 2017). Finally, performing student-based investigations may build the skills and knowledge of authentic inquiry (Capps & Crawford, 2013) and these experiences may build familiarity with scientific and mathematics practices, which in turn may support teaching practices in the future (Graybeal, 2013).

Cultural Aspects of UREs

Culture is relevant to preservice STEM teachers' UREs. While there have been many definitions of culture connected to ethnographic studies of scientific spaces, including the relationships between people and objects within laboratory settings (Ayar et al., 2015) and social and individual aspects within science institutions (Godin & Gingras, 2000), we adopt Falk and Dierking's (2000) notion of culture as a collection of shared beliefs and customs. These may include: 1) customary ways of being, 2) codes or assumptions, 3) artifacts, 4) institutions, and 5) patterns of social relations (Ogbu, 1995). Mathematics and scientific working groups possess distinct structure, routines, and collaborations (Hagstrom, 1976), and these disciplinary differences are expressed through the disciplinary practices. These practices provide a shared set of customs within their respective disciplines about important abilities and the generation of knowledge. For example, scientific practices are customary ways of developing scientific knowledge. Epistemological understandings within science, like the nature of science, outline specific codes and assumptions within the scientific community (e.g., scientific theory). Also, each discipline has its own set of codes (common procedures), assumptions, and artifacts (e.g., equipment, thinking tools, methodological techniques) to accomplish the overarching goal of continuing to advance knowledge. The development of disciplinary knowledge varies based on the institutional goals (e.g., teaching versus research focus) and societal norms (e.g., grant-funding). Finally, each individual research setting has specific patterns of social relations that separate it from other spaces, even within the same institution. An individual interacting within a research space potentially interacts with all of these elements of culture, including disciplinary practices.

While scientific and societal culture is used in the broad sense, UREs occur within specific cultural units. Communities of practice (CoPs), a theoretical framework developed through observations of apprenticeships, are relationships among individuals that share activity and work together to improve their performance (Lave & Wegner, 1991). CoPs have a continuum of individuals (e.g., novice to expert, newcomer to old-timer) moving from the periphery to the center of the community (Lave & Wegner, 1991; Nistor et al., 2015; Wenger, 1998). In addition, CoPs require a domain or shared interest, a community in which members share information with each other, and a practice or shared experiences, stories, tools, and/or procedures (Wegner-Trayner & Wegner-Trayner, 2015). CoPs embed learning with collaboration and collaboration with learning (Matusov, 1999). UREs often occur within CoPs. For example, the development of scientific culture occurs within social learning and participation in inquiry (López Cerezo & Cámara, 2007). Within research settings, students share a domain; they interact with peers, graduate students, and faculty; and they work toward shared goals using shared disciplinary practices.

With the intertwined nature of UREs and CoPs, it is important to remember individuals within the communities (Godin & Gingras, 2000). To genuinely belong to a CoP, individuals must be connected to the community or be in the process of building their sense of community (McMillan & Chavis, 1986). McMillan and Chavis (1986) highlighted aspects needed for an individual to develop their sense of community including 1) a sense of belonging and being regarded by other community members; 2) a sense of influence and trust of authority; 3) an ability to satisfy the needs of the community; and 4) a set of shared experiences (McMillin & Chavis, 1986; Nistor et al., 2015). Just as the disciplinary practices are rooted within the culture of the discipline, CoPs provide opportunities for participants to become integrated in the process and constructs of their discipline. However, without a sense of belonging, an individual may not be integrated into the CoP. In other words, without a sense of belonging, an individual may not identify with the culture of their discipline. Given this, we posit that engagement in a community of science or mathematical practice is necessary for preservice STEM teachers to come to identify with their discipline and foster SEP or SfMP in their classrooms.

Learning within Research Experiences

There are multiple forms of research opportunities for students at all levels of education: undergraduate research experiences (UREs), course-based undergraduate research experiences (CUREs), and research experiences for in-service and preservice teachers (RETs). While each research experience may have different goals, participation groups, and demographics, they all have a common thread of providing opportunities for individuals to participate in research, promoting STEM disciplinary knowledge and practices, and integrating participants into STEM culture (NASEM, 2017). In addition to the goals above, UREs and CUREs focus on increasing participant retention and engagement in STEM majors (NASEM, 2017), while RETs focus on translating research experiences to classroom pedagogy and developing relationships with university settings (National Science Foundation (NSF), 2020a).

Undergraduate Research Experiences (UREs). Undergraduate research experiences (UREs) often occur within individual research groups which engage a handful of participants in authentic research directed by the faculty (Auchincloss, et al., 2017; NASEM, 2017). Most UREs allow for one-on-one mentoring between the participant and faculty mentor (Linn et al., 2015). Participants are selected or self-selected to participate (Auchincloss, et al. 2017), and UREs can occur over a school year, a summer, or extended over multiple years. Often UREs allow undergraduates to learn from more experienced faculty and graduate students through apprentice-style programs outside of class time and in research spaces (NASEM, 2017). UREs are more common in science disciplines than in mathematics disciplines (Gallian, 2012; Groth, et al., 2016); therefore, most of the evidence on outcomes of UREs is based in the science disciplines.

UREs increase participant graduation and retention rates and interest in pursuing advanced degrees (Sadler et al., 2010). Beyond encouraging participant retention, UREs have documented learning gains, including learning lab techniques, personal development, research process skills (Lopotto, 2004; Kardash, 2000; Russel et al., 2007), scientific problem-solving skills (Lopatto, 2004; Russell et al., 2007; Seymour et al. 2004), interest in science (Hunter et al. 2007), and sense of responsibility (Hunter et al., 2007). UREs build a stronger understanding of the research process (NASEM, 2017) and provide real-world connections to coursework (Hunter et al., 2007; Hurtado et al., 2009; Miller & Walston, 2017). In addition, UREs support the intellectual growth of participants as they collaborate and share opinions with fellow students and their faculty mentors (Hunter et al., 2007). UREs allow students to think like scientists and learn how to communicate scientific ideas (Seymour et al., 2003). This learning and collaboration are often supported by a faculty member who mentors how research is completed within their research setting (Hunter et al., 2007).

As noted above, UREs are less common in mathematics. For example, a comparison of NSF-funded Research Experiences for Undergraduates (REU) in 2020 noted 38 REU sites in mathematics compared to 71 chemistry, 67 physics, and 136 biology REU sites (NSF, 2020b). However, there has been a push to incorporate authentic mathematics research for undergraduates with REU programs highlighted by the American Mathematical Society (American Mathematical Society, 2020) and mini-grants offered through the Center for Undergraduate Research in Mathematics (Center for Undergraduate Research in Mathematics, 2020). Mathematics UREs look different from science UREs. Instead of focusing on data collection and experimentation, mathematics research focuses on addressing questions about the structure of mathematics systems or applying mathematics to solve practical problems (Subcommittee on Undergraduate Research, 2006). Also, mathematics URE research takes time to deeply think about mathematics problems and questions; therefore, mathematics UREs are less likely to create published works (Subcommittee on Undergraduate Research, 2006). However, similar to science-based UREs, mathematics URE participants note the value of the experience (Connolly & Gallian, 2007), increased participation in graduate school (Connolly & Gallian, 2007; Garcia & Wyels, 2014; Leonard, 2008), creation of research presentations (Das, 2013; Gallian, 2012; Leonard, 2008), development of mathematics research skills (Connolly & Gallian, 2007; Das, 2013), and enhanced ability to communicate mathematics (Leonard, 2008). Das (2013) discussed their experiences and challenges with Academic Year Research (AYR) in mathematics and noted the potential participant benefit of connecting with faculty. However, most papers on mathematics research experiences are program descriptions with benefits outlined through a handful of student quotes. More empirical research is needed on mathematics UREs, and research specifically should focus on the integration of participants into mathematics research culture and the development of mathematic knowledge and practices.

Course-based Undergraduate Research Experiences (CUREs). CUREs tackle novel research questions in a more structured format than apprentice-style URE programs (NASEM, 2017). Participant research experiences are connected to coursework, both electives and required, with one faculty engaging with many students in research at one time (Auchincloss, et al., 2017;

NASEM, 2017). Participation is open to all students eligible to take the course (e.g., completed prerequisites), and research occurs during class time in a teaching laboratory (Auchincloss, et al., 2017). It is unclear how many CUREs are built into course curricula for undergraduates in science and mathematics disciplines as most research has focused on describing specific CURE programs and outcomes. Documented benefits of science discipline CUREs include higher STEM graduation rates (Rodenbusch et al., 2016), development of discipline specific content knowledge, increased interest in discipline (Kortz & van der Hoeven Kraft, 2016; Nadelson et al., 2010), development of technical skills (Kortz & van der Hoeven Kraft, 2016) and real-life connections to coursework (Miller & Walston, 2010).

Authentic mathematics research opportunities for undergraduates sometimes occur as experimental mathematics courses. In this case, the course curriculum is similar to that of CUREs in the science disciplines and explores mathematics by thinking experimentally through discovery of patterns, development of conjectures, and creation of algorithms (Brown, 2014). Experimental courses work on complex solved or unsolved problems (Brown, 2014). Benefits of experimental math courses include “ownership” of mathematics ideas and concepts, and a stronger articulation of mathematics ideas (Brown & Yürekli, 2007). In addition, students participating in experimental mathematics build their ability to question and explore mathematics concepts and view math beyond memorization of formulas or plugging in numbers (Brown & Yürekli, 2007; Pudwell, 2017). More empirical research is needed to confirm course outcomes and how curricula influence students’ understanding of mathematics concepts and practices.

Research Experiences for Teachers (RETs). RETs are specific research programs, often occurring over the summer, that engage preservice and/or in-service teachers in authentic research that can be applied to their pedagogy (NSF, 2020a). RET participants often self-select based on personal interests and goals. Preservice teachers or in-service teachers participating in UREs or RETs have unique learning outcomes. In-service teachers often enter their research experiences with specific goals, which are related to outcomes of the research experience (Faber, et al., 2014). Participants entering with goals focused on conventional teaching are less functional within the research settings than those hoping to integrate research into their courses (Faber, et al., 2014). While individual goals may influence what a participant gains from their research experience, many positive outcomes are likely, including increased understanding of science content knowledge and methods (Boser & Faires 1988; Cutucache et al., 2017; Herrington, et al., 2016; Raphael et al., 1999; Westerlund, et al., 2002), renewed excitement in subject matter, changed attitudes toward inquiry-based teaching practices (Herrington, et al., 2016), and increased awareness of connections between science and education through genuine examples and experiences (Boser & Faires, 1988; Buck, 2003; Raphael et al., 1999; Westerlund, et al., 2002). First-hand scientific experiences increase likelihood of desirable changes in pedagogical beliefs and practices (Miranda & Damico, 2013; Windschitl, 2004). In addition, RETs support pedagogical change by building confidence in use of scientific instruments, which may increase the likelihood of incorporating similar scientific processes into curriculum (Buck, 2003; Cutucache et al., 2017; Dresner & Worley, 2006). RETs value extends beyond content knowledge and pedagogical change. RETs build partnerships with scientists and fellow participants as resources when participants return to their classrooms (Dresner & Worley, 2006).

Most RETs programs are focused on recruiting science in-service teachers. Some RETs have recruited both math and science teachers (Boser & Faires, 1988). However, currently there is a dearth of literature on the experiences of participants in mathematics RETs, because they are so few.

Research Experiences and Culture. All forms of research experiences are an effective way to integrate participants into the process of disciplinary research. Time within the research setting is an important consideration, as the more time spent in a research setting enhances outcomes (Linn et al., 2015). Individualized research experiences, like those offered through URE and RET programs provide more time to develop and learn science and mathematics processes; however, the culture and social structures within these research settings can impact student outcomes. Participants within science laboratories are embedded in the culture of science (Westerlund, et al., 2002). Research experiences increase participant confidence to practice research and contribute to science and mathematics through building professional relationships with faculty and peers (Baum et al. 2017; Hunter, et al., 2006). Research experiences hold the potential to shift participant identity and sense of belonging, allowing participants to 'feel like a scientist' (Hunter, et al., 2006; Seymour et al., 2004) or 'feel like a mathematician.' This finding is shared with other research studies, highlighting the authentic participation and integration into the disciplinary community that occurs over time within an URE or RET (Faber, et al., 2014; Westerlund et al., 2002). UREs and RETs develop a participants' sense of community within a CoP. As a participant becomes more integrated into the research setting, participants feel like they belong (Faber, et al., 2014); an individual's identity evolves to fit within a specific research-oriented CoP (Lave & Wegner, 1991).

CoPs include relationships within settings. Studies of research experiences demonstrate that the relationships with faculty and peers impact learning gains and beliefs within UREs and RETs (Burgin & Sadler, 2016; Eagan et al., 2013; Southerland et al., 2016). These relationships may be influenced by the culture developed within each research setting's CoP. For example, in a study of a summer high school research apprenticeship, scientific laboratories that seemed to support nature of science learning included 1) a variety of methods used during research, 2) an opportunity for students to make meaningful contributions to research as a team member, and 3) a faculty mentor who discusses the nature of science with their students (Burgin & Sadler, 2016). These findings demonstrate McMillan and Chavis's (1986) four aspects of the sense of community framework (i.e., sense of belonging, trust of authority, ability to contribute; shared experiences).

Similarly, aspects of CoP are reflected in other URE studies. Russell et al. (2007) noted students involved in the culture of research, including attending conferences, mentoring peers, and authoring papers, had more positive outcomes than those that were less involved within laboratory settings. These outcomes included increased confidence in research skills and interest in advanced degrees in the STEM fields (Russell et al., 2007). UREs reflect the legitimate peripheral participation that facilitates a new member's integration into the CoP (Lave & Wegner, 1991). With a number of studies noting the development of confidence in laboratory work and scientific practices (Harsh et al., 2011; Hunter et al., 2006; Russel et al., 2007; Westerlund, et al., 2002), URE structure may influence a student's sense of community and build research identity (Buxton, 2001). Socialization into the community provides validation and recognition of the individual's new identity (Hurtado, et al., 2009).

In addition, collaboration between mentors and students to develop personalized research projects based upon student interest and skill-sets foster student confidence while conducting research and long-term interest in STEM careers (Harsh et al., 2011). The design of research experience programs and mentorship style (e.g., collaboration) play a role in student outcomes

(Harsh et al., 2011). The research setting culture and relationships between mentors and students can enhance collaborative learning and develop the competence needed for success within the discipline (NASEM, 2017). While aspects of positive mentoring relationships have been considered in previous research, few studies have considered which aspects of mentoring are important for positive student outcomes (NASEM, 2017).

As discussed, research experiences often occur within communities of practice. They provide opportunities for students to engage within a research domain, develop relationships and collaborations, and learn the practice of researchers. Through these unique interactions, undergraduates have opportunities to build their personal identities as researchers and learn how to engage in the practices of the scientific community (Lave & Wegner, 1991; Linn et al., 2015). CoPs within research settings and the relationships between research faculty and students that develop within the CoPs enhance student outcomes. Mentoring within UREs and RETs is an important aspect of learning within research settings. Mentors have many roles within research laboratories: coordinating research tasks, monitoring progress, guiding research, fostering skill development, facilitating participation, building networks, and enhancing student identification with the discipline (NASEM, 2017). Strong mentors are able to rotate between shifting roles but also provide students with opportunities to become contributing members to the research setting (Faber et al., 2014). These mentors engage students in research practices, emphasize teamwork, allow mastery of techniques, communicate results, and slowly increase the responsibility of the students over time (NASEM, 2017). UREs and RETs have the potential to build participant agency (Faber, et al., 2014; NASEM, 2017; Westerlund et al., 2002), and this sense of agency is likely connected to the mentoring relationship developed over the course of the research experience.

Research Experiences and Preservice Teachers. Few preservice teachers apply for URE programs or present authentic research at conferences (Manak & Young, 2014). Barriers to preservice teacher participation in UREs or RETs include the amount of time to complete teacher accreditation and a focus on finding teaching opportunities to enhance professional resumes (Manak & Young, 2014). Therefore, there is limited knowledge on how mathematics or science disciplinary research experiences impact science and mathematics preservice teachers. Research describes similar outcomes from preservice science teacher research experiences as in-service teachers participating in RETs, including increased procedural, content, and technical knowledge, comfort with research unknowns, and confidence in open-ended experimentation (Brown & Melear, 2007; Raphael et al., 1999). The Maryland Collaborative for Teacher Preparation was developed for mathematics and science preservice teachers and noted similar gains in confidence and disciplinary content knowledge, but also shifts in pedagogical viewpoints toward inquiry (Langford & Huntley, 1999). O'Hanlon et al. (2015) describe the development of preservice mathematics teacher participants' procedural skills and changes in pedagogical orientations toward more discovery-based lessons during a summer research experience. Preservice teachers, embedded in authentic research experiences, learned science by doing and encountered relevant examples of how mathematics and science connect to real-life, which could be incorporated into their pedagogy (Raphael et al., 1999). Other research experiences for preservice teachers provide training in action research (Groth et al., 2016). Action research was perceived as useful to preservice teachers because it develops the skills of reflection on teaching in tandem with increasing content knowledge (Groth et al., 2016; McIntyre et al., 2015; Myers et al., 2018). Most of the literature on education action research focused on developing pedagogical skills of reflection for preservice education majors (e.g., English education, special education, middle school education); however, less attention was given to the growth of disciplinary practices understanding while conducting research projects. Teachers with long-term research experiences were more likely to use inquiry-based pedagogies in their classrooms (Windschitl, 2004), connect their coursework with real-life examples, have increased confidence in subject content and procedures, and build useful relationships with faculty and researchers (Raphael et al., 1999). We would hope scientific and mathematics content coursework would provide a foundation for building disciplinary practices understanding; however, we argue that traditionally taught content courses do not provide the experiences necessary to develop a robust understanding of inquiry as action or the disciplinary practices. For example, Windschitl (2004) noted traditional science content coursework did not enhance preservice teacher scientific argumentation skills. Therefore, without participation in authentic research, teachers may fail to develop understanding of the scientific enterprise (Faber, et al., 2014), which we argue will undermine their ability to implement the standards by engaging students in disciplinary practices.

A Call to Action

Since the development and adoption of the CCSSM and NGSS, science and mathematics teachers are expected to teach inquiry through SEP or SfMP, respectively. Many studies demonstrate the potential benefits of UREs, including increased interest, understanding, and knowledge within scientific and mathematics disciplines (NASEM, 2017). However, few have considered how preservice teachers develop disciplinary practices, and research experiences seem like the most obvious setting in which they could gain experience practicing as a scientist or mathematician. It is unclear how many teacher education programs require a research internship in addition to discipline-focused methods coursework. Also, it is uncertain whether these internships imbed the foundations of scientific or mathematics practices within preservice teachers, which then extends into their teaching. While some studies have considered mentoring relationships within UREs and student experiences, very few studies have considered the culture of URE and understanding of disciplinary practices, let alone how the unique characteristics of research settings may impact student outcomes (NASEM, 2017). In addition, few studies have considered the long-term understanding and teaching integration of scientific and mathematics processes within classrooms.

Therefore, we call upon our STEM education community to engage preservice teachers in UREs and further explore UREs and their influence on preservice secondary science and mathematics teachers' understanding of their disciplines' practices. We argue that UREs allow preservice teachers to become acculturated into a community of practice that would facilitate deep understanding of the practices of their discipline, enabling them to integrate engagement in disciplinary practices into pedagogy. Therefore, we suggest that research experiences that allow preservice teachers to interact within their disciplinary community via RETs or UREs are likely to accomplish these goals. We hope to see an expansion of current knowledge of factors that allow preservice science and mathematics teachers to engage their students in their disciplinary practices, which may have implications for undergraduate preservice STEM teacher education.

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Don’t Run Out of STEAM! Examining Instructional Barriers to a Transdisciplinary Learning Approach

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Abstract

Reform-based instruction can maximize learning and provide equitable access for students in both mathematics and science. A proposal for change by national organizations shed light on the need for programs in integrated science, technology, engineering, and mathematics (STEM) or with the inclusion of the arts (STEAM). A balanced approach to integrated STEAM education uses real issues from around the world to challenge students to be innovative, creative, and think critically about ways they can provide solutions. The purpose of this article is to highlight the potential of a transdisciplinary STEAM instructional approach, while examining the barriers that teachers face in implementation, and provide possible suggestions that allow for successful implementation of transdisciplinary STEAM instruction. With the growing interest in STEM education, it is important to better understand teacher challenges and obstacles to provide support for educators who are developing and implementing integrated STEM instruction. Integrated STEAM allows for creativity across disciplines and promotes students to become conceptual thinkers who are ready to approach future careers and education with more imagination and innovation.

Keywords: STEAM, STEM, education, barriers, transdisciplinary

It is no secret that education approaches have changed dramatically over the years. We can all reach into a memory of our learning experiences as children, and no two of them are alike. Imagine a classroom where desks are always in straight rows, most work is assigned from a textbook, and lessons are taught through direct instruction with students following notes on the board. Many of us have similar memories of this type of learning at some point in our education, while others may have an experience that was much different. Many parents and educators feel their children should be taught using the same methods they were taught, through memorization, formulas, procedures, and repetition.

The National Council of Teachers of Mathematics (NCTM, 2009) disagrees with these traditional methods, stating that mathematics should be taught to promote reasoning and problem solving, where lessons are focused on discourse through engaging students in high quality tasks. The National Research Council (NRC) provided a Framework in 2012 that gave further support to the call for change in education practices, stating that learning experiences should engage students with fundamental questions focused on the world around them through scientific investigations and engineering design. Such reform-based teaching is intended to provide equitable access to both science and mathematics content and practices in a way that can maximize the learning potential of each and every student (Bush & Cook, 2019). This proposal for change by national organizations such as National Council of Teachers of Mathematics (NCTM), National Council of Supervisors of Mathematics (NCSM), National Science and Technology Council (NSTC) and National Research Council (NRC) shed light on the need for programs in integrated science, technology, engineering, and mathematics (STEM) or with the inclusion of the arts (STEAM).

In particular, this change is needed at the middle school level, when young adolescents are searching to find their place in the world. This work aligns to the Association for Middle Level Education's (formerly National Middle School Association) *This We Believe*, which identifies one of the 16 characteristics of successful schools as engaging students in curricula that is challenging, exploratory, integrative, and relevant (NMSA, 2010).

A balanced approach to integrated STEAM education prepares students to use innovation, creativity, critical thinking, collaboration, and effective communication to solve some of the world's most pressing issues (Quigley & Herro, 2016). Bush and Cook (2019) explain how integrated STEAM education helps to prepare students for future careers by engaging students in transformative learning experiences in the classroom. STEAM-based instruction increases academic achievement in schools and builds knowledge in critical areas that will be important to tomorrow's workforce (Quigley & Herro, 2016). Dewey's (1938) progressive education movement provided insight into the roots of integrated STEM and supports that an integrated approach is necessary to deal with today's problems in society. Global and national attention to STEAM poses a challenge to education, calling for innovative ways that teachers can implement quality tasks and help students to be successful (Quigley & Herro, 2016).

A Call for Change

STEM education has become a priority in the United States as students persistently score low in science and mathematics on international and national assessments (Du et al., 2019). The United States Congress enacted the *STEM Education Act of 2015* after Programme for International Student Assessment (PISA) produced a report in 2015 showing that the situation in the United States had not improved in nearly a decade, which provided concerns that STEM workforces would be impacted in the future (Du et al., 2019). The *STEM Education Act* was enacted by the US Department of Education (2016) which renewed commitments with the National Science Foundation (NSF) calling for a more integrated approach while moving away from the traditional approaches of learning science and mathematics in isolation to better prepare students with the skills that are necessary to solve societal problems of today (Du et al., 2019). A new vision for STEM education was introduced in 2018 by the United States Department of Education Office of Innovation and Improvement which calls for STEM to be meaningful and inspiring, where students are engaged in transdisciplinary activities that require them to identify and solve problems using knowledge across disciplines with initiative and creativity (NSTC, 2018).

The purpose of this article is to highlight the potential of a transdisciplinary STEAM instructional approach, while examining the barriers that teachers face in implementation. By identifying these barriers, we can offer possible suggestions that allow for successful implementation of transdisciplinary STEAM instruction.

A Transdisciplinary Approach

A transdisciplinary approach is, in essence, "beyond the disciplines," where students and teachers are using collaborative expertise to pose and solve problems in a way that foregrounds the problem outside a single discipline (Quigley & Herro, 2016). Bush and Cook (2019) define transdisciplinary as "going beyond the disciplines to create new knowledge or ideas" and suggest connecting with the community to identify real issues in the community so student learning can be situated in meaningful contexts. Edelen et al. (2019) describe a transdisciplinary inquiry as a way to present problems where the students become so engaged in the problem that they use previous knowledge to acquire new knowledge from multiple disciplines where the focus is on the student, allowing them to decide on their learning and the knowledge needed to find solutions to authentic problems.

Bush and Cook (2019) offer quality STEAM inquiries in their publication, *Step Into Steam.* An ideal STEAM inquiry sample task, a second-grade inquiry titled "Preventing Dehydration in a Blizzard: Melting Ice" (p. 129) from this publication lays out both content and standards and explains what students are doing during the inquiry. The problem statement for the students provides a context with a family snowed in for a blizzard. Students are asked to find a way to melt the ice so they can get their family to necessary supplies for survival. For this inquiry, students are using multiple materials to design a heater to melt ice for science, using a timer to track the time it takes to melt for technology, choosing appropriate materials and modifying their design for engineering, creating a bar graph for materials tested for mathematics, and finally simulating movements of ice and water molecules for arts. This STEAM inquiry example helps to outline the importance of an approach to learning that is transformative, allowing students to solve problems that go beyond the classroom and find solutions to issues that could be meaningful (Bush & Cook, 2019).

When examining a transdisciplinary approach, Quigley and Herro (2016) explained that life is rarely confined to artificial boundaries of a specific academic discipline, and in order to meet the demands of the societal, environmental, industrial, scientific and engineering problems of the real world, it is important to examine a problem through frameworks that allow for this type of thinking. This type of approach tends to be the most difficult to achieve, as it requires a common perspective as members of different disciplines work together to share a conceptual framework and have the same shared goals (Choi & Pak, 2006). A transdisciplinary approach integrates the natural, social, and health sciences in a way that it focuses on a humanities context and transcends individual traditional boundaries (Choi & Pak, 2006). Herro and Quigley (2016) explain that transdisciplinary teaching helps students to explore content areas using a multiple inquiry process in which students connect to the disciplines naturally through the problem-solving process.

Transdisciplinary teams share both goals and skills, using a shared conceptual framework to approach a common problem (Choi & Pak, 2006). This type of instructional approach can strengthen student learning and increase their desire to pursue a career in science or mathematics, but it is difficult to know how to effectively support transdisciplinary teaching with pedagogical techniques that meet curriculum requirements (Herro & Quigley, 2016). A transdisciplinary approach is the movement from one discipline to another fluidly (Figure 1) where students are using the skills necessary to solve problems while making connections to the world around them.

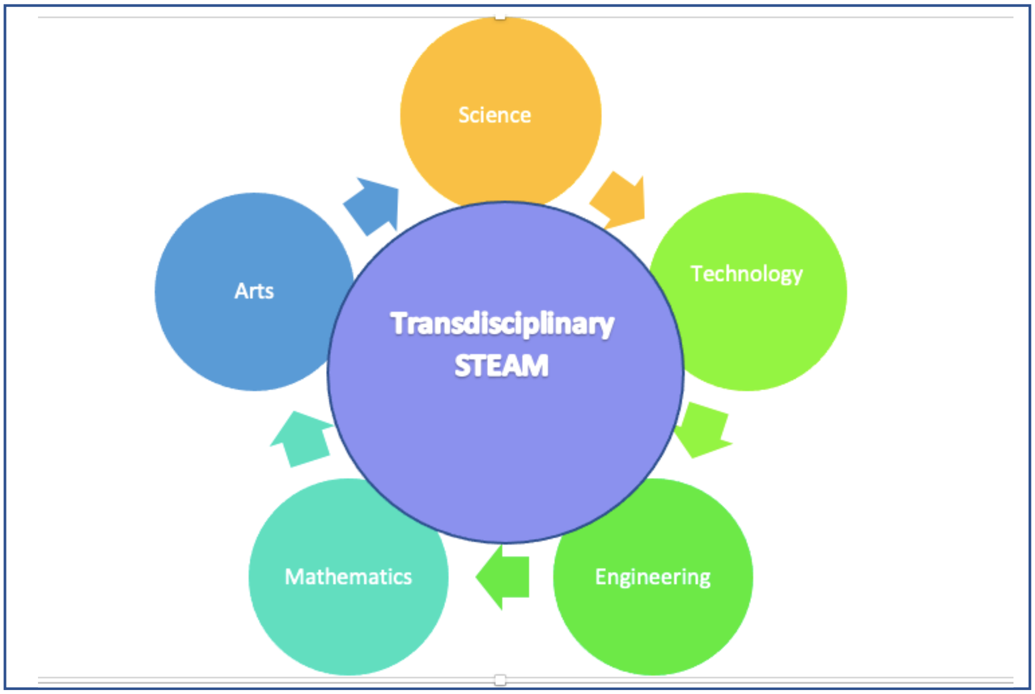

Figure 1. A diagram to illustrate the idea of transdisciplinary, showing that it moves fluidly from one discipline to another.

STEM to STEAM

Teachers need a clear definition of integrated STEAM education to allow them to truly understand what is expected and improve their practice (Quigley & Herro, 2016). The addition of the arts in the original STEM approach allows for new approaches to problem solving that provides a natural platform for a transdisciplinary inquiry and provides us with the new anacronym of STEAM (Quigley & Herro, 2016). The addition of the A acknowledges the importance of adding emotional connections and an appreciation for beauty, creativity, and aesthetics into the development of solutions in problem solving (Bailey, 2015. Art, science, music, and mathematics are fluid and breaking the boundaries between disciplines allows educators to engage learners in creative ways to solve problems (Henriksen et al., 2015).

With a focus on STEAM teaching practices in science and mathematics in middle school classrooms, Quigley and Herro (2016) found that STEAM teaching involves a major shift in teaching for many, and it takes time to refine and implement effectively. It is common for educators to express concern that content could lack rigor if not taught in a concentrated manner (Park et al., 2007; Bush & Cook, 2019). However, integrated STEAM learning helps students understand how concepts or skills are connected across disciplines and encourages them to use those skills in meaningful ways (Bush & Cook, 2019). A desire for a balanced approach lends itself to a STEAM focus, where art can incorporate new approaches to problem solving and delivers a natural entry to a transdisciplinary inquiry (Quigley & Herro, 2016). Some barriers that may prevent teachers from implementing transdisciplinary STEAM teaching include time constraints, lack of understanding of problem-based versus project-based learning, testing pressures, lack of understanding of other content areas, and collaboration among students (Quigley & Herro, 2016).

It is important to consider the reason STEAM instruction is still elusive to so many and figure out why it remains a struggle to broadly implement successfully. Eliminating barriers would allow teachers to create a learning environment that promotes investigations that allow for students to engineer solutions to problems and construct explanations based on evidence of real-world phenomena (Shernoff et al., 2017). The goal of transdisciplinary STEAM instruction is to prepare students to solve the pressing issues facing the world through critical thinking, effective communication, and collaboration (Quigley & Herro, 2016). Due to the rising trend of integrated STEAM education in K-12 schools and newly created schools specifically dedicated to STEAM instruction, it is imperative to research and support ways to support teachers in implementation. Quigley and Herro (2016) note that research is necessary to discover any barriers that could be holding back implementation and find ways to help educators to make sense of this innovative teaching practice.

Many educators have implemented inquiries in their classrooms which they have considered to be STEAM focused, but they have done so without complete understanding of what these inquiries are and what they are intended to achieve. Problems are commonly introduced by providing a problem to be solved, but the process lacks the depth and opportunity for connections or conceptual development across disciplines. Providing a real issue with a meaningful context could potentially allow the students to transcend the boundaries of a single discipline and form their own learning and understanding as they seek a solution to the problem. Problems similar to "Preventing Dehydration in a Blizzard: Melting Ice" (p. 129) by Bush and Cook (2019) have the potential to encourage engineering design, science and mathematics simultaneously without consideration of acknowledging subjects as individuals. The way an inquiry is implemented plays an instrumental role in the learning that students obtain from the inquiry. STEAM inquiries should engage students in an authentic open-ended problem with multiple solution paths where all students can contribute and work together toward a common goal (Bush & Cook, 2019). This transition in selection and implementation is what is needed in order to prepare students for the real-world problems they will face.

Barriers Educators Face in Implementing Transdisciplinary STEAM

Despite the many calls to increase integrated STEAM approaches in the classroom, there exists many barriers that have prevented educator efforts from being successful. Originally referred to as SMET by the National Science Foundation, STEM brought about educational initiatives to challenge students with critical thinking tasks designed to ready them for the future workforce (White, 2014). Barriers to STEM and STEAM instruction include a lack of teacher understanding, lack of time for collaboration and planning, and barriers of school organization (Shernoff et al., 2017; Herro & Quigley, 2016). With the growing interest, it is important to better understand challenges and obstacles to provide support for educators who are developing and implementing integrated STEM instruction (Shernoff et al., 2017).

Lack of Teacher Understanding

A lack of understanding may be a barrier that can be contributed to the somewhat recent age of technology, where teacher preparation has failed to keep up with the rapid introduction of new technologies. Teachers must be prepared to teach with technology and twenty-first century skills to have the foundation to practice, collaborate and implement STEAM units successfully (Quigley & Herro, 2016). Shernoff et al. (2017) contend that most teachers went to college before integrated

STEM became a focus, which leads to many teachers who have little to no practice in STEM approaches. The national K-12 STEM movement provided a push to develop educators in STEM areas which has been met with very little attention to teacher preparation or professional development where little research exists on methods to effectively prepare teachers for implementing STEM (Rinke et al., 2016). The call for a transdisciplinary focus also poses the barrier of lack of understanding in content and standards of subjects outside of the focused discipline of the middle school teacher (Shernoff et al., 2017). It is difficult to imagine a way to prepare teachers with the pedagogical content knowledge required to teach all STEM subjects simultaneously and effectively, when science, mathematics or technology require large amounts of content knowledge to teach each subject individually (Sanders, 2009). Introducing STEM educators to foundations, pedagogies, curriculum, research and contemporary issues allows them the opportunity to integrate complementary content and better understand integrative approaches in their classrooms (Sanders, 2009).

Lack of Time for Collaboration

This lack of understanding leads to the next barrier—a lack of time for collaboration among colleagues. Creating effective learning environments full of student engagement and effective instruction requires collaborative teacher planning that must be supported consistently by school leaders (NCTM, 2014). Time for collaboration during the school day is inadequate, and most schools do not have a daily schedule that provides time for professional collaboration that is necessary to strengthen pedagogical skills (NCTM, 2014). Both the lack of time for collaborative planning and the lack of time for STEM instruction are discussed as barriers that hinder the abilities of teachers to generate ideas and support each other’s work (Shernoff et al., 2017). A team that is considered transdisciplinary is composed of members who have developed trust and mutual confidence that allows them to transcend disciplinary boundaries to move toward a holistic approach (Choi & Pak, 2006). Allotted time for collaboration would allow for teamwork to support transdisciplinary STEM education (Shernoff et al., 2017). Collaboration allows an opportunity to connect with experts in other fields to provide necessary support for implementation of multiple content areas (Herro & Quigley, 2016). Collaboration is believed to assist teachers in understanding STEAM content and connect to experts in the field which allows for transdisciplinary teaching (Herro & Quigley, 2016). Time for collaboration must be considered as a crucial component to the implementation of effective STEAM inquiries.

Barrier of School Organization

Though many teachers desire the time for collaboration with their colleagues, others suggest STEM should be its own class completely (Shernoff et al., 2107). With the arrangement of middle school bell schedules, time to implement STEM activities in the classroom is restricted (Shernoff et al., 2017). Bush and Cook (2019) explain that integrating STEAM subject areas allows for subject area standards to be addressed simultaneously, helping to address the issues of time constraints in schedules. Herro and Quigley (2016) noted the lack of flexibility over the pacing of the courses, explaining limits to transdisciplinary approaches due to the prescribed nature of the scope and sequence of the courses they wish to integrate. STEAM can be interwoven into time that is already dedicated to mathematics and science, toward the end of instructional units, or during specific blocks of time each week or month as possible solutions to scheduling issues (Bush & Cook, 2019).

Discussion, Implications, and Suggestions

With the identification of the barriers that teachers face in the classroom, it is important to examine ways to overcome those barriers and move forward. Today's young adolescents are exposed to technology in ways that were unforeseen decades ago and dated approaches to pedagogy will not be sufficient for students who are entering schools now or in the future (Wynn & Harris, 2012). Transdisciplinary approaches will take practice, and each inquiry should prove a learning opportunity for teachers to grow and improve. Professional development sessions or workshops could offer opportunities for teachers to work together to experience STEAM activities and help support them as they design and implement them in the classroom. The increase in focus on STEAM instruction as a powerful learning area for future workforce should be noted in the development of curriculum and design of school organizational structures. Building community partnerships that allow students the opportunity to experience STEAM careers or speaking with professionals that hold STEAM careers can help build interest and provide teachers with content for lessons. Support from coaches, administrators, and districts is key in promoting a positive learning environment that allows for teachers to embrace change. Further research is needed to help educators overcome the barriers in the implementation of integrated STEAM principles to allow them to provide impactful contextual learning opportunities for all students. Integrated STEAM opportunities allow for creativity across disciplines and promotes students to become conceptual thinkers that will approach future careers and education with more imagination and innovation (Wynn & Harris, 2012). Transdisciplinary STEAM should become a forefront of educational focus and discussions to allow for teachers and students to embrace this innovative learning experience.

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Supporting STEM Teachers through Online Induction: An E-Mentor's Exploration in Cyberspace

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Abstract

This self-study examines the processes involved in e-mentoring novice STEM teachers while using a university-sponsored comprehensive online induction platform. During this self-study, I e-mentored three STEM teachers for four months. The self-study of teaching and teacher education practices (S-STTEP) methodology was used to study my own e-mentoring facilitation. Data were collected from interviews, online textual data, and my own personal reflective journals. By studying the process of e-mentoring, I gained a more thorough understanding of the challenges involved in e-mentoring novice STEM teachers. This research also helped me better understand the induction of novice STEM teachers through e-mentoring on a university-sponsored online induction platform.

Keywords: online induction, e-mentoring, STEM, self-study

E-mentoring has been used to support novice teachers who may not have adequate school-based mentoring. Smith and Israel (2010) define e-mentoring as "the use of online tools such as e-mail, discussion boards, chat rooms, blogs, web conferencing, and growing internet-based solutions that are changing the way mentors and mentees interact" (p. 30). E-mentoring can provide beginning teachers with a peer in the same discipline even if that person does not teach at the same school. The perceived lack of e-mentoring support for new STEM teachers led to my interest in conducting a self-study of my own e-mentoring teacher education practices. A self-study is defined as the "critical examination of one's actions and the context of those actions in order to achieve a more conscious mode of professional activity" (Samaras, 2002, p. xiii). By studying the process of e-mentoring through self-study, I felt that I could gain a more thorough understanding of the challenges involved in e-mentoring beginning STEM teachers. Additionally, I felt that this research could help me better understand the induction of new STEM teachers through e-mentoring on a university-sponsored online induction platform.

Literature Review

What does the research say about the needs of beginning STEM teachers?

Some beginning teachers leave the profession because they do not receive the support they need. In the United States, the attrition rates for new teachers within the first five years is 42% (Perda, 2013). When new teachers have a mentor in their own subject area, the risk of those teachers resigning at the end of the school year is reduced by 30%. Even a mentor outside of their subject area reduces the risk of attrition by 18% (Smith & Ingersoll, 2004). Beginning teachers require a myriad of supports from mentors and school leaders to thrive in the classroom. The Excellence in Teaching program 2010 Excel Award winners identified that to become highly effective, new teachers need help with lesson planning, classroom management, professional decision-making, routine school procedures, modeling, effective mentoring relationships, and support from school administrators (Ross et al., 2011). Similarly, in a needs survey administered to 594 new and experienced STEM teachers, Jones et al. (2016) found that both groups needed the most support with instructional strategies, data literacy, and differentiated instruction. The findings from these two studies suggest that mentors could meet the needs of mentees if the mentor lacks content knowledge.

What does the research say about online induction?

Technological advancements in computer-mediated communication (CMC), or synchronous or asynchronous online communication tools, have transformed teacher induction. Online induction has emerged from these advancements in technology as a specific type of induction that requires the use of CMC tools. Online induction utilizes CMC tools to facilitate mentoring, collaboration, and reflection. The mentoring component of online induction is often referred to as e-mentoring. The flexible nature of online induction makes it possible for school systems to provide support when traditional teacher induction programs (TIPs) with face-to-face support are not a viable option.

Recent online induction studies primarily focus on e-mentoring support for beginning teachers, online induction support through online learning communities (OLCs), and the development of new teacher's reflective skills. Studies by Bang and Luft (2014), Hunt et al. (2013), and Jones et al. (2016) provide insight into how e-mentoring supports novice content area and special education teachers.

Bang and Luft (2014) investigated the interactions of novice teachers and experts in a subject-specific, e-mentoring program developed to boost STEM achievement. The interactions between two beginning science teachers and their mentor teachers were examined over the course of one year. WebCT served as the online platform for communication between mentors and mentees. This platform included a virtual room for asynchronous communication between mentors and mentees. During the study, participants were advised to post comments approximately four times a week regarding science teaching issues. In addition, e-mentors and mentees were asked to plan, implement, and reflect on a lesson together. Computer-mediated discourse analysis was used to analyze participation patterns, interaction, and social behavior. The findings indicated that all participants felt like they were partnered with like-minded individuals, and the experience helped them develop a sense of comradery. Mentees believed that online mentoring helped their teaching practices, while e-mentors believed that the experience helped them improve their pedagogical content knowledge. This study was significant because the formal e-mentoring partnerships afforded benefits to both mentors and mentees. Additionally, asynchronous communication tools within an online platform offered flexibility of time and location.

Hunt et al. (2013) examined the efficacy of novice special education teachers using the New Teacher Center's Electronic Mentoring for Student Success (eMSS) mentoring and induction platform. The New Teacher Center (NTC) is a non-profit organization driven to improve student achievement by contributing to the effectiveness of novice teachers and administrators ("About New Teacher Center," n.d.). Twenty-two novice special education teachers participated in the eMSS e-mentoring program. Data was collected from a pre- and post-survey that was administered to these teachers. The eMSS platform was designed to provide mentoring according to a teachers' content area or exceptionality specialization (e-Mentoring for Student Success (eMSS)," n.d). However, Hunt et al. (2013) found that the perceptions of the novice teachers regarding knowledge acquisition, teaching practices, and professional growth were unfavorable. This study was important because the results indicated that "one size fits all" online induction programs may not be appropriately tailored to the needs of novice teachers who teach in different contexts.

Jones et al. (2016) piloted the Florida STEM TIPS online induction platform with four school district partners. STEM TIPS supports school district induction programs with the goal of retaining new STEM teachers. The platform includes online curriculum resources and an array of CMC tools designed to facilitate communication between mentors and mentees. Jones et al. (2016) examined the impact of the platform by administering a survey to 1075 enrolled users. Sixty-one teachers completed the survey. The data indicated that new teachers requested support for lesson planning, instructional strategies, data literacy, and differentiated instruction. Respondents indicated that the flexibility of the platform helped to meet the complicated needs of teachers. The findings also showed that 34 out of the 61 respondents shared that lack of time affected their usage of the platform. Finally, the platform was shown to help teachers solve their problems without worrying about how they would be perceived by mentors.

The results of Bang and Luft (2014), Hunt et al. (2013), and Jones et al. (2016) show that there is a need for e-mentoring for novice teachers who teach within the same subject area, exceptionality, or grade level. While Bang and Luft (2014) found that tailored e-mentoring programs provide benefits to mentors and mentees, it is apparent from the findings of Hunt et al. (2013) that careful consideration is required in the design of e-mentoring support for new teachers who require specialized support. In other findings, Jones et al. (2016) reported that beginning STEM teachers requested e-mentoring support for instructional planning including teaching strategies, differentiating instruction, and using data. Additionally, time was considered a factor for those teachers who did not interact with e-mentors.

Some online induction programs feature OLCs as the primary means of support for novice teachers. OLCs evolved from professional learning communities (PLCs) which are comprised of a small group of practitioners who collaboratively work together to focus on learning and hold each other accountable for results (DuFour, 2004). OLCs also work toward these aims but are carried out with CMC tools.

Taranto (2011) examined how OLCs and TIPs complement each other with CMCs. This study used a mixed-methods approach. Quantitative data included surveys and tracking of the types of social interactions that took place on the wiki. Qualitative data included textual data from discussion board threads, questionnaires, and transcriptions from focus group interviews. A cohort of 16 new teachers who were hired for the 2009-2010 academic year participated in this study for one year. The OLC investigated in this study included participation on the wiki by a wide variety of educators including four experienced teachers, five district administrators, five principals, and four professors. The OLC was housed on Wikispaces, an online wiki platform. Wikis are a collaborative CMC tool that allows users to edit the content of the website. The researcher created wiki pages based on professional development themes from a pilot study. Within each wiki page, the researcher uploaded content to share with participants. Additionally, a discussion board was created on each wiki page to stimulate discussion. Taranto (2011) found that new teachers in the study supported the use of the OLC. In addition, all the new teachers in the study reported that the online learning community was helpful and useful and contributed to improved classroom instruction.

OLCs can also be developed through school-university partnerships. Donne and Lin (2013) examined how a university-sponsored online induction website supported recent special education teacher education program graduates. In response to limited funding, the small private university involved in the partnership initiated the OLC to fulfill state requirements and support new teachers. Additional goals of the initiative included providing professional support, developing a peer mentoring community, and sharing resources and experiences. A wiki served as the platform for the OLC. The wiki included sections such as “Working as a Special Educator,” “Teacher Community,” and “Stay Connected with the University.” Data were collected on frequency and use of specific resources on the wiki for one year. The results showed that 83% of graduates participated on the wiki, although the total number of graduates was not provided. Graduates benefited from the wiki through the contributions from multiple users. The wiki also provided a free platform where it was unnecessary to have a designated leader. Finally, the wiki was flexible in terms of time and location. The study by Donne and Lin (2013) illustrated how universities can provide low-cost support for school districts.

The studies by Donne and Lin (2013), and Taranto (2011) support the use of OLCs for induction. Wikis were found to have multiple benefits for beginning teachers (Donne & Lin, 2013; Taranto, 2011). While Taranto (2011) found that wikis impacted classroom instruction, Donne and Lin (2013) found that wikis provide financial savings to educational institutions.

A limited number of studies have examined the effectiveness of technology tools that are used for reflection in online induction. In one study, Hwang and Vrongistinos (2012) investigated the Quality Teachers for Quality Students (QTQS) project developed by the University of Southern California. The purpose of the QTQS project was to increase instructional support for beginning teachers who were working with English language learners (ELLs) in San Bernardino County, California. The QTQS project featured an online support platform that provided opportunities for mentoring, training, support, and networking with experienced teachers and university faculty. Thirteen beginning teachers and four mentor teachers participated in the study. Participants in the study were experienced teachers who served as mentors and the new teachers who were the mentees. Three mentees were assigned to work with one mentor. Mentors primarily supported mentees with the instructional strategies for ELLs. Initially, Blackboard was the technology tool used to support mentoring partnerships in the online platform. This technology is a web-based learning management system that provides several learning and communication tools. Skype, a video conferencing tool, was later added which increased flexibility. Mentees were required to self-evaluate his/her recorded lesson. The QTQS project included multiple tasks for mentors-mentees related to a video self-reflection. These tasks primarily focused on teaching of ELLs and literacy development. Between 2007 and 2010, a qualitative survey was administered to the participants at the end of each year. The survey questions focused on the use of Blackboard and Skype as mentoring tools. The results showed that the online technologies used in the QTQS project reduced the time constraints of face-to-face mentoring. Furthermore, the novice teachers in the study felt that QTQS benefitted their instruction and provided non-judgmental support. This study was significant because it provided support for the benefits of video conferencing during informal online mentoring partnerships.

McFadden et al. (2014) examined the use of video annotation as a tool for developing reflective practices for secondary science teachers who participated in an online teacher induction course. Annotations extracted from sixteen first and second-year teachers between 2009 and 2011 were coded. The findings indicated that teachers discussed their own teaching practices and decisions, rather than the interactions and behavior of students. In addition, most annotations focused on description and explanation, rather than higher-order reflective practices such as interpretation and evaluation. Although video annotation and feedback provide new methods for self-reflection in TIPs, it is apparent from the McFadden et al. (2014) study that novice teachers require professional development on the topic of effective reflection.

The findings from McFadden et al. (2014) indicate that the use of technology tools does not necessarily lead to increases in reflective practices. Accountability and professional development are two considerations that should be addressed prior to implementation. Hwang and Vrongistinos (2012), on the other hand, were able show that the development of reflective skills improved when novice teachers worked directly with a mentor.

The technology tools used in online induction support varied in the literature. More importantly, many of the studies featured in this literature review focused on the outcomes of the use of specific technology tools including asynchronous discussions (Bang & Luft, 2014; Hunt et al., 2013), wikis (Donne & Lin, 2013; Taranto, 2011), Blackboard and Skype (Hwang & Vrongistinos, 2012), and video annotation and feedback tools (McFadden et al., 2014). Little is known regarding which combination of these tools is most effective for online induction. Furthermore, there is limited research on the process of e-mentoring in online induction platforms. In other words, we have more information about the tools to use, but not specifically the process of how to use them in the context of e-mentoring beginning teachers.

___This gap in the literature led to the development of the following self-study research questions: (1) How has e-mentoring on a university-sponsored online induction platform informed my understanding of the induction of novice teachers? (2) How has e-mentoring novice teachers on a university-sponsored online induction platform informed my practice as a teacher educator? Research in this area helped me better understand how to make mentoring decisions to best meet the needs of my mentees. In addition, filling this gap in the literature can help university-sponsored online induction e-mentors learn effective methods for supporting new graduates and school district teacher induction programs.

Theoretical Framework

The "Phases of First-Year Teacher' Attitudes toward Teaching" developed by Moir (1999) was used as a framework for guiding my work with the mentees during the self-study. I chose this framework because these phases are helpful to mentors when developing supports for beginning teachers. According to Moir (1999), not all new teachers go through these phases (Figure 1) sequentially, but understanding these phases is important for educators who are supporting beginning teachers. Moir's "phases" have been only used as a theoretical framework in a limited number of agricultural education studies focused on beginning agriculture education teachers' experiences (Disberger, 2020) and attitudes toward teaching (Rayfield, McKim, Lawrence, & Star, 2014; Rayfield, McKim, Smith, & Lawrence, 2014).

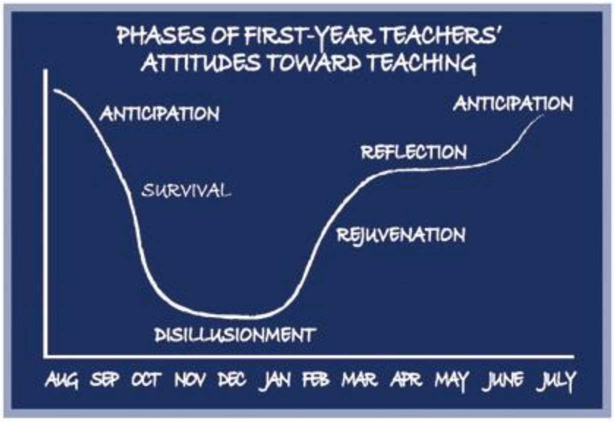

Figure 1. Moir's (1999) Phases of First-Year Teacher's Attitudes toward Teaching

This self-study began during the anticipation phase which lasted through the first few weeks of school. During this phase, beginning teachers are typically optimistic about the upcoming school year. Beginning in September, new teachers go through the survival phase where they are very busy but maintain a positive outlook. In mid-October, new teachers begin the disillusionment phase where they succumb to the stresses of the job. I decided to end the e-mentoring partnerships before winter break. This allowed me to work closely with my mentees to help them through the trials and tribulations of the two most challenging phases.

Methods

S-STTEP

Self-study of teaching and teacher education practices (S-STTEP) methodology was employed during this self-study. S-STTEP is a systematic approach for educators who want to research their own teaching and teacher education practices (Pinnegar & Hamilton, 2009). The eight components that guide S-STTEP include:

1. Provocation - An idea within one's teaching practice that evokes interest;
2. Exploration - Potential resources, ideas, and knowledge are explored:
3. Refinement - Connecting background and experience to build a case for the topic of the inquiry;
4. Identify Focus - The focus of the topic for the inquiry is introduced;
5. Design of the Study - Choice of data sources, data collection, participant selections, data analysis, and other design decisions;
6. Reconsideration Process - This process involves developing understandings based on the data and dialogue with others;
7. Ethical Action - A discussion of how the inquiry is conducted with integrity and transparency; and
8. Presentation - Sharing of the self-study with the educational research community.

During this self-study, I e-mentored three novice science teachers while using a university-sponsored online induction platform for a period of four months. This technology is designed to support induction programs with the goal of retaining new STEM teachers. In this study, the online induction platform will be referred to as the "Platform." I worked with my mentees to mutually decide on two teaching practices that each wanted to focus on while being e-mentored. These teaching practices were based on the mentees' district instructional framework.

Participants

The teachers that I recruited were recent graduates of a STEM educator preparation program (EPP) at a large research-intensive university located in the Southeast. A small sample of new science teachers was selected to participate in this self-study. The mentees for this study were recruited based on the following criteria:

1. A first- or second-year science teacher who was a University graduate and completed the STEM educator preparation program;
2. A secondary science teacher.

After contacting all mentee prospects, three teachers volunteered to participate. Kara and Dan were both first-year teachers. Nancy was a second-year teacher. Pseudonyms are provided for the names of mentees and the schools where they were employed at the time of the study.

Mentee Vignettes

The vignettes below provide context related to my mentees' background, experience, and my familiarity with each of them. Additionally, this section provides an overview of my work with each mentee.

Kara

Kara, who identified as a white female, was a first-year middle school science teacher at the time of my study. In the EPP the year prior, I was her instructor for the capstone "Apprentice Teaching" course. Upon graduation, Kara accepted a position at Achieve Middle School, which is an urban charter school that prides itself on educating under-served students.

At the time of the study, Kara taught seventh grade physical science. I learned during Kara's first interview that her school did not have a teacher induction program (TIP) for beginning teachers. However, her school did provide mentoring support for all teachers. Interestingly, Kara's mentor was her principal, Mr. Johnson.

Kara shared with me that she wanted differentiated instruction and problem-based learning (PBL) to be the focus of our work together. She chose differentiated instruction because she had limited experience with it, and her principal wanted her to begin planning and implementing that instructional strategy in her classroom. Regarding PBL, Kara stated, "I want a very engaging curriculum throughout the year, and I know to plan a year of PBL is very difficult" (Interview 1). Once her school year began, I realized I could not begin working with Kara on these strategies until she was more settled in her teaching job. Kara seemed to have difficulty adjusting to her students and the demands of full-time teaching. She required emotional support and help with her most immediate needs, such as lesson planning.

In October, we started focusing on differentiated instruction because Kara was more settled. Initially, I uploaded several resources for her on the Platform. During weekly video conferences, we discussed how to plan and implement differentiated lessons but her activity on the platform stalled due to technical issues that she was experiencing.

In November, our work together shifted to PBL. I had limited experience with PBL myself, so this type of instruction was going to be a learning experience for both of us. During the planning stage, Kara and I had three productive video conferences where we generated ideas and developed plans. Unfortunately, the action items that Kara assumed responsibility for were never completed.

For Kara, mentoring focused on planning for differentiated instruction and PBL. In the final interview, she mentioned that the resources that I provided helped her the most. However, Kara often did not follow through with plans which hindered our progress together.

Dan

Dan, who identified as a white male, was a new high school science teacher at Opportunity High School. Like Kara, his school was located in an urban setting. I was also his instructor for the "Apprentice Teaching" course when he was in the EPP.

Dan taught physical science and advanced physics classes. Most of Dan's physical science students were culturally diverse and came from poverty. His physics students, on the other hand, were primarily white. Dan was hired shortly before the first day of school. Consequently, we started online induction one week after my other two mentees because he needed some additional time to get settled into his new classroom. I learned that Dan's school district did not offer induction support. However, he did have some mentoring from a member of his department.

Dan decided to focus on student engagement and unit planning. During interview one, Dan shared with me why he chose student engagement in his physical science course. He explained that his supervisor said, "Don't worry about innovating with them right now. They are your lowest priority." Dan was charged with increasing achievement in the advanced physics classes. However, Dan did not want to continue teaching through worksheets and dismissed the suggestion from his supervisor. He believed that his physical science students deserved the same level of engaging curriculum as his advanced students. In the second interview, Dan stated, "I think the major thing is I am sure after four chapters the students are very tired of those worksheets. . . . I don't know, there is not a lot of innovation going on." It was at this point that I started helping Dan find some more engaging learning activities for his physical science class. In late September, I shared with Dan a variety of resources, lesson plans, and strategies to engage his students. Dan implemented some of the items that I provided him on the Platform. For example, Dan used the Socrative online assessment tool to help his students review for an upcoming assessment.

Later, Dan and I worked together to develop two unit plans using the Understanding by Design (UbD) framework (Wiggins & McTighe, 2005). We first planned a unit on forces. My content knowledge related to physics was limited, therefore, I mostly helped Dan better understand the UbD unit planning framework. I feared that Dan would think that the work we had done on the unit plan was a waste of time. I was more helpful to Dan during our second unit plan on chemical reactions. Dan and I collaborated on the unit plans during our video conferences, but he often did not follow through with the action items that he committed to completing.

For Dan, mentoring consisted of providing him with a wide variety of engaging learning activities for his physical science classes, as well as developing unit plans. In the final interview, Dan stated that the resources that I provided him were "very beneficial". According to Dan, I helped him "both from just an actual education standpoint and from a mental health standpoint."

Nancy

Nancy, who identified as a white female, was a second-year teacher at Success Middle School. I previously knew Nancy through her involvement as a peer mentor in the EPP. Her school was located in a suburban setting. Nancy taught both standard and advanced science courses.

During Nancy's first year, she was assigned a school district mentor. She met with her mentor, Mr. Jones, on a weekly or bi-weekly basis. Mr. Jones was a veteran English language arts teacher. Although he had limited science content-area knowledge, she found his pedagogical support invaluable. In the initial interview, I learned that he modeled teaching strategies for her, and they co-taught some lessons together. In year two, Nancy was not provided any school-based mentoring support. Nancy seemed more confident and optimistic going into her second year.

Nancy decided that her focus during online induction would be planning engaging inquiry-based science activities. During interview one, Nancy expressed how she aspired to plan more engaging inquiry-based lessons:

> I'd like to work on doing more cool science labs or integrate the scientific method more throughout the year. . . . It would be nice to get back into that and you know really focus on that throughout the year.

Nancy also believed she lacked skills related to integrating technology in the curriculum. I was especially excited to help her build knowledge and skills in that area.

For Nancy, mentoring focused on technology integration in her curriculum and planning engaging science activities for her students. In the final interview, Nancy shared with me, "I think that it was good to be exposed to different websites and then virtual labs and things that I otherwise wouldn't have seen or tried." Our e-mentoring partnership seemed to push Nancy to try new things to improve student engagement and academic achievement.

Data Collection

Except for an early visit in person to each of my mentees' schools, all mentoring activities and communications took place on the Platform. All communications were saved for data analysis. The Platform includes online curriculum resources and the following CMC tools designed to facilitate communication between mentors and mentees:

1. Zoom video conferencing tool offers several features including screen sharing, annotating, and recording. This tool was used for the mentee interviews and video conferencing.
2. Collaboration Groups are asynchronous meeting spaces. They were used for leaving messages at different time intervals. I established private groups for communication with each mentee. Additionally, I created an OLC for all mentees. Protocols were not used in the Collaboration Groups.
3. Torsh TALENT video analysis of teaching tool supports the recording, upload, storage, and management of classroom videos. The mentees in my study had the option to record some of their lessons using this tool. After a lesson was recorded, it was automatically uploaded to the Platform. Later, I added time-stamped feedback and summary comments to the uploaded video.

The mentees were required to participate in three semi-structured interviews that were conducted with Zoom. In order to improve my own e-mentoring practices, it was critical to learn the perspectives of those whom I would be mentoring (Kosnik et al., 2009). Semi-structured interviews provided me with the flexibility to plan questions, but I could deviate if needed.

The first interview focused on the background and teaching experiences of the mentees. During this interview, I guided mentees toward identification of two teaching practices that they felt needed improvement. The second interview focused on the experiences of my mentees during online induction. Interview data was used to adjust my online induction mentoring practices. The third interview focused on the experiences and reflections of mentees related to online induction and mentoring. Protocols (see Appendices A-C) were prepared so that consistency was established regarding the questions and topics that were discussed (Patton, 2002). Each interview was digitally recorded and transcribed.

Additionally, I maintained three reflective journals including Weekly Memos, a Running Journal, and Critical Friend Journal. The Weekly Memos consisted of written narratives related to my reflections during the self-study. Also, I recorded details about my mentees and my interactions with them in a Running Journal.

I maintained a Critical Friend Journal that detailed my relationship and interactions with my critical friend, Susan. Dialogue with others can help self-study researchers to develop better understandings of the teaching practice under investigation (Beck et al., 2007). These weekly meetings provided me with an opportunity to receive feedback from a colleague who challenged and supported my decisions, interpretations, and findings.

During our meetings, I shared with Susan what I learned from data analysis and sought feedback from her. On occasion, I would provide Susan with writing samples in advance of our meetings so that I could gain her feedback. These journals allowed me to track my ideas as they evolved through the self-study. Later, these journals were addressed during the Reconsideration Process component of S-STTEP.

Data Analysis

The Miles et al. (2014) qualitative inductive thematic analysis approach was used to analyze all data sources. I chose this data analysis method because it was useful for the analysis of textual data and helped me identify patterns that were shared among the data sources (Miles et al., 2014). This approach involves selectively collecting data, identifying patterns by comparing/contrasting the data, seeking more data to confirm emerging themes, and making inferences based on the developing themes. Specific steps guide this process including first cycle coding, second cycle coding, and assertions.

Step 1: First Cycle Coding. This step involved labeling chunks of data with a descriptive label. This process allows for the identification of relevant data as well as provides a way to form comparisons with similar data.

Step 2: Second Cycle Coding. Second cycle coding involved reducing the number of first cycle codes into fewer categories.

Step 3: Assertions. Assertions are declarative statements, or findings, that are supported with evidence from the data.

Findings

Through the S-STTEP process, I know more now about the induction of beginning STEM teachers and the e-mentoring role. Since e-mentoring was a new experience for me, I encountered several dilemmas that I needed to reflect and act on in a way that would best support my mentees. These tensions provide a way to describe teacher educators' experiences of their practice (Berry, 2007). During data analysis, dilemmas pertaining to the "confidence and uncertainty" tension was prominent in the data that were collected. Berry (2007) describes this tension as "experienced by teacher educators as they move away from the confidence of established approaches to teaching to explore new, more uncertain approaches to teacher education" (pp. 120). The following findings are framed around this tension.

Mentee Participation

The voluntary nature of the online induction support that I was providing competed with my mentees' time. The support that I offered my mentees was strictly voluntary and supplemental to any school-based induction supports. My mentees sometimes did not complete tasks or respond to my inquiries on the platform. This was particularly the case with my first-year mentees. On one occasion, Dan emailed me to inform me that he could not participate in a video conference because of a social engagement. In that email, Dan stated, "I'll try and add a few more things to the unit plan to complete it, but I'm pretty swamped." Unfortunately, he did not make any additional changes to the unit plan. In another example, I received an email in December from Kara informing me that she could not meet for our weekly video conference. She stated, "Totally thrown in a loop. They changed the schedule on us today for a band concert field trip." In response, I asked Kara to let me know if she needed any help with her PBL unit that we were planning together. Additionally, I asked her to record one of her lessons on Torsh TALENT. Unfortunately, Kara did not follow through with my requests. Besides cancelling meetings or not following through with tasks, Kara and Dan sometimes seemed unengaged during our weekly video conferences. In week seven, I wrote:

> I was a little put off during my video conference with Kara. She was conferencing with me on her mobile device and was setting up for class as she spoke with me. I could tell she was busy and unfocused so I asked her if we should reschedule. (Week 7 Memo)

Based on my secondary teaching experience, I was familiar with the time pressures a new teacher must contend with. It was not surprising to me that these new teachers did not follow-through on tasks. Voluntary online induction programs may hinder full mentee participation because it is easy to ignore when teachers face other demands on their time.

Addressing Mentee Participation

Throughout the self-study, I reflected on my dilemmas and decisions in my weekly memos. These memos helped me reflect on the uncertain nature of voluntary online induction so that I could best support my mentees and reduce that tension I was experiencing. During week four, I reflected on this tension that I experienced with Kara:

> During our first two video conferences, she mentioned that she cried a couple of times. . . . Her experience so far seems reminiscent of my first month as a teacher.

> I think that being a listening ear and showing empathy will help our mentoring partnership. (Week 4 Memo)

My reflection regarding Kara's difficulties in the classroom helped guide future conversations with her. It seemed that my role included more than helping Kara navigate her first year.

Dialogue was another key strategy for helping me address the uncertainties of voluntary online induction. My meetings with Susan afforded me the opportunity to share my ideas regarding how I wanted to e-mentor my mentees. During one critical friend meeting in early October, I asked Susan if "try-its" would be an effective strategy to use with my mentees. Susan supported my idea and after that meeting, I started rolling out the try-its with Nancy. In the following Week 10 Memo, I reflected on the use of the try-its:

> I felt like try-its are the way to go with e-mentoring. I had such a great experience with Nancy. She told me before the interview how well her Glogster activity went. Students were engaged and it seemed like this one tool opened up many possibilities for her in her curriculum.

My meetings with Susan also helped me cope with my e-mentoring role and boosted my self-confidence. The following excerpt from one of my Critical Friend Journal entries illustrates how Susan supported me through some of the trepidation I was feeling related to working with Kara on her PBL unit:

> I learned from Susan that I do not have to be an expert on all teaching practices to be an effective e-mentor. Furthermore, I learned from Susan that e-mentoring requires some negotiation to determine how I can best help my mentees despite my own weakness areas.

Entering the teaching profession is hard, especially in high-poverty contexts. The same could be true of e-mentoring beginning STEM teachers who have low SES students. E-mentors need support as do beginning STEM teachers. A critical friend might have been that type of support for me. Reflection and dialogue with a critical friend were useful for addressing the confidence and uncertainty tension that I experienced so that I could better understand and meet the needs of my mentees.

Building Rapport in an Online Environment

The e-mentoring I provided was designed to supplement, not replace, any existing face-to-face mentoring the novices were receiving from their schools. The lack of face-to-face time with my mentees made building rapport unpredictable.

All three participants discussed some of the ways in which e-mentoring provided challenges as compared to face-to-face mentoring. It seemed difficult for an e-mentor to develop the same level of rapport with mentees without face-to-face interaction. For example, Dan said, "I eat lunch with her every day. We can talk about things there . . . after school she comes in and asks if I need anything" (Interview 1). During the initial interview, Nancy described some of the instructional support that she received from her mentor that would not be possible through online induction:

> I taught with him . . . or sometimes he would teach one of my class periods and then I would see what he was doing, and I would teach the next class period. I feel

> like I learned a lot just watching him teach too because I don't get to observe the teachers especially when they are with my students that I struggle with sometimes.

Through communication with my mentees, it seemed that traditional mentoring and e-mentoring both provide professional and emotional support. Furthermore, both provide novice teachers with an opportunity to learn, implement, and receive feedback on new strategies. The lack of face-to-face contact with e-mentoring was limiting. It seemed much more difficult to develop mentoring relationships online. There are also things that e-mentors cannot do including modeling and co-teaching.

Effective facilitation on an OLC is critical. My eight announcement posts were not engaging, nor did they stimulate collaboration. Kara, Dan, and Nancy did not know each other prior to online induction. I missed opportunities to build rapport, such as setting up introductions. I was naïve to think that my mentees would collaborate with each without having met or being introduced to each other.

Addressing Building Rapport in an Online Environment

The online induction platform afforded me the opportunity to provide increased levels of support to my mentees despite being completely online. E-mentoring through the platform proved to be convenient for video conferencing and asynchronous communication that allowed me to interact with the teachers more often than typical mentors do. Kara video-conferenced with me weekly during her planning period. Nancy and Dan chose to schedule their weekly video conferences after school. In addition, the Collaboration Groups that I created on the platform allowed me to post questions, provide encouragement, and upload resources at any time of day. The Platform also provided flexibility. I was able to schedule video conferences at times that worked best within my mentees' schedules. Establishing a specific day each week for a video conference may have held my mentees more accountable for following through with action items. During the third interview, Dan discussed how video conferencing held him accountable during online induction:

> If this was something where you just laid it all out at my feet and said okay do this stuff, I probably wouldn't have done it just because I have so many other things I have to constantly worry about.

Early in the self-study, I realized that it would be important to make at least one face-to-face visit with my mentees. These visits were scheduled to further build the mentoring relationship and to help me understand their teaching context. In this Running Journal entry, I detailed my experience visiting Achieve Middle School:

> I was impressed that the principal stopped by Kara's classroom to meet me. . . . He seemed very supportive of Kara and online induction. . . . Mr. Johnson wants outside institutions and organizations to be involved with his school, and he encouraged me to visit any time and observe classes. (Running Journal)

Although Kara described her teaching context during interview one, I gained some valuable insights from the visit that I did not expect. For example, after speaking with Mr. Johnson, I learned my work with Kara was supported by her school.

Although I did not solve the OLC challenges, I did learn how to make these communities more engaging for mentees. Most importantly, it seems like I should have waited until there was a perceived need from my mentees before developing an OLC. Also, I learned some other uses for the community from my mentees. In the final interview, Nancy described how her mentor would periodically email strategies to her when she stated, “he sent more common strategies that I would be more aware of as a second or maybe even a fifth-year teacher but didn't really know of as a first-year teacher.” This concept of sharing strategies could be applied in the OLC and might boost participation if mentees found the tips valuable. Engaging mentees on an OLC may also require that I initiate dialogue by posing questions or challenges.

Initially, it was unclear how I would build rapport through online induction as this was a new experience for me. However, I integrated and experimented with the CMC tools on the Platform in an effort to address this tension and build the mentoring partnerships. Additionally, taking initiative to visit my mentees’ schools elevated my relationships with my mentees and alleviated the tension of confidence and uncertainty pertaining to rapport building.

The Timing of E-Mentoring

Online induction requires ongoing support, planning for upcoming video conferences, and time for mentees to get acquainted with the CMC tools. Based on the struggles that Dan and Kara experienced during their first few months of teaching, the timing of e-mentoring may need to be adjusted so beginning teachers can adjust to their schools, students, and curriculum. It seemed that Kara and Dan needed more emotional support and help with immediate problems, rather than professional learning.

Initially, I planned to work with each mentee on two teaching strategies, but this was delayed so that I could assist them with their most immediate needs. Kara had difficulty adjusting to the fast-paced school environment and unanticipated changes in the school schedule. She seemed to struggle the most with the emotional stress of teaching. For instance, Kara admitted during the third interview that she underestimated how difficult teaching full-time would be. She referred to her experience as “being in shambles all the time.” Kara mostly experienced challenges related to parents and students. During one of our early video conferences, she explained how a parent showed up at her room and confronted her about an issue related to her child:

> I cried at school yesterday. . . . Luckily, there were adults around. . . . One swooped me into an empty room. And then I just broke down. It's a very low class. And they don't get along. . . . I don't know how to handle that. (Video Conference)

Addressing the Timing of E-Mentoring

During online induction, it was unclear how long it would take to work with my mentees on the two instructional practices that they identified. Careful planning was a strategy I used to address this tension. Below is an example of how I planned an agenda in my Week 2 Memo:

> This week, I plan on doing the following:
>
> 1. Email twice.
> 2. Focus on encouragement and helping my mentees with their immediate needs.
> 3. Tell my mentees that I plan on visiting them in the next few weeks.

4. Prepare questions for each video conference.

The memos were critical to the planning process. Within these memos, I detailed next steps for planning.

Four months of online induction did not seem like enough time for mentees to adjust to using an unfamiliar platform. My mentees primarily used the Platform for accessing the Zoom tool. It seemed that my mentees did not want to invest too much time on familiarizing themselves with the Platform. Early in the self-study, I stated, “Email seems to be a better form of communication with Dan. He always seems to respond to that” (Running Journal). Following that entry, I began emailing Dan more frequently as method to be more responsive to his needs.

Since I lacked experience with the timing of online induction for beginning STEM teachers, the ambiguity of the process was disconcerting. Planning for video conferences allowed me to manage this tension. In addition, due to the unpredictable nature of mentee Platform use, I discovered that that it may be beneficial to introduce mentees to all the tools and then tailor use based on their preferences.

Discussion

Through S-STTEP, I know more now about the induction of beginning STEM teachers than when I started, thus answering my first research question, “How has e-mentoring on a university-sponsored comprehensive online induction platform informed my understanding of the induction of novice STEM teachers?” Furthermore, the literature on the needs of beginning STEM teachers and online induction was instrumental in informing my self-study. While contending with Berry’s (2007) confidence and uncertainty tension, I began to understand through my experiences that the induction of novice STEM teachers through online induction allows for more opportunities for one-on-one support than traditional mentoring partnerships. In addition, the focus of online induction may need to be adjusted as e-mentoring proceeds to meet the diverse needs of mentees which connects to Hunt et al.’s (2013) finding that a “one size fits all” approach to online induction is ineffective.

The instructional strategies that were the focus of online induction with Kara, Dan, Nancy were similar (e.g., lesson planning and differentiated instruction) to some of the needs of new teachers identified in the findings from Ross et al. (2011) and Jones et al. (2016). The only challenge pertaining to my lack of content knowledge during online induction occurred when I helped Dan with a physics unit plan. Although only science teachers were selected to participate in this study, the findings have implications for mentors in other STEM disciplines. The findings are relevant to mentors who are paired with beginning teachers from STEM disciplines different from their own, as well as partners who teach in the same content areas.

While addressing the confidence and uncertainty tension, I also came away from this self-study with several useful strategies for e-mentoring novice STEM teachers through an online induction platform. These strategies provided answers to my second research question, “How has e-mentoring novice STEM teachers on a university-sponsored online induction platform informed my practice as a teacher educator?” Self-study gave me a structured approach for better understanding the e-mentoring role working toward continuous improvement. The need for dialogue with a critical friend was imperative for maintaining my focus and mentoring partnerships. I also learned that face-to-face visits with mentees at the beginning of online induction builds rapport. Furthermore, establishing an engaging OLC may encourage collaboration among mentees. This jibes with Donne and Lin's (2013) findings that OLCs can be beneficial if engaging topics that attract multiple users are included. E-mentoring also requires careful planning for upcoming video conferences and more time should be allocated for mentees to get acquainted with the platform.

Revisiting Moir's (1999) "Phases of First-Year Teacher's Attitudes toward Teaching" Framework

After encountering tension related to the short online induction period, I revisited Moir's (1999) framework. I learned that actively listening to my mentees, as well as providing emotional support, was what they needed most during the first couple of months. The phases in the framework are closely connected to the challenges that I experienced with Kara and Dan. I e-mentored them during the anticipation, survival, and disillusionment phases of a first-year teacher. In retrospect, I should have waited until the rejuvenation phase to begin work on the two teaching practices with each of them. This phase would have been the optimal time to support Kara and Dan with teaching strategies because new teachers tend to be invigorated following the winter break. Ultimately, it would benefit mentees professional learning if online induction lasted at least through the first year of teaching. I also missed an opportunity to experience the rejuvenation and reflection phases. Additionally, it would have been a celebratory opportunity to return to the anticipation phase with my mentees (anticipation is the first and last phase).

Implications for Practice

The findings have implications for those engaged in, or planning to, e-mentor beginning STEM teachers. There are four main implications from my self-study: two of them stem from the reflections on my own e-mentoring facilitation, and the other two are related to the rich possibilities that e-mentoring can provide.

E-mentors Should Study Their Own Practice to Become Aware of Their Areas for Growth. During my self-study, I strived to be reflective. I documented what I learned while e-mentoring when I answered the reflective prompt, "What did I learn this week about how to mentor novice teachers?" I responded to this prompt in each of the 17 weekly memos. For example, in the Week 3 Memo I wrote, "This week, I learned that e-mentors need to be empathetic. Sometimes mentees need a listening ear. During video conferences, active listening skills are essential for ensuring that mentees know that you are concerned about their issues."

E-Mentors Need Training on the Online Induction Platform. Based on my experiences, I did not have adequate training on the use of the Platform prior to my work with the mentees. At the onset of this self-study, I thought that I had enough experience using the Platform. I had the opportunity to use the Platform for one semester with my preservice students. In addition, I conducted a research study that used the video analysis on teaching tools within the Platform. I was confident in my ability to teach my mentees how to use the Platform. However, I was unfamiliar with the nuances of the Platform. Therefore, it may help e-mentors to receive structured and comprehensive training program before working with mentees.

Considerations for Developing University-Based Online Induction Programs. Since voluntary online induction may present obstacles, it is essential that EPPs develop strong partnerships with school systems that employ recent graduates. This may ease the path for EPPs that are working toward establishing online induction partnerships. In addition to supporting recent graduates, university-based online induction can be relatively inexpensive to develop and maintain which is what Donne and Lin's (2013) study found through using a wiki. Once these partnerships are established, EPPs should consider communicating with schools to ensure that the focus of online induction aligns with the needs of the school. Platforms for e-mentoring beginning STEM teachers should be in place well before they graduate. Students would then be familiar with the technology and will have established strong relationships with the e-mentors before they become teachers. These platforms afford pre-service STEM teachers with another vehicle to communicate and collaborate with instructors, cooperating teachers, and peers.

Concluding thoughts

E-mentoring beginning STEM teachers through a comprehensive university-sponsored online induction platform is one more layer of support that can be used to turn struggles to successes and improve teaching and learning. Through my active participation as an e-mentor, I learned first-hand the need for effective methods for supporting beginning STEM teachers within a university-sponsored online induction platform. I am confident that my decisions and actions while e-mentoring increased the support that my mentees were receiving.

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APPENDIX A

FIRST PARTICIPANT INTERVIEW PROTOCOL

Participant #: ____

Date: ___________

First Participant Interview Protocol

1. Tell me a little bit about your school.
2. Tell me a little bit about your classroom – what do you teach? What are your students like?
3. How prepared do you feel to teach?
4. What do you still need to learn?
5. How did your preparation help you become ready to teach?
6. Did you have a mentor? Did that person help you learn anything about teaching?
    a. (PROBE) If yes, ask for an example.
7. Do you have a mentor assigned to you now in your school? Describe that relationship to me.
    a. (PROBE) Can you give me an example of how you two work together?
8. What do you know about your district induction program?
    a. (PROBE) Can you describe how it works to me?
9. Prior to this interview, I asked you to think about two specific teaching practices that you felt needed improvement based on your district's instructional framework. These teaching practices are going to be the focus of the e-mentoring. What were the two teaching practices that you identified? Why did you choose these two teaching practices?

APPENDIX B

SECOND PARTICIPANT INTERVIEW PROTOCOL

Participant #: ____

Date: ___________

Second Participant Interview Protocol

1. How has teaching been going for you so far this fall?
    a. (PROBE) What are some challenges you have experienced?
    b. (PROBE) What are some successes you have experienced?
2. What is working for you related to our work together?
    a. (PROBE) How do you know it is working?
3. What is not quite as helpful?
    a. (PROBE) What else might be helpful to you?
4. Describe the teacher induction supports that you are currently receiving from your school and school district.
    a. (PROBE) What is helpful to you?
    b. (PROBE) What is not quite as helpful?
5. In our first interview, we developed an action plan based on two teaching strategies that you wanted to improve during the course of the online induction that I would provide. So far, you and I have _______. Did that help you _____?
    a. (PROBE) What else do you think you need in order to get better at ______?
    b. (PROBE) How can I help you get that support?
    c. We also did ______. Tell me about that….
    d. (PROBE) What else do you think you need in order to get better at ______?
    e. (PROBE) How can I help you get that support?

APPENDIX C

FINAL PARTICIPANT INTERVIEW PROTOCOL

Participant #: ____

Date: ___________

Final Participant Interview Protocol

1. In general, how did e-mentoring work out for you this fall?
    a. (PROBE) What are some challenges that you experienced?
    b. (PROBE) What are some successes that you experienced?
2. Did you experience any unexpected challenges? Explain.
3. When receiving e-mentoring support, what seemed to facilitate your learning during the process?
    a. (PROBE) Can you give me an example?
4. What suggestions do you have for how e-mentors should use an online induction platform like Florida STEM TIPS in the future?
5. Can you talk a little bit about how this e-mentoring was similar to or different from your district's induction supports?
    a. (PROBE) Can you give me an example?