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The effects of an early childhood-elementary teacher preparation program in STEM on pre-service teachers

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Abstract

The increasing interest in early and elementary STEM education comes with a need to increase training and support for teachers of children in the early grades. Early and elementary pre-service teacher preparation in science, math, and integrated STEM can play a critical role in enhancing teachers' self-efficacy and pedagogical content knowledge in these areas. However, few quantitative research studies have been published on this topic, especially involving early childhood and elementary programs. Because few STEM courses are typically offered in these programs, we need courses and experiences that can be transformational. This study evaluates the short- and long-term impacts on pre-service teachers who participated in our STEM Collaboration approach (n=164), which was created to meet this goal through an innovative early childhood and elementary collaboration. Analyses of mixed methods data collected from surveys, tests, open-ended feedback, and a focus group revealed immediate, long-term, and positive impacts on science, math, and integrated STEM self-efficacy and pedagogical content knowledge. Participation in STEM education experiences in pre-service programs that include innovations such as collaboration across colleges and professionalization opportunities made a difference, and one that persisted.

Keywords: STEM education, early and elementary pre-service teacher preparation, self-efficacy, pedagogical content knowledge

"I cannot thank you enough for your passion. I never thought I would be a teacher that plans around science but learning through inquiry is so powerful. I find myself designing our curriculum around science and pulling in the other subjects" (Former pre-service teacher participant in STEM Collaboration).

INTRODUCTION

Science, math, and integrated STEM (i.e., science, technology, engineering, and math) skills and knowledge in early grades are critical to later learning and achievement (Grissmer et al., 2010; National Research Council, 2014; Watts et al., 2014). However, many teachers do not feel well-prepared to support science, math, and integrated STEM learning in these grades (Malzahn, 2013), do not feel confident in their own scientific literacy (Cavas et al., 2013), or are unsure of how to support diverse young learners (O'Neal et al., 2008). In turn, the resulting limited experiences in STEM provided in early grades (Early et al., 2010; La Paro et al., 2009; Piasta et al., 2014; Tu, 2006) can exacerbate opportunity gaps, such as between those who live in affluent areas versus those who live in high-poverty and rural areas like Appalachia (Ladson-Billings, 2006; Sackes et al., 2011). Down the road, we see underrepresentation in STEM careers for many groups who did not get the same early opportunities as others (Carrico et al., 2016; Turner et al., 2019).

Fortunately, teacher preparation programs can play a role in positively influencing pre-service teachers before they start teaching in science (e.g., Deehan et al., 2019)

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Contribution to the literature

- The current study contributes to the literature a mixed methods design to evaluate pre-service teachers' self-efficacy and pedagogical content knowledge.
- This study will add to the limited studies that are either quantitative or qualitative.
- This work has the potential to serve as a model for other teacher preparation programs seeking to partner and innovate in the areas of early and elementary STEM.

Figure 1. Model of key STEM Collaboration components

and in math (Parks & Wager, 2015). However, we know less about how pre-service teacher preparation programs can influence skills and knowledge in teaching science and integrated STEM, the extent to which these impacts last into teaching careers, and whether we can support transformative learning in regions like rural Appalachia. In addition, no studies we found addressed these issues and connected traditionally separate worlds of early childhood and elementary programs.

Our STEM Collaboration project addresses all of these, with the aim of improving the quality of pre-service teacher preparation in pre-K through 5th grade for regions like Appalachia and beyond. Our approach was originally developed based on principles of effective pre-service teacher education generally and in STEM specifically (Robertson et al., 2020), including key components we believe to be powerful drivers of transformative science, math, and integrated learning experiences (see **Figure 1**). We infused typical college courses with collaborative components, applied learning experiences, and professionalization opportunities not typical of pre-service preparation programs. This study reports on initial results of effectiveness for pre-service teachers in these innovative STEM courses in terms of their science teaching self-efficacy, their science, math, and integrated STEM content knowledge, and their perceived immediate and long-term impacts of participation more broadly.

Importance of Early STEM

Starting early in STEM is critical because learning experiences in early grades in these areas make a difference for children's career and learning trajectories (e.g., Grissmer et al., 2010; Maltese & Tai, 2010; Watts et al., 2014). Early math (Watts et al., 2014) and science (Grissmer et al., 2010), in particular, have gathered substantial evidence of demonstrated relations to later learning over the years. Early science experiences are closely correlated with later achievement in science and in school generally (Curran & Kitchin, 2019; Grissmer et al., 2010). Similarly, early math skills and knowledge at the start of kindergarten predict how well students will do in math *and* in reading at third grade (Duncan et al., 2007) and into high school (Watts et al., 2014). Evidence is emerging related to other aspects of STEM as well, including engineering (NASEM, 2021), technology broadly defined, elements of computational thinking, and the value of integrated STEM teaching and learning (National Research Council, 2014).

Interests in STEM are largely established by the end of elementary school (Maltese & Tai, 2010). We can capitalize on this through preparing teachers to foster enthusiasm for this content for the next generation who will be their students. However, we must do so in a way that prepares teachers to meet every student where they are academically with respect for their cultural backgrounds and everyday lives, while holding students to high academic standards, such as those demanded by the NGSS. Increasing the quality of teacher preparation programs for early and elementary levels is especially important because misconceptions can develop early about the nature of science or scientific phenomena. These misconceptions follow into adulthood, and they are hard to change (Smolleck & Hershberger, 2011; Yilmaz-Tuzun, 2017). We need to start early to support pre-service teachers to become aware of their own misconceptions and develop the skills to challenge their perceptions and those of their future students.

Equity and Diversity

Equitable access to high-quality early STEM education experiences matters as well. The need for access to high-quality science learning experiences is evidenced from the fact that gaps in achievement test scores between White students and others appear in the United States by kindergarten and first grade, and these gaps are higher in science than in math and reading (Curran & Kellogg, 2016). Further, well-known studies that ask students to "draw a scientist" or "draw an engineer" have historically resulted in drawings of White males, with differences appearing at an early age (Miller et al., 2018). We need to start early (McClure et al., 2018) to build the confidence and the belief that ALL children are capable of being mathematicians or scientists. Promising evidence suggests that young children are drawing women as scientists more often than they used to (Miller et al., 2018), but we would like to see these drawings include even more diversity, including those from others traditionally underrepresented in STEM careers and those who live in regions like Appalachia.

Programs for teachers who will work with children are important because targeting programs "... to children from under-represented groups who excel in math and science at early ages is likely to maximize their impact" (Bell et al., 2018, p. 34). Boys outperform girls in some areas of STEM (Reilly et al., 2015), and they are more likely to choose careers in areas related to STEM (OECD, 2019), but an achievement gap does not appear until later in school. A study by Maltese and Tai (2010) found that females were more likely than boys to report that their interest in STEM was sparked by school-related activities. These findings suggest the value of intervening in school settings at even earlier ages to foster emergence of these interests, especially for girls.

What happens in early and elementary classrooms matters and can close the opportunity gap more broadly (Nores & Barnett, 2014).

> "Educational strategies that challenge stereotypes about the essential attributes of a successful [STEM] professional and about the nature of work in [STEM] can increase interest, improve performance, and instill a sense of belonging in these fields among White women, women of color, and other underrepresented groups (e.g., first-generation college students and men of color)." (NASEM, 2020a, p. 5).

Increasing access to equitable early STEM experiences starts with pre-service teacher preparation.

STEM in Appalachia

Tennessee is 41st in the United States in the percentage of students who graduate from high school and adults with a bachelor's degree. Further, in the Appalachian region of Northeast Tennessee, educational attainment is very low compared to the rest of the State (Wright et al., 2016). The COVID-19 pandemic has only exacerbated challenges to science, math, and integrated STEM teaching and learning (Di Pietro et al., 2020; NASEM, 2020b), especially in regions like Appalachia, where negative views about science are prevalent (Funk, 2020; Nowlin, 2020). The workforce demands are changing with STEM knowledge and skills increasingly sought after by employers (Costa & Kallick, 2008; McClure et al., 2017). Scientific literacy, "… the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22) will soon be a necessity for every student to work and live in our increasingly technological society. Students in this region need to build their scientific literacy even if they do not end up in STEM careers.

Students in high poverty rural areas, females, non-white, non-middle class are all underrepresented in STEM careers (NASEM, 2020a). Opportunity gaps in areas like Appalachia have led to a lack of participation in STEM and limited innovation. The "Lost Einsteins" report noted that there is a wasteland of innovation in regions like ours, with very few patents coming from this area (Bell et al., 2018). Access to science, math, and integrated STEM education in PK-5th grade settings in areas like East Tennessee is critical for the future of our workforce (Patrick et al., 2009).

Approximately 30% of the 2021 graduates in our programs report being 1st generation college students, and almost ¼ of the 2021 pre-service teachers come from counties that are considered distressed (ranked in the lowest 10%) or at-risk (in the lowest 10-25%) of all counties in the nation on poverty rate, per capita market income, and three-year unemployment rate. Through powerful, transformative experiences in which we face our own biases and understand systemic barriers, undergraduate pre-service teachers will feel competent in teaching science and integrated STEM and informed about issues related to equity, which will lead to closing opportunity gaps and increasing participation in STEM for underrepresented groups.

Our region also struggles with recruiting and retaining highly qualified teachers, and preparing students for STEM careers (Wright et al., 2016). To this end, we must involve pre-service teachers in planning, designing, and implementing science, math, and integrated STEM lessons as soon as possible in order to discontinue the cycle of marginalizing STEM in the early grades in this region (Berg & Mensah, 2014; Goldston, 2005; Maulucci, 2010). We can–and we must–address barriers to scientific literacy with higher quality training for, and incorporated into, teacher preparation programs. This is critically important because of the demands of teaching science, math, and integrated STEM according to new standards.

Demands of Teaching Science, Math, & Integrated STEM

The "*Framework for K-12 science education"* calls for reform-based teaching in science and STEM, which includes thinking about science education in a more integrated fashion (National Research Council, 2012). In math, current standards demand more teaching for conceptual understanding and less memorization than traditional methods (Porter et al., 2011). In addition, we must highlight the importance of supporting students to make connections through intentional integrations across STEM and between STEM domains and others, such as language and literacy (National Research Council, 2014).

A shift from traditional to inquiry-based teaching approaches is needed for all students (Minner et al., 2010). However, as noted above, such high-quality learning experiences in science, math, and integrated STEM in the early grades are not always available (Early et al., 2010; Sackes et al., 2011; Tytler & Griffiths, 2003), and this shift asks current and future teachers in many cases to teach in a way that they themselves were not taught. One of the ways that we try to address these challenges is by collaborating across early childhood and elementary education programs.

Different Approaches to Teacher Preparation

Pre-service teacher preparation programs are organized differently, with a common division occurring between early childhood and elementary education lines, in terms of philosophical and pedagogical approaches. Early childhood programs (ECE) focus more on child-centered and play-oriented instructional and assessment strategies (e.g., learning centers), whereas elementary education programs tend to be more teacher-directed, focus on large-group instruction, and use traditional methods like worksheets (Claessens et al., 2014; File & Gullo, 2002; Goldstein, 1997). We believe that science, math, and integrated STEM are natural places to connect these worlds, taking a strengths-based approach. The national standards in science (NGSS) and math (Common Core) emphasize a more constructivist approach to teaching math and science than was previously used. Constructivism is a philosophy more common in ECE than in elementary education (File & Gullo, 2002). In addition, elementary education has a strong history of documentation and assessment of learning, deep knowledge of science, math, and STEM content, and other structures which could benefit the early childhood community.

Advocates have called for increasing the alignment (also called coherence or continuity) between these worlds because the divide may have detrimental impacts on student learning (Abry et al., 2015; Bailey et al., 2017; Coburn et al., 2018). In some cases, children who come from rigorous preschool programs spend all of their kindergarten year learning the same content, instead of building on what they learned (Claessens et al., 2014). In addition, there is often overlap. In our program, early childhood graduates are licensed to teach pre-K through 3rd grade, while elementary graduates are licensed to teach K-5. Collaboration and communication across these siloed programs would address debates and overcome entrenchment.

The current way of thinking in terms of how to teach science, math, and STEM teaching and learning (e.g., NGSS) may provide an opportunity to bridge the divides for the benefit of students. As Whitebook et al. (2009) noted,

> "We encourage researchers, policymakers, and practitioners to abandon the 'silo' view of K-12 as one world, and ECE as another, and to approach all of their efforts with an eye to recognizing and understanding differences, working toward shared terminology, and building collaborative research agendas that will enable both arenas to learn from one another" (p. 11).

Unfortunately, most literature on teacher education and impacting pre-service teachers' attitudes, beliefs, self-efficacy, and knowledge focus on one or the other "silo." There are many studies of impacts of preparing students using the STEBI-B instrument (Deehan et al., 2019), and fewer that refer to influencing early childhood students (Deehan et al., 2019). We could not find any that evaluated impacts of a collaborative approach on both early childhood and elementary students. Our study aims to fill this gap by evaluating a project that collaborates across these worlds. We do not intend to compare impacts across programs, but rather to evaluate how effective a collaboration like this can be in enhancing the quality of both programs.

Barriers to Effective Teacher Preparation

A number of barriers exist in the provision of developmentally appropriate, evidence-based science, math, and integrated learning experiences in the early grades. Many early childhood and elementary teachers do not feel ready to teach science or integrated STEM (Malzahn, 2013; Ryu et al., 2018), as many pre-service teachers did not have positive experiences when they were in elementary school or did not learn related pedagogy during their pre-service programs (National Research Council, 2014). In addition, some educators do not see the value in science or integrated STEM or feel unsure about how to incorporate it into the day given the prevalence of pacing guides and emphasis on literacy and math (Early et al., 2010). Supporting teachers who are already teaching plays an important role in addressing gaps in knowledge and empowering teachers in early science, math, and integrated STEM education (Aldemir & Kermani, 2017; Lange et al., 2021).

However, we must also confront the challenges early in teachers' careers, during their pre-service teacher education. Evidence suggests that reform efforts to undergraduate pre-service teacher preparation can improve knowledge, skills, and attitudes towards teaching science and STEM (Deehan et al., 2019; McGinnis et al., 2002). One study found that hands-on, inquiry-based experiences for undergraduates helped pre-service teachers recognize inquiry-based teaching as an effective method for engaging student learning in science and led to changes in pre-service teachers' confidence in teaching inquiry-based elementary science (Lewis et al., 2014). The quantity and quality of college-level courses can impact teachers' science teaching efficacy (Hechter, 2011). McCall (2017) found positive significant gains on the PST subscale of the STEBI-B, but not on the other subscale. However, this study only included 12 participants, and the participants were mostly in their first year of college. In addition, the focus was only on science. Although our focus was also science, our study emphasized integration with STEM and other domains as well, our sample is larger, and our participants are in their third year of an undergraduate program.

One of the challenges to supporting high-quality early STEM teaching and learning can be traced back to the pressures that teacher preparation programs face to emphasize math and literacy. Many experience requirements from schools, districts, and even states that dictate content and curricula. In many cases, teacher preparation programs include limited space for math, science, or integrated STEM courses. Therefore, it is imperative that pre-service teachers experience transformative learning during the one or two science courses that they do have (see more in theoretical framework below).

Generally, much of the research thus far has focused on science, math, or integrated STEM education in elementary school separately (Deehan et al., 2019). Less work has evaluated early childhood and elementary pre-service education programs together, focused on science, math, and integrated STEM self-efficacy and knowledge, evaluating the extent to which learning in the programs is transformative (e.g., by following participants into their teaching careers), or highlighting issues in regions like Appalachia.

The STEM Collaboration Approach

The Early Childhood/Elementary STEM Collaboration (STEM Collaboration) approach was developed to positively impact the quality of science and integrated STEM teacher preparation for both early childhood (pre-K through 3rd grade) and elementary education (K-5th grade) programs in our region (Robertson, et al., 2020). Our team of higher education faculty, pre-service teachers in early childhood and elementary education programs, and in-service teachers collaborate using a strengths-based approach to this end, with the shared value that early and elementary educational programs–and children from diverse backgrounds–will be stronger when we learn from one another. Our approach is grounded in current standards and frameworks in science and STEM education (e.g., Bybee et al., 2006). The specific features of our model that align across programs include five evidence-based practices. These components are collaboration, authentic problems, applied projects, scaffolded feedback and reflection, and professionalization opportunities.

Theoretical Framework

As noted above, misconceptions in science start early and are hard to change (Yilmaz-Tuzun, 2017). Confronting misconceptions is an integral aspect of Piaget's theory of learning (Smith et al., 1994) and is critical in a constructivist approach to teaching and learning (Sewell, 2002). Learners have strong pre-existing beliefs and conceptions (including those related to equity, scientific phenomena, or the nature of science), so presenting new information alone is not always enough to eliminate inaccuracies. Learners need innovative, applied learning experiences that transform the way they see, understand, and ultimately, teach STEM. Our approach to training undergraduate pre-service teachers in science, math, and integrated STEM is grounded in the value of a constructivist approach to teacher preparation and principles of effective adult learning in general (see The STEM Collaboration approach below).

We are driven by the belief that transformative learning is critical and necessary. "Transformative learning refers to processes that result in significant and irreversible changes in the way a person experiences, conceptualizes, and interacts with the world" (Hoggan, 2016, p. 71). The three aspects of transformative learning outcomes include **depth, breadth, and relative stability** (Hoggan, 2016). Depth is the impact of the change, breadth refers to various contexts in which the learner can apply what they learned, and relative stability refers to the irreversibility of the outcome. In terms of science, math, and integrated STEM, depth might be pre-service teachers seeing themselves differently as capable STEM educators, breadth would refer to ways in which our pre-service teachers can or do apply what they learned to contexts outside our class or even outside of STEM. Relative stability may present itself in years following instruction in which former participants report continuing to be different and/or impacted in intended ways by participation in the course and what they learned.

We argue that our approach will lead to transformative learning because the components of our model breathe life into the content. Pre-service teachers apply what they learn in their coursework to real teaching scenarios (applied projects) that build on authentic problems from the field (authentic problems). We have an explicit focus on hands-on and minds-on science, math, and integrated STEM learning experiences for our pre-service teachers (e.g., labs and microteaching), in which they are asked to construct their own knowledge, create their own similar activities, and then apply them to teach small groups of students (applied projects). Woven throughout coursework and alongside in-service teachers, pre-service teachers

Table 1. Number of pre-service teachers from whom data were collected during each year

Instruments	Year 1 Spring 2018	Year 2 Spring 2019		Year 3 Spring 2020		
	E	EC	E	EC	E	Total
Self-efficacy in teaching science (pre-post)				27	41	68
Science and STEM teaching knowledge (pre-post)		25	71	27	41	164
Reflection questions survey (post)		25	71	-	41	137
Focus group/interviews (delayed)	1	1	1	2	0	5

Note. E: Elementary & EC: Early childhood

participate in regular drafting and revising based on verbal and written feedback and reflection (scaffolded feedback and reflection). Finally, we include professionalization opportunities such as publishing completed projects, sharing them with actual in-service teachers, and co-writing professional publications or co-presenting at professional conferences (professionalization opportunities). These components we believe will lead to learning that has depth, breadth, and relative stability (NASEM, 2018, 2021).

Research Questions

1. What were the immediate effects of participation in the STEM Collaboration on pre-service teachers' self-efficacy and pedagogical content knowledge? Were there differences by department? (qualitative/quantitative).
2. How did former pre-service teachers view their participation in the STEM Collaboration in the following months and years? (qualitative).

METHOD

Design

This study used a mixed-methods, explanatory sequential design. In order to assess immediate impacts of our approach, we collected quantitative and qualitative data. The quantitative data were from pre-post semester surveys and the qualitative data were from pre-service teacher feedback (post-semester only). The qualitative data included open-ended survey questions. These data were analyzed, and the results used to create focus group questions that were used to assess delayed impacts in a focus group for prior participants to help explain and elaborate our findings (Creswell & Plano Clark, 2018).

The data reported here span three years of implementation, in spring of years one-three. All years included instruction by the same four faculty members and the same six elementary school teachers. In year 2, one additional instructor (a doctoral student) was added to a section of the early childhood education department's courses. Focus group interviews, in which we interviewed past students and asked them to reflect on their experiences, occurred after the end of year 3. **Table 1** shows the data collected from students who participated in the courses each year.

Participants

The sample for the quantitative data collection portion included 164 undergraduate pre-service teacher education candidates (three male, 161 female) in the spring of their 3rd year from two university departments (52 early childhood, 112 elementary education), in a regional university in the southeastern United States. These data were collected across two years with two different groups of pre-service teachers. In addition, we collected qualitative data from six former pre-service teachers in a delayed focus group. They included one male and five females. Only those pre-service teachers who signed consent forms were included in our analyses. **Table 1** displays the sample numbers by year.

Approach to Pre-Service Teacher Preparation in STEM

As noted above, our STEM Collaboration approach to pre-service teacher education aims to improve the quality of teacher preparation in teaching science and integrated STEM. Guiding principles in the collaboration include frameworks such as the 5E lesson-planning model, developed by the Biological Sciences Curriculum Study (BSCS) (Bybee et al., 2006). We also are driven by the "*Framework for K-12 science education*" (National Research Council, 2012) in terms of the "what" of science teaching. Our collaborative model of pre-service teacher education is grounded in research on impactful adult learning, based on learning for understanding (National Research Council, 2000), the value of applied, hands-on experiences, with appropriate time to learn the content in depth so that the hands-on learning does not detract from understanding the concepts in the abstract (National Research Council, 2014), and the benefits of authentic problem-solving (Power, 2010; Stein et al., 2004).

The Early Childhood/Elementary STEM Collaboration (STEM Collaboration) approach was developed to positively impact the quality of science and integrated STEM teacher preparation for both early childhood (pre-K through 3rd grade) and elementary education (K-5th grade) programs in our region (Robertson et al., 2020). Our team of higher education faculty, pre-service teachers in early childhood and elementary education programs, and in-service teachers collaborate using a strengths-based approach to this end, with the shared value that early and elementary educational programs–and children from diverse backgrounds–will be stronger when we learn from one another. Our approach is grounded in current standards and frameworks in science and STEM education (e.g., Bybee et al., 2006). The specific features of our model that align across programs include five evidence-based practices. These components are collaboration, authentic problems, applied projects, scaffolded feedback and reflection, and professionalization opportunities.

The content of the courses is relatively similar across programs, with specific differences. For example, both programs use frameworks like 5E learning cycle, a widely used instructional model for inquiry-based instruction (Bybee, 2014; Bybee et al., 2006), classroom-based unpacking the science standards activities; learning through hands-on, minds-on labs; doing activities like "draw a scientist" to confront implicit biases related to equity (Miller et al., 2018); and integrating STEM (Stohlmann et al., 2012). Notable differences include the elementary program incorporating the claims, evidence, reasoning (CER) framework, and early childhood integrating with multiple domains, such as literacy and social studies, while elementary focuses on integrating mainly math and science.

The specific features of our model that align across programs include five evidence-based practices. These components are collaboration, authentic problems, applied projects, scaffolded feedback and reflection, and professionalization opportunities. For example, we include microteaching experiences in which pre-service teachers can apply lessons from our courses with students (Kartal & Dilek, 2021). These components work together and are centered around high-quality content, including science, math, and integrated STEM content noted above (Lewis et al., 2014). The model has evolved over time as part of an intentional and iterative development process since its inception.

The STEM Collaboration involves a semester of a STEM course in early childhood or elementary education departments, faculty across departments meeting and planning together, discussions with in-service teachers, and meetings during the semester with pre-service teachers in both departments. Pre-service teachers create projects during the semester based on in-service teachers' and their students' needs and interests. More information about our procedures is published in more detail elsewhere (Robertson et al., 2020).

Pre-service teachers participated in a semester-long course in early childhood or elementary education licensure programs. Each of the five components were a part of the experience for all pre-service teachers, including collaboration, authentic problems, applied projects, scaffolded feedback and reflection, and professionalization opportunities (see more details in Robertson et al., 2020).

Due to the COVID-19 pandemic, year 2 involved less of the "applied projects" component for our pre-service teachers than in prior years. They were not able to teach small groups of students at the end of the semester. However, all pre-service teachers from year 2 did get 1-2 opportunities to teach actual students, such as pre-school science small group teaching, and teaching with the elementary students' mid-semester in order to learn about what elementary students already knew.

Instruments

The science teaching efficacy belief instrument (STEBI-B)

The STEBI-B is a paper-and-pencil tool that has been used extensively to measure science teaching self-efficacy and beliefs in pre-service elementary teachers (Riggs & Enochs, 1990). The tool's two subscales include science teaching outcome expectancy (STOE) and personal science teaching self-efficacy (PSTE). Science teaching outcome expectancy refers to a teacher's belief that science learning can be influenced by effective science teaching; science teaching self-efficacy is associated with a teacher's belief about his/her own ability to effectively teach science for students (Riggs & Enochs, 1990). Each of the 23 items are rated using the following Likert scale:1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, and 5-strongly agree. More recent analyses of the tool are reported elsewhere (Bleicher, 2004).

STEM pedagogical content knowledge test

This researcher-developed tool included four closed-ended items and two open-ended items aligned to key ideas that were taught in the courses across both departments. No existing tool met the needs of this study. The instrument included closed-ended items such as, "Name the five elements of the 5Es framework for science teaching" (Bybee et al., 2006; Scott et al., 2014) and multiple-choice items, such as, "Identify the three dimensions of the Tennessee State Science Standards" (National Research Council, 2013). To get the 5Es item correct, the respondent had to name all five of the components correctly. Each item counted for one point and was scored as correct or incorrect. The remaining three items were each worth one point each, for a total possible score of 0-7. The tool has face validity as it was developed by the faculty to align with course objectives.

Reflection and feedback survey

At the end of the STEM courses, pre-service teachers were asked to complete a reflection and feedback survey about their experiences in the collaboration. Over a two-year period, responses were collected from 118 pre-service teachers, 30 from early childhood education and 88 from elementary education. Participants responded to a variety of questions including what was most difficult, what was most valuable, and what they had learned from the projects they completed.

Focus group

After the third year of the collaboration, we held a focus group using a structured interview protocol (Jacob & Furgerson, 2012) with five participants from the STEM Collaboration. Two participants were from elementary education and three participants were from early childhood education. Two participants were still pre-service teachers, with six months having passed since they completed the reflection and feedback survey. Three participants had graduated and were working as elementary teachers, with one and half years having passed for two members and two and a half years having passed for the third. The focus group questions were similar to the reflection and feedback questions, asking the participants to consider how the collaboration had impacted their self-efficacy and pedagogical content knowledge toward science, math, and integrated STEM, and how the collaboration had impacted their teaching.

Procedure

All procedures in this study were approved by the university's institutional review board (IRB). The research team informed participants of the purpose of the study during the first week of the semester and sought consent. We told participants that

(1) answers would not impact their grades,

(2) we would only look at the data once the semester was over and grades were submitted, in order to reduce any anxiety respondents might have about their responses, and

(3) they were not required to participate in the research and could opt out at any time.

The research team was available to answer questions but did not help pre-service teachers with any answers.

The team checked the surveys for completeness (e.g., no inadvertently missed items), but otherwise, did not review the responses until the semester was over. During the last two weeks of the semester, pre-service teachers completed the same instruments. The data were entered, cleaned, and analyzed using SPSS. The reflection and feedback survey were also collected at the end of the semester from all participants and data from those who consented were analyzed. Participant responses were collected using an online survey. The faculty did case selection by inviting focus group participants based on full participation in the model and representation of departments and project years. The focus group was facilitated over an online video conferencing platform by a faculty member from early childhood and one from elementary education. The video conference platform automatically generated a transcript which was used for coding.

RESULTS

Data Analysis Plan

Data for both scales of the STEBI-B were normally distributed, so we conducted a repeated measures ANOVA for the two subscales of the STEBI, with department in the analysis as an independent variable. Data for the content measure that we developed for the course were normally distributed at post-test, but not at pre-test. We therefore used a non-parametric analysis, the Wilcoxon signed ranks test, with a two-related samples analysis. We used survey data collection to inform the questions used in the focus group.

Analysis of qualitative data from the feedback surveys was coded using the strategy of inductive analysis, which moves from particular observations to general themes (Erickson, 1986). The responses of participants were coded in cycles and analyzed for patterns and themes. Two researchers coded the reflections independently and then met to discuss and identify emergent themes in the data. For the focus group, the data were coded longitudinally to identify changes in the themes across time (Saldaña, 2021) from the feedback surveys to the focus group. Using a summary matrix, the data were analyzed for changes over time relative to consistency and increases or decreases in themes as well as relevant contextual conditions for the participants at the time of data collection. The results of the focus group analysis are discussed chronologically by first summarizing the emergent themes of the feedback surveys and then relating how those themes increased, decreased, or stayed consistent for the focus group as well as emergent themes from the focus group.

Descriptive Statistics

Descriptive statistics based on the surveys are shown in **Table 2** and **Table 3**. These include outcomes that we have for each year of the project. Data reported here were collected across two years. Not all data were collected for both years. This is in part because the project has been evolving over time and as the team has expanded the project.

Research question 1: What were the immediate effects of participation in the STEM Collaboration on pre-service teachers' self-efficacy and pedagogical content knowledge? Were there differences by department? (qualitative/quantitative).

Table 2. Descriptive statistics by department for STEBI-B (year 2 only)

	OE		PSTE	
	Pre	Post	Pre	Post
Early childhood	35	37	46	52
	(4.8)	(4.5)	(5.9)	(6.8)
	27	27	27	27
Elementary	35	36	46	53
	(4.2)	(3.5)	(6.5)	(5.6)
	41	41	41	41
Total	35	36	46	52
	(4.4)	(4.0)	(6.2)	(6.0)
	68	68	68	68

Note. OE: Outcome expectancy & PSTE: Personal science teaching self-efficacy

Table 3. Descriptive statistics by department and year for four-item STEM education content measure

		Year 1		Year 2		Total	
		Pre	Post	Pre	Post	Pre	Post
Early childhood	M	0.1	3.0	0.1	3.0	0.1	3.0
	SD	(0.37)	(0.93)	(0.39)	(0.8)	(0.38)	(0.86)
	n	25	25	27	27	52	52
Elementary	M	0.1	1.8	0.2	2.6	0.2	2.1
	SD	(0.45)	(0.91)	(0.71)	(0.91)	(0.56)	(0.98)
	n	71	71	41	41	112	112
Total	M	0.1	2.1	0.2	2.7	0.2	2.4
	SD	(0.43)	(1.05)	(0.6)	(0.89)	(0.51)	(1.03)
	n	96	96	68	68	164	164

Science teaching self-efficacy (quantitative)

Scores on the outcomes expectancy (OE) subscale of the STEBI-B increased significantly for the sample from before to after the semester, F(1, 67)=14.7, p=.0002, with an effect size of Cohen's d=0.27. Means increased from 35 (4.4) at the pre-test to 36 (4.0) at the post-test. The scores on the other subscale of the STEBI-B, the personal science teaching efficacy (PSTE), also increased significantly from pre-semester, 46 (6.2) to post-semester, 52 (6.0), with an effect size of d=1.04. When the department (ECE versus elementary) was added to the analysis, there was no statistically significant interaction between department and time point for either of the two subscales. There was a trend towards the elementary department pre-service teachers' scores increasing more than scores of the early childhood pre-service teachers from before to after the course in PSTE, and the opposite trend for outcome expectancy. Neither difference reached significance. **Figure 2** illustrates the mean scores in the OE subscale by department.

STEM pedagogical content knowledge (quantitative)

Total scores on the STEM pedagogical content knowledge test ranged from 0 to 4. At pre-test, scores were positively skewed, with a floor effect, such that 82% of the sample scored 0. At post-test, scores were

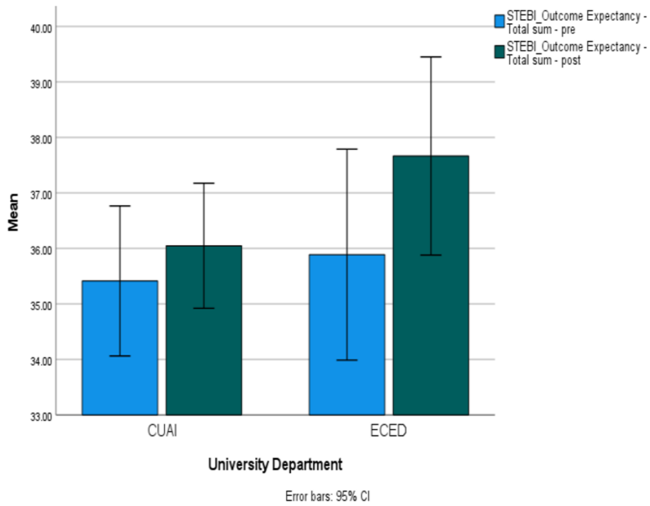

Figure 2. Average total STEBI-B-outcomes expectancy by department

normally distributed across the range of possible scores. No respondent scored a 0 at post-test. The Wilcoxon signed ranks test results, with two related samples and two-tailed, showed that scores on this measure increased significantly for the sample from before to after the semester, Z=-11.08, p<.0001. We calculated an effect size of r=.86. Means increased from 0.3 (.61) at the pre-test to 2.8 (.89) at the post-test. When we compared results and effect sizes for each project year and for each department, we found that there was no significant difference for either variable or effect sizes were comparable across groups (**Table 4**).

Reflection & feedback survey (qualitative)

In the reflection and feedback questions answered by the pre-service teacher participants (n=137) at the end of the semester, six themes emerged related to teaching efficacy and knowledge,

(1) integration,

(2) unit planning,

(3) working with students,

(4) engaging learning,

(5) increased confidence for future teaching, and

(6) hands-on learning.

Results were similar for participants from early childhood and elementary education for all themes except for hands-on learning. These themes, including the departmental differences for hands-on learning, are discussed in the following sections.

Integration

Across the reflection questions, **integration** was the topic most frequently mentioned by the pre-service teachers. They reflected on learning how to integrate math and science as well as the value of integration to

Table 4. Results of the Wilcoxon signed ranks test by year and department

	Year 2			Year 3			Total		
	Z	n	R	Z	n	R	Z	n	R
Early childhood	-4.42	25	-0.88	-4.64	27	-0.89	-6.36	52	-0.88
Elementary	-7.30	71	-0.87	-5.56	41	-0.87	-9.13	112	-0.86
Total	-8.47	96	-0.86	-7.20	68	-0.87	-11.08	164	-0.86

Note. $p<.0001$ for all analyses on negative ranks & r is effect size calculated using the formula $r=Z/\sqrt{N}$ (Rosenthan, 1994).

learning. For example, one pre-service teacher stated, "I have learned how many options there are to integrate math and science. Even more so, I have learned how beneficial it can be to integrate multiple subject areas." The pre-service teachers cited the value of integration as it related to engaging students, connecting to the real world, and conserving instructional time. Integration was also one of the elements of the project that participants felt was most difficult. Participants described their trouble "finding the right fit" for their math and science standards and balancing the coverage of the subject areas.

Unit Planning

Another theme that emerged was the process of **unit planning**. The pre-service teachers mentioned numerous tasks and learning experiences related to designing multiple days of instruction, using the 5E instructional model, connecting to standards, and planning hands-on activities. Participants described the course project as their first experience with unit planning and one that was "overwhelming" and "scary" at first; however, pre-service teachers reflected that the process was valuable and one which built their confidence for future STEM units. Participants specifically noted the value of learning to "unpack" standards and design hands-on learning experiences connected to the standards. In the words of one pre-service teacher, "I learned that integrat[ing] the 5Es in science and math might take a little time to get used to and be a little time consuming, but it is well worth it to see the kids engaging in hands-on and minds-on lessons and activities."

Working with Students

The pre-service teachers described **working with students** as one of the most difficult and valuable aspects of the project. Difficulties included managing student behavior, pacing instruction, and being flexible when things do not go as planned. One participant reflected, "I figured out that I need to improve my ability to be flexible with change and modifications to my lesson or the particular learning environment." Many noted the challenge of working with students that they did not know and described the importance of building relationships with students. Likewise, they often stated that they had underestimated the prior knowledge of the students and the importance of assessing prior knowledge in planning.

Engaging Learning

A related theme that emerged was that of **engaging learning**. Two areas were noted by pre-service teachers as important aspects of engagement, its value to learning and the inherently engaging nature of STEM. After working with elementary students, the participants reflected that they realized the value of student engagement to active learning and deepening student understanding. A few participants noted that their learning activities were not as engaging as they had thought and that they had resulting issues with classroom management. Several participants connected student engagement to the integrated nature of the projects and STEM. For example, one pre-service teacher stated, "once I found an activity that incorporated both a math and science standard, my activity was more interesting and engaging for the students."

Increased Confidence for Future Teaching

Many of the participants cited the process of developing the projects over the semester as difficult but one which **increased their confidence** and provided a sense of accomplishment. A participant reflected, "I feel way more comfortable with my ability to plan, integrate, and teach. I was really proud of my work." Participants expressed the intention to use what they had learned in their future teaching with statements such as, "This project really challenged and tested me, because it required things of me that I did not think I could do…[I] learned a lot from this challenge. I feel a lot more confident in teaching science in the future."

Hands-on Learning

All of the themes discussed so far were evident in similar ways in the responses of early childhood and elementary pre-service teachers. For the theme of **hands-on learning**, there were similarities and differences between the two groups. Both groups of pre-service teachers discussed hands-on activities as one of the most valuable aspects of designing and implementing the integrated projects. Participants appreciated the hands-on activity examples shared in class by peers and instructors as well as the hands-on activities they designed and implemented for their projects. A difference that emerged between the two groups was that only the elementary pre-service teachers reported learning *how* to use hands-on activities from the project.

Merging Results

Results from quantitative and qualitative sources used to answer research question 1 supported the conclusion that the STEM Collaboration was impactful for pre-service teachers in a variety of ways. We found evidence of a positive impact on **teaching efficacy** in science, math, and integrated STEM from qualitative and quantitative data sources. In qualitative, teaching efficacy in science and integrated STEM appeared across all six themes. In addition, we found strong positive significant changes in science teaching outcome expectancy and self-efficacy from the STEBI-B (quantitative). The pre-service teachers reported **pedagogical content knowledge** gained about teaching science, math, and integrated STEM in qualitative data again across all of the themes that emerged. Similarly, their knowledge of science and integrated STEM teaching as measured by the STEM pedagogical content knowledge test increased from before to after the semester (quantitative). The results were used to inform the focus group questions in order to understand how the impacts of the collaboration on teaching efficacy and knowledge persisted or changed over time.

Research question 2: How did former pre-service teachers view their participation in the STEM Collaboration in the following months and years? (qualitative)

Focus Group

The five focus group participants cited positive changes in their teaching efficacy and pedagogical content knowledge of teaching science and integrated STEM, similar to the responses on the reflection and feedback survey, and enduring impacts of the collaboration. In addition, they described related experiences that had occurred after the course ended from their time in their residency (student teaching) classrooms and personal classrooms. The time elapsed since the survey varied from six months to two and a half years for the focus group participants. Of the six themes that emerged from the analysis of the reflection and feedback survey, three themes persisted in the focus group data (i.e., integration, hands-on learning, and increased confidence), three themes had refined ideas (i.e., unit planning, working with students, and engagement), and one new theme, teaching as problem solving, emerged. The patterns of these findings are described in following sections.

Persistent Themes Supported by Experience & Memory

For the themes of **integration**, **hands-on learning**, and **increased confidence**, the focus group participants expressed similar views as those captured by the reflection and feedback survey, with supporting field experiences that had occurred after the course ended or memories of the course. For example, the focus group participants recalled that they valued their "first-hand experiences" of what integration is and how it works from the STEM course which helped prepare them to work with other teachers in their schools to plan integrated lessons. Likewise, the value of integration as an effective strategy to address limited time was mentioned by one first-year teacher in a lower grade who used integration when trying to "finagle and figure out" how to include time for science during the school day. It was notable that the focus group participants recalled similarly memorable experiences for the course for the themes of hands-on learning and increased confidence. Relative to hands-on learning, the focus group participants cited the value of observing and participating in the hands-on activities of their peers when they were students in the STEM course. The course helped shift the negative attitudes of participants toward excitement, in part, because of knowledge about how to approach it through the 5Es and examples shared in class. Despite the elapsed time from the survey, the themes of integration, hands-on learning, and increased confidence were very similar in the responses of the focus group.

Themes with Refined Ideas

Three themes from the reflection and feedback survey showed shifts in thinking in the responses of the focus group participants. These themes were **unit planning**, **working with students**, and **engagement**. In the survey feedback, the theme of unit planning related to a variety of skills, teaching strategies, and planning experiences, but in the focus group, the participants focused specifically on the value of the 5Es. One participant noted that the 5Es gave her "a well-rounded idea of how to go about integrating subjects together," while another stated that knowing the format of the 5Es provided "guidelines" that made teaching science less scary. One participant who was a practicing teacher mentioned that all of the examples of model lessons he had learned about in professional development used a 5E format, and that his team had fully adopted the 5E format for all of their planning for science and social studies. The participants also discussed the value of the 5Es for building student engagement when students "experience the phenomenon themselves."

The themes of working with students and engagement seemed to merge into the idea of considering the student. One participant described how her experiences in the STEM course impacted how she planned for students sharing, "[It] was really great to be able to do the 5E lesson and, like, us take the role of the students...because it really helped me think about, 'Okay, well, what are the students doing? What are they thinking about? [What] is this like for them?' And I think that helped me when I took the teacher role to consider their standpoint in the lesson." Throughout the discussion, the participants cited ways in which they plan for the specific students in their classrooms. They discussed the importance of learning about students' prior knowledge and not underestimating student abilities. They described their planning to help students build knowledge by carefully crafting guiding questions, fostering curiosity and engagement, and planning for "Aha moments" in learning activities. The participants noted that it was critical to find time to observe and work with students as well as build relationships that would foster productive learning experiences.

New Theme

One new theme emerged from the focus group responses that was not evident in the survey responses, the theme of **teaching as problem solving**. The focus group participants repeatedly cited ways in which their participation in the collaboration had helped them to address problems they faced as in-service and pre-service teachers. They mentioned the importance of using time efficiently and finding time for science, and cited integration as a key strategy they used to do so. Likewise, the participants mentioned the importance of being flexible and creative in the classroom. They cited experiences from the STEM collaboration which helped them to recognize and practice these skills. One participant reflected on her experiences in the class project by stating, "It was really helpful for me...to think about what I knew about [the standard] and then to go from there and kind of explore and, like build my own content knowledge. Because it's really easy once you see that standard, like oh, this means this. I can jump right in." The participants discussed the importance of addressing the standards, using backwards design, and being able to justify a hands-on or 5E approach in their teaching. Their experiences in the collaboration helped them feel confident in their abilities to do these tasks.

DISCUSSION

This project evaluated our STEM Collaboration approach to pre-service teacher preparation in early childhood and elementary education at one regional university in Appalachia (Robertson et al., 2020). Our data from over three years provided evidence of the extent to which our approach led to immediate and delayed impacts on pre-service teachers' teaching efficacy and pedagogical content knowledge and whether or not these shifts were transformative in science, math, and integrated STEM.

Merging Data

Results that combined quantitative and qualitative data analyses suggest that participation in our STEM Collaboration led to positive impacts on pre-service teachers immediately (RQ1) and longer term (RQ2). We found that participating in this collaborative pre-service teacher education project led to positive changes in both the early childhood and the elementary education departments, with few departmental differences.

Self-Efficacy to Teach Science, Math, & Integrated STEM

Pre-service teacher scores on both subscales of the STEBI-B significantly increased from before to after the semester, although the impact was more pronounced for the self-efficacy scale than for the outcomes expectancy (OE) scale. This is in line with another research using this tool. For example, Deehan et al. (2019) conducted an analysis of studies that reported using the STEBI-B with pre-service elementary teachers. Our results extend this prior work because it included elementary and early childhood pre-service teachers. Qualitative data strongly supported our quantitative results, with themes emerging from our data directly related to increased confidence in teaching in science, math, and integrated STEM. This is finding is important in addressing the need to increase teachers' confidence in themselves in these areas (National Research Council, 2014), which is especially pronounced in early and elementary settings (Malzahn, 2013; Ryu et al., 2018). We were enthused that pre-service teachers showed significant increase in their self-efficacy in science because this can be a substantial barrier to incorporating best practice in science teaching according to the most recent NGSS standards (National Research Council, 2014).

Our project provided preliminary evidence that our work influenced pre-service teachers' self-efficacy in supporting science, math, and integrated STEM in the longer term. Qualitative data from past participants suggested that their increased confidence in teaching in these areas persisted. This was powerful because for some, it had been 2.5 years prior that they were involved. In addition, focus group participants discussed teaching as problem solving; they noted that what they had learned increased their confidence to solve problems related to using time efficiently, integrating subjects, and planning for student learning. This long-term result is compelling and worth further study. What do practicing teachers retain specifically from their pre-service teacher preparation and what gets left behind? Are there elements that the team could add that would extend participants' retention or extent to which they adapt prior knowledge to their new contexts?

Pedagogical Content Knowledge

Pre-service teachers in our study increased their content knowledge immediately as measured by a quantitative researcher-developed tool that was aligned to course content. At the beginning of the semester, most pre-service teachers had little or no knowledge of the key math, science, and integrated STEM content from the course, and their scores significantly improved by the end. Evidence from qualitative data immediately following participation in the collaboration indicated similar increases. In the reflection and feedback questions as well as the focus group, participants described increases in their knowledge of how to integrate subjects and use the 5Es to organize instruction as well as increased confidence and attitudes toward teaching science. At the end of the semester, participants described the value of working with students, such as for recognizing the importance of student engagement in learning. In the focus group with participants months to years after taking the course, these themes persisted. They specifically noted that the experiences helped them to find time in the day for teaching science by integrating it with other subjects, a challenge noted by Early et al. (2010). We have found it powerful to bring former participants back to our classrooms as guest speakers, sharing their experiences and assisting our pre-service teachers in thinking about their experiences in our courses in relation to what they will see in the classroom. This is an area of future research for our team.

Transformative Learning

Hoggan (2016) identifies three aspects of transformative learning, depth, breadth, and relative stability. Our data suggest that in a single course that includes collaborative innovations such as ours can be transformative for pre-service teachers. The immediate impacts of the collaboration, as measured by the surveys and reflection questions, indicated a depth of learning about teaching math, science, and integrated STEM, in that participants appeared to fundamentally alter their views and identities as science, math, and integrated STEM educators. Evidence from the focus group indicated that the collaboration impacted the breadth of applications (e.g., planning and integrating other subject areas) as well as relative stability with participants citing lasting impacts up to two and a half years later. While such findings are not definitive, the initial findings are promising and worthy of future study. We hope to follow up in future years to delve further into each of these components: depth, breadth, and relative stability.

Limitations

Our measure of content was limited in that it was researcher-developed, so results on that tool should be interpreted with caution. Our challenge has been finding a tool that is appropriate for our needs. We will include additional measures with evidence of reliability and validity in future years to determine if increases in knowledge and pedagogical content knowledge appear using less well-aligned measures.

Another limitation is that the present study evaluated the project's impact as a whole. For example, we know that our participants appreciated the personal reflection, such as on their biases about who can be a scientist and equity in science and STEM education. But we did not measure that piece separately. Future work might unpack the differential impacts of individual components of the model and add additional outcome measures. However, for this early stage of the research the scope was reasonable to first identify global impacts.

Future Steps

Additional future ideas include adding to our data collection plans. We will identify additional measures, such as one for math self-efficacy (Enochs & Riggs, 1990) and additional content measures (e.g., Greene et al., 2013; Wheeldon & Ahlberg, 2012) that are less aligned with the course content, and measures of pre-service teachers' views on equity and diversity in STEM. One option for the impact of participating on content knowledge is to give tests normally given to the future students of our teacher candidates, such as a 3rd grade science test.

Another option is concept maps, which have been used as a research instrument to document the development of students' conceptual understanding, and to explore misconceptions in student knowledge (Shavelson et al., 1994; Watson et al., 2016). We are also exploring a larger study that would include a comparison group of educators who learn math, science, or STEM content in their pre-service programs that use teaching methods (e.g., traditional lecture) other than our model's approach.

Trends in departmental differences might be worth exploring in future semesters to see if the departmental differences hold with a larger sample or if trends appear in subsequent years. If these differences reach significance or the trends appear in later years, we will explore if there is content or if our teaching methods across departments might be differentially impacting our pre-service teacher candidates' self-efficacy or the extent to which they believe that changes in science teaching can positively impact student learning. This could relate to larger philosophical stances in education that are important in understanding the settings in which they will work when they start their teaching careers. Reflecting on their own philosophical views will be important as they consider these in relation to views on science and the role of science in communities such as Appalachia.

CONCLUSION AND IMPLICATIONS

This study presents promising results related to changes in pre-service teachers' self-efficacy and knowledge that may better prepare our future teachers to teach math, science, and integrated STEM. Qualitative data suggest that pre-service teachers across departments perceived components of our model specifically to be valuable to their future teaching careers. This content can be intimidating for many adults, so we need to continue to support future teachers to tackle the content with confidence. We want our future teachers to *want* to include science, math, and integrated STEM in their teaching, and to see rigorous, hands-on, minds-on science and STEM experiences as important for their students' learning now, as a path towards equity, and as critical for their students' educational and career trajectories. Our STEM Collaboration tackles this by implementing transformative learning experiences to increase the skills and knowledge of our pre-service teachers and by supporting and broadening participation in STEM for students of Appalachia. The innovative pieces of the approach were critical–especially the broad collaboration across the university, with diverse schools and community partners, applied experiences grounded in real challenges early in the pre-service teachers' program, and the professional opportunities like article writing and conference presentations. We can–and we must–address barriers to scientific literacy with higher quality training for, and incorporated into, early childhood and elementary teacher preparation programs.

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