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Elementary Pre-Service Teachers’ Reflections on Integrated Science/Engineering Design Lessons: Attending, Analyzing, and Responding to Students’ Thinking

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ABSTRACT

The Next Generation Science Standards (NGSS) and recent efforts in STEM education have highlighted a multi-disciplinary vision of teachers’ integrating science education and engineering design problem-solving for student learning and critical thinking development. However, elementary pre-service teachers (PSTs) typically are unfamiliar with engineering design. Since research is limited on elementary PSTs’ ability to notice student thinking for engineering problem-solving, the purpose of this exploratory study was to identify patterns in PSTs’ written reflections from their fourth-grade practicum teaching experience with an integrated science/engineering STEM unit. We adapted Barnhart and van Es’s (2015) teacher noticing coding scheme to examine PSTs’ level of focus (low, basic, or strong) in their professional noticing (attending, analyzing, and responding) of students’ thinking and engineering disciplinary core ideas. The results indicated that PSTs’ reflections focused more on attending to students’ engineering ideas than on analyzing and responding to students’ thinking. For NGSS engineering disciplinary core ideas, the PSTs reflected the least on defining and delimiting the engineering problem, focusing more on students’ idea generation to solve the problem and students’ thinking to optimize their design with less emphasis on evaluating design ideas. These findings suggest possible areas of emphasis for teacher educators to prepare elementary PSTs in developing their ability to attend to, analyze, and respond to students’ engineering thinking when integrating engineering design with science education.

Keywords: Integrated science/engineering education; engineering design; pre-service teachers; elementary education; professional noticing

With current reform efforts in science, technology, engineering, and mathematics education (STEM) to provide the next generation of students with knowledge and skills for solving national and global problems (U.S. Department of Education, 2015), teacher educators face new challenges when preparing prospective elementary teachers to teach. The Next Generation Science Standards (NGSS) released in the U.S. in 2013 provided a vision for K-12 science education that teachers offer learning opportunities integrating science and engineering design to develop students’ knowledge, practices, and ways of thinking for understanding and solving problems (NRC, 2012). Yet, results from a national survey of science and mathematics education showed that only 3% of
elementary teachers felt well prepared to teach engineering in contrast with 73% who felt well prepared to teach mathematics and 31% for science (Banilower et al., 2018).

The STEM subject of engineering is emphasized in the new standards with the inclusion of disciplinary core ideas (DCIs) and practices of engineering design (NGSS lead States, 2013) that were not part of previous science education standards (NRC, 1996). The framework underlying NGSS defines engineering as “a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants” and positions design as the central activity of engineering (NRC, 2012, p. 202). Through engineering design problem-solving, students are expected to understand three engineering DCIs: (a) defining and delimiting engineering problems, (b) developing possible solutions, and (c) optimizing the design solution (NGSS Lead States, 2013). Yet, for elementary pre-service teachers (PSTs), this new expectation may pose challenges given that elementary teachers tend to have limited science content knowledge and little or no exposure in the STEM subject of engineering design (Cunningham, Lachapelle, & Lindgren-Streicher, 2006; Hammack & Ivy, 2017).

To meet the NGSS expectation, PSTs need an understanding of the inter-relationship of science practices and engineering design problem-solving for student learning. From scientific investigations, students observe patterns, provide explanations for natural phenomena, and generate science knowledge (NRC, 2012). In combination with the engineering design process, students apply this knowledge in developing solutions through problem definition; design planning and construction; and solution testing, evaluation, and redesign (Cunningham & Carlsen, 2014; NRC, 2012). The teacher’s role would be to encourage students to seek knowledge from investigations and use their science ideas to think as engineers to inform design proposals, troubleshoot design failures, and reflect meta-cognitively to improve the solution (Dalvi & Wendell, 2017).

The developers of NGSS highlighted the students’ role as key in engineering design; students define and delimit the problem, design solutions, and optimize the solution (NGSS Lead States, 2013). This emphasis on student ownership of the design process necessitates that PSTs be able to notice students’ ideas and practices in order to be responsive to student thinking as well as promote students’ analysis and reasoning about design decisions (Dalvi & Wendell, 2017; Levin, Hammer, & Coffey, 2009). Yet, research has indicated that novice teachers tend to focus more on content delivery and social conflicts within the class than on student conceptions (McCormick, Wendell, & O’Connell, 2014). Specifically, from research with three groups of participants (elementary education PSTs, engineering majors, and STEM educators specializing in STEM curricula/teacher workshops) who examined a video of fourth-grade students solving an engineering problem, Dalvi and Wendell (2017) found that PSTs noticed students’ science/engineering thinking less often than engineers or STEM educators. Thus, teacher educators are faced with the challenge of preparing PSTs not only to broaden their view of science education to include engineering, but also to notice student thinking for engineering design. The purpose of our study is to contribute further to this field by examining PSTs’ noticing of their own students’ engineering thinking from reflecting on their STEM practicum teaching experiences.

Informed by research in teacher noticing (Barnhart & van Es, 2015; Miller, 2011; van Es & Sherin, 2008), we sought to gain insight into PSTs’ attention, analysis, and response to student thinking for each NGSS engineering DCI. The first author mentored PSTs for their science methods practicum experience with an integrated science/engineering STEM unit on electric circuits for fourth-grade students. The students were challenged to solve a school soccer field
lighting design problem. The meta-cognitive practice of reflection, typically used in teacher preparation programs to promote PSTs’ professional growth (Davis, 2006; Loughran, 2002), provides a means for teacher educators to understand PSTs’ thinking as they implement new pedagogies. Using PSTs’ reflections on each lesson of the STEM unit as data sources, two questions guided our study: (a) How do elementary PSTs attend, analyze, and respond to students’ thinking in their written practicum reflections on integrated science/engineering design lessons? (b) What do elementary PSTs focus on regarding students’ thinking for each disciplinary core idea of engineering design in their written practicum reflections on integrated science/engineering design lessons?

**Background**

Our research is grounded in three theoretical frameworks that inform our study of what elementary PSTs describe in their reflections from integrated science/engineering design lessons. First, we draw from the NGSS framework for engineering design in grades K-5 (NRC, 2012) and empirical work with PSTs’ and elementary teachers’ implementation of engineering design lessons. Next, we consider research on PSTs’ professional noticing of student thinking (Sherin, 2001). Finally, we incorporate scholarship on reflection in teacher education programs as a tool to gain insight into PSTs’ thinking (Davis, 2006).

**Engineering Design in Elementary Grades**

The framework for NGSS describes the intent for elementary students’ engagement in engineering design for different grade spans (NRC, 2012). At grades K-2, students consider problems, use materials and representations to solve the problem, and compare different solutions. By grades 3-5, students engage more formally in engineering. Students define constraints of an engineering problem as well as criteria for judging the success of a solution. They research and generate multiple design options noting pros and cons of each in meeting the criteria and constraints of the problem. Finally, they test design options, revising them several times after considering failure points, in an iterative process to improve the solution.

With regard to elementary PSTs’ understanding of engineering design, research is limited on teacher education preparation for engineering design (Wendell, 2014). Wendell (2014) compared the engineering design practices of 26 PSTs in an elementary science teaching methods course with those used by novice and expert engineers. The findings showed that the PSTs focused on idea generation to solve the problem without detailed evaluation of their potential designs. Similar to beginning college engineering students, the PSTs did not attend to “problem scoping”—gathering information to define the problem or identifying constraints or criteria for design (Atman et al., 2007, p. 360). Wendell posited that the PSTs may have assumed the information provided for the engineering task was adequate and did not perceive a need to frame the problem or search for more explicit information.

Since elementary PSTs likely have similar background experiences to in-service elementary teachers, we examined the more extensive body of research into elementary teachers’ perceptions of engineering and engineering design. Studies have indicated that elementary teachers tend to be unfamiliar with design, engineering, and technology; hold overly broad views about the work of engineers; and have conceptions that do not necessarily align with the NGSS definitions of engineering disciplinary core ideas and practices (Cunningham, Lachapelle, & Lindgren-Streicher, 2006; Hammack & Ivy, 2017; Hsu, Purzer, & Cardella, 2011). Furthermore, research has indicated
that there is variability in elementary teachers’ perceptions of how to teach engineering design and how to respond to students’ design ideas (Capobianco, Diefes-Dux, & Mena, 2011; McCormick et al., 2014; Wendell, Swenson, & Dalvi, 2016). Teachers may adopt a conventional teacher-directed approach whereby students use a step-by-step linear process to problem-solving and teachers instruct students in science concepts to apply to the engineering problem, and/or teachers may operate from a student-constructivist frame of learning encouraging student sense-making of the design process to figure things out. In addition, similar to Wendell’s findings with elementary PSTs (2014), Hsu, Purzer, & Cardella (2010) suggested that elementary teachers may need to place greater emphasis on students’ defining the engineering problem and planning design solutions since students tend to focus on building and testing prototypes.

Pre-service Teacher Noticing of Student Thinking

Development of expertise in a profession involves growing skill in noticing meaningful aspects of complex situations as well as ignoring the unimportant (Miller, 2011). This capacity is termed “professional vision” (Goodwin, 1994), which Sherin (2001) applied to education. For an expert teacher, this awareness includes noticing salient features in a class such as individual student’s thinking or causes of student behaviors as well as interpreting and responding to situations (Sabers, Cushing, & Berliner, 1991). A body of research has examined PSTs’ noticing in mathematics (Jacobs, Lamb, & Phillip, 2010; Sherin, Jacobs, & Phillip, 2011; Sun & van Es, 2015) and secondary science (Barnhart & van Es, 2015; Levin & Richards, 2011). Evidence has shown that PSTs often focus on class management, task completion, and whole class learning without attending to or analyzing individual student’s understandings, thus, developing an inaccurate perception of their teaching effectiveness (Loughran, 2002; Sabers et al., 1991).

To study PST noticing of students’ ideas, researchers have examined three components: (a) attending to student thinking, (b) analyzing student understanding from observed evidence, and (c) responding by determining next steps (Barnhart & van Es, 2015; Jacobs et al., 2010). Barnhart and van Es (2015) developed a framework with three levels of sophistication to identify PSTs’ professional noticing in their written reflections to a video recording of their own science inquiry-based teaching. A reflection with high sophistication in attending highlighted students’ thinking from a science conceptual focus when students interpreted investigation data, in contrast with a medium sophistication reflection of noting students’ procedural collection of data, or low sophistication of describing teacher actions, student behavior, or classroom events. The skill of analyzing at a high level of sophistication involved consistently making sense of students’ thinking using evidence to support claims; whereas, PSTs would provide some evidence at the medium level or no evidence or analysis of student ideas at the low sophistication level. For responding, a high sophistication reflection included the teacher’s action on a student’s idea and specific next steps based on evidence. At the low sophistication level, PSTs would provide no description of acting on a student’s idea or vague next steps. The reflections provided a data source to examine PSTs’ noticing of student thinking in their process of learning to teach.

From their research, Barnhart and van Es (2015) found that PSTs tended to seek “correct” answers from students rather than attending to, analyzing, and responding to students’ science ideas. In addition, their results indicated that PSTs’ attention to students’ science conceptions did not guarantee that they were able to analyze or respond to students’ thinking. Finally, they also noted that high level PST scores occurred most frequently with the skill of attending, then analyzing, and lastly responding to students’ science ideas—suggesting that these three skills may
be successively more complex for PSTs to acquire. Specific to the field of elementary engineering, Dalvi and Wendell (2017) reported that from examining video cases of elementary students engaged in engineering design, PSTs most frequently noticed students’ suggesting or modeling design ideas. However, the PSTs gave less attention to students’ justifying design ideas or refining a solution from alternative suggestions. Similar to findings from Barnhart and van Es, the PSTs provided insufficient detail in their responses to students’ engineering thinking.

Reflection: A Window into PSTs’ Thinking for Engineering

Scholars in teacher education have noted that for PSTs to adopt innovations in education, they not only need clinical experience, but also opportunities to reflect on their developing teaching practices (Hammerness et al., 2005; Loughran, 2002). PSTs need to be metacognitive and “analyze their acts of teaching as well as reactions and interactions that occur, so that they can reflect on these outcomes and adapt what they do” (Hammerness et al., 2005, p. 377). This manner of thought would require examining evidence, broadening areas for observation, considering possible explanations, questioning initial assumptions, reasoning through alternative approaches, and evaluating one’s own practice (Schön, 1983; Valli, 1997).

However, Schön (1983) noted that practitioners may not be aware of areas in need of observation or assumptions to be questioned. For teachers to make sense of situations through reflection, they must be able to name what they will attend to and frame the context, necessitating that teachers recognize the situation in need of examination (Loughran, 2002). For PSTs in practicum settings who are learning about engineering pedagogy and teaching students for the first time, they may focus on a narrow set of engineering design components, as Wendell (2014) noted, and not be aware of factors to attend to regarding student thinking. This novel experience may challenge their ability to reflect while engaged in teaching (Davis, 2006). Schön (1983) recognized that reflecting while in the midst of an activity, “reflection-in-action,” may interfere with a person’s smooth performance in the moment. Though in-service teachers can reflect-in-action and then make decisions while teaching, Davis argues that, for PSTs, written “reflection-on-action” (Schön, 1983) is a more reasonable expectation. From timely retrospective reflections, PSTs can evaluate their growing teaching practice and teacher educators can have a window into what PSTs notice about students’ learning.

However, research in science education has revealed that some PSTs reflect on their teaching using a narrow frame focused more on their performance as teachers than on students as learners (Anderson, Smith, & Peasley, 2000). When they do attend to the student learner frame, they may make observations emphasizing students’ activity in science investigations rather than students’ conceptual ideas (Abell, Bryan, & Anderson, 1998). This limited attention to student thinking could impact the fidelity with which PSTs adopt the NGSS intent for student ownership of engineering design problem-solving.

Methods

Given the NGSS emphasis on student generation, analysis, and optimization of engineering designs, examination of PSTs’ reflections on their engineering lessons with elementary students would shed light on their professional noticing of student thinking for engineering design as well as their own understanding of engineering design pedagogy. This study employed qualitative methodologies to identify and describe PSTs’ levels of focus on attending, analyzing, and responding to elementary students’ engineering thinking.
Participants and Study Context

Participants were third year undergraduate elementary education PSTs enrolled in a science education methods course at a small liberal arts university. Of 17 PSTs in the course, 14 agreed to participate in the study (13 females and 1 male, ages 20 and 21). The goals of the methods course were to promote PSTs’ understanding of NGSS, develop their ability to identify students’ understandings, and experience integrating a design problem into a science unit. To apply their learning from the methods course, PSTs participated in a science teaching practicum in fourth-grade classrooms in an urban elementary school. Each PST worked with a group of four students providing four lessons for a science/engineering STEM unit on electric circuits. The PSTs facilitated students’ inquiry-based investigations and mathematical thinking comparing the voltages and brightness of series and parallel circuits of bulbs and batteries within the context of a real-world, relatable problem in order for students to experience engineering design and apply their developing knowledge about series and parallel circuits.

The integrated science/engineering unit format was modeled after Boston Museum of Science Engineering is Elementary units (Museum of Science, Boston, 2015) and developed by the methods instructor (first author). For the first session, PSTs introduced a story about four friends who wanted lights on the school’s ball field to play soccer at night. In the story, the father of one of the friends, an electrical engineer, explained the engineering design process prompting students to ask questions about the problem (i.e., cost, location of power source, number of lights allowed). During the second session, student teams investigated series and parallel circuits of bulbs and batteries, noting results they could use in designing a scale model of a lighting scheme. In the third session, teams generated ideas of lighting designs that satisfied the budget constraints and design limitations, and each team selected, constructed, tested, and evaluated one design in addition to calculating its cost. In the last session, teams identified design features needing improvement and redesigned, tested, and evaluated a second design, presenting results to their peers.

To prepare the PSTs for this challenge, the PSTs first worked through the lighting problem in small groups during the methods course. They constructed understanding of the engineering DCIs by discussing criteria for a lighting design and the material/budgetary limitations, generating possible circuitry designs, testing and evaluating a prototype, and improving the design.

Data Sources

Data for this study consisted of two sources: (a) PSTs’ reflections for each of their four practicum teaching sessions with the integrated science/engineering design STEM unit and (b) transcriptions from audio-taped interviews. These sources were selected as a means for PSTs to provide “reflection-on-action” (Schön, 1983), as recommended by Davis (2006). Though video-cases of elementary teachers’ lessons are sometimes used as prompts to develop PSTs’ professional noticing skills (Jacobs et al., 2010), our goal was to collect metacognitive reflections from the PSTs about their own teaching experience and noticing of students’ thinking; therefore, we focused this research on the PSTs’ written and oral reflections.

For each reflection, the PSTs responded to basic question prompts addressing attending, analyzing, and responding to students’ science and engineering thinking with minor modifications in questions to account for the focus of each session. For example, for attending to student thinking, the PSTs responded to the question, “What ideas did your students come up with for …?” The purpose of this question was to elicit PSTs’ comments about their attention to students’
understanding of the science concepts and their generation of engineering ideas in solving the engineering problem. For analyzing students’ thinking, PSTs responded to the question, “What did you learn about each student’s understanding and misconceptions of…?” For the second session, they would reflect on students’ thinking about series and parallel circuits for a potential design; whereas, for the third session the PSTs would address how students explained what did and did not work in their design. To discover the PSTs’ conceptions about how to respond to students’ thinking, they addressed the question, “How will you plan for the next lesson to help students…?” This question was designed to prompt the PSTs to consider how they would guide students in addressing their misconceptions about different circuits as well as facilitate students’ next steps in the iterative engineering design process. To capture the PSTs’ thinking as soon as possible, all reflections were completed within two days of each lesson, totaling 56 reflections.

A second data source included transcriptions from audio-taped interviews with 11 of the PSTs following the integrated science/engineering unit. The second author conducted six individual interviews and one focus group interview with five PSTs using a semi-structured interview guide. The purpose of the interviews was to triangulate findings from the reflections (Denzin, 1978) and gain insight into the PSTs’ perspectives on students’ understanding of science content and adoption of engineering practices as well as approaches used to learn about students’ thinking.

Data Analysis

To minimize the PSTs’ perception of risk or conflict of interest given the first author’s dual role as researcher and methods course instructor, data analysis began after the semester concluded (Patton, 2002). To prepare the data for analysis, we segmented each reflection into “idea units” indicating a distinct shift in topic of discussion (Jacobs, Yoshida, Fernandez, & Stigler, 1997, p. 13). In this study, an idea unit constituted a segment of a reflection that addressed one particular aspect of professional noticing. For example, if a PST first wrote about a student’s idea suggesting that team members check the battery connection to troubleshoot an inoperable circuit, and then the PST followed up with analyzing the student’s understanding and reasoning about circuits, this section of the reflection would be identified as two different idea units—one for attending to student thinking and one for analyzing student thinking.

To answer the first research question, we engaged in a series of steps to create a coding scheme for data analysis adapted from Barnhart and van Es’s (2015) framework characterizing differences in PSTs’ ability to attend, analyze, and respond to student thinking. First, we examined reflections from seven PSTs to gain insight into similarities and differences among their reflections for this integrated science/engineering STEM unit in attending, analyzing, and responding to student thinking. Next, we coded each idea unit and wrote analytic memos (Patton, 2002) informed by research in the field of professional noticing and science lesson analysis, which emphasized the need for teacher attention to student thinking, teacher analysis of students’ understandings and misconceptions, student generation of ideas, evidence-based claims, and student-centered learning (Anderson et al., 2000; Barnhart & van Es, 2015; Davis, 2006). From a review of the memos, we created a three-level framework, termed the AAR Noticing Framework, delineating differences in PSTs’ attending, analyzing, and responding with a low, basic, or strong focus on student thinking in their reflections (see Table 1). As indicated by research in teacher development with reform-based science teaching (Davis & Smithey, 2009; Zembal-Saul, Blumenfeld, & Krajcik, 2000), the levels progressed from a novice, procedural focus to a student-centered, conceptual focus. Using this framework, two researchers independently scored the reflections of four randomly selected
PSTs, achieving 95% inter-rater reliability (Stevens, 2002) and resolving discrepancies before scoring the remaining PSTs’ reflections.

To answer the second research question of the PSTs’ focus (low, basic, or strong) on student thinking for each of the engineering DCIs, the researchers re-examined the data through the lens of the three DCIs for design: defining and delimiting the engineering problem, developing possible solutions, and optimizing the solution (NGSS Lead States, 2013). Informed by research in engineering education (Cunningham, 2008; Wendell, 2014), the authors identified possible levels from a teacher-directed to a student-centered focus in the PSTs’ reflections on engineering design (see Table 2). For example, a reflection with a low focus on student thinking for the DCI, developing possible solutions, would involve a PST providing teacher-directed input for design solutions; whereas, a reflection with a strong focus on student thinking would note students’ ideas and how the teacher supported the students in generating their own ideas. The framework, termed the Engineering Design Framework, describes the ranges of focus on student thinking for the three engineering DCIs. The researchers independently scored reflections of four randomly selected PSTs using this framework with inter-rater reliability of 94% (Stevens, 2002) and resolved all discrepancies before scoring the idea units from the remaining PSTs’ reflections.

Table 1
Levels of focus for reflecting on student thinking—the AAR Noticing Framework

<table>
<thead>
<tr>
<th>Skill</th>
<th>Low focus on student thinking</th>
<th>Basic focus on student thinking</th>
<th>Strong focus on student thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Attending</td>
<td>A1-Describes classroom climate, teacher decisions, teacher pedagogy, student behavior with little or no attention to student thinking.</td>
<td>A2-Describes student thinking for constructing circuitry investigations and collecting data (science procedural focus) with little or no connection to engineering problem.</td>
<td>A3-Describes student thinking in using results from circuitry investigations to generate designs to solve the engineering problem (science concepts-engineering design connection).</td>
</tr>
<tr>
<td>B- Analyzing</td>
<td>B1-Describes highlighted points of what students say without elaboration or analysis. Little or no use of evidence to support claims.</td>
<td>B2-Provides some analysis of highlighted points of what students say. Analyzes student thinking with some use of evidence to support claims.</td>
<td>B3-Provides analysis of student thinking using evidence to support claims. Identifies students’ understandings and misconceptions.</td>
</tr>
<tr>
<td>C- Responding</td>
<td>C1-Provides no response or disconnected descriptions of what to do next time to act on a specific student’s circuitry or engineering design ideas.</td>
<td>C2-Provides limited description of what to do next time to act on a specific student’s understanding of circuitry or engineering design ideas.</td>
<td>C3-Provides detailed description of next steps to act on a specific student’s circuitry or engineering design ideas to promote engineering problem-solving.</td>
</tr>
</tbody>
</table>

Based on these analyses, we created frequency distribution tables generated from tallying the PSTs’ scores for idea units using each framework (Gravetter & Wallnau, 2008). These tables indicated the number and percentage of reflective comments made in each category for the AAR Noticing Framework.
Framework and the Engineering Design Framework including reflection examples (see Tables 3 and 5) as well as the number of scores in each category for each PST (see Tables 4 and 6).

Analysis of the interview data involved first reading through each transcription and writing memos describing the nature of each PST’s statements regarding professional noticing of student thinking and core ideas in engineering (Merriam, 1998). We compared the memos with results from the AAR Noticing Framework and Engineering Design Framework seeking confirming and disconfirming evidence of patterns that emerged regarding the PSTs’ professional noticing of student thinking for engineering design (Erickson, 1986).

Table 2
Levels of focus on student thinking for engineering DCIs—the Engineering Design Framework

<table>
<thead>
<tr>
<th>Engineering DCIs</th>
<th>Low focus on student thinking</th>
<th>Basic focus on student thinking</th>
<th>Strong focus on student thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Defining and delimiting engineering problem</td>
<td>D1-Describes teacher presentation of criteria and constraints for solving the engineering problem. Does not address students’ ideas of criteria/constraints.</td>
<td>D2-Describes how the teacher notes students’ ideas about the criteria and constraints for solving the engineering problem.</td>
<td>D3-Describes how the students define criteria and constraints for solving the engineering problem, and how the teacher supports students with this DCI.</td>
</tr>
<tr>
<td>E-Developing possible solutions</td>
<td>E1-Describes teacher suggestions for design options. Does not address students’ ideas of design options or choice of a design to pursue.</td>
<td>E2-Describes how the teacher notes students’ ideas for design options and design choice without indicating student analysis of the pros/cons of each design option.</td>
<td>E3-Describes how the students generate multiple design options, analyze pros/cons of each, and engage in reasoned debate to decide on design to test, and how the teacher supports students with this DCI.</td>
</tr>
<tr>
<td>F-Optimizing the design solution</td>
<td>F1-Describes teacher suggestions for how to refine the design. Does not address students’ identification of design features that need improvement.</td>
<td>F2-Describes how the teacher notes students’ ideas of design features needing improvement and guides students to consider ways to refine the design.</td>
<td>F3-Describes how the students test the design, identify failure points needing improvement, and refine design, and how the teacher supports students with this DCI.</td>
</tr>
</tbody>
</table>

Results

We report on the results of the PSTs’ focus on student thinking in their reflections for each component skill in professional noticing and each engineering DCI, providing excerpts from PSTs’ reflections with supporting evidence from their interviews. PSTs’ names used are pseudonyms, and fourth-grade students’ names are designated by an initial.

Attending, Analyzing, and Responding to Student Thinking

In answer to the first research question, the results indicated PSTs’ levels of professional vision (Sherin, 2001) with attending, analyzing, and responding to students’ thinking when reflecting on their first experience teaching a science/engineering design unit (see Tables 3 and 4). From
examining idea units across four reflections for all PSTs, evidence showed that PSTs’ reflections most frequently addressed attending to student thinking (235 idea units); then, analysis (174 idea units); and least frequently, response to student thinking (80 idea units).

Table 3
Pre-service teachers’ levels of focus on student thinking—the AAR Noticing Framework

<table>
<thead>
<tr>
<th>Levels of focus on student thinking</th>
<th>Idea units per category</th>
<th>Percentage</th>
<th>Examples of PST reflection comments for each category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Attending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1-Low focus on student thinking</td>
<td>82/235</td>
<td>35%</td>
<td>“I’m not used to asking so many questions to get information out of students. Usually, you just assume that they know.” (Laura) “He continued to reference the room temperature as causing him to lose focus.” (Dana)</td>
</tr>
<tr>
<td>A2-Basic focus on student thinking</td>
<td>87/235</td>
<td>37%</td>
<td>“Student T was able to tell me that bulbs in series were dim because ‘the voltage of the battery is split between the two bulbs.’” (Molly)</td>
</tr>
<tr>
<td>A3-Strong focus on student thinking</td>
<td>66/235</td>
<td>28%</td>
<td>“Observing their diagrams, especially when they would draw arrows, was eye-opening. It allowed us to understand their thoughts.” (Meg)</td>
</tr>
<tr>
<td>B-Analyzing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1-Low focus on student thinking</td>
<td>125/174</td>
<td>72%</td>
<td>“Student T said, ‘Well, all bulbs lit a little bit, so that’s good.’ I [PST] agreed with him. (Ella)</td>
</tr>
<tr>
<td>B2-Basic focus on student thinking</td>
<td>34/174</td>
<td>20%</td>
<td>“Student S suggested not to use series for the challenge because it is dim. The student realizes we need bright lights for the engineering challenge and the series circuit does not produce bright lights.” (Anne)</td>
</tr>
<tr>
<td>B3-Strong focus on student thinking</td>
<td>15/174</td>
<td>8%</td>
<td>“I saw this as a theme amongst all the students that it was hard for them to see the missing connections on paper, but easy for them to identify them when they were actually piecing the circuit together.” (Sandy)</td>
</tr>
<tr>
<td>C-Responding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1-Low focus on student thinking</td>
<td>46/80</td>
<td>58%</td>
<td>“They should be modifying the designs they already created… Perhaps, I will have ideas of modifications that they can make.” (Anne)</td>
</tr>
<tr>
<td>C2-Basic focus on student thinking</td>
<td>24/80</td>
<td>30%</td>
<td>“Based on Student W’s misconception, I would have emphasized the difference between the power provided by a parallel circuit with two batteries and a series circuit with two batteries. Perhaps I could have used more visuals such as a string of Christmas lights.” (Dana)</td>
</tr>
<tr>
<td>C3-Strong focus on student thinking</td>
<td>10/80</td>
<td>12%</td>
<td>“It is evident that they do not completely understand series and parallel circuits… We will need to discuss voltages that the bulbs receive and why this is happening.” (Chloe)</td>
</tr>
</tbody>
</table>

**Attending to student’s thinking for engineering design.** Though the greatest number of idea units addressed the professional skill of attending, every PST displayed a range of abilities from a low focus to a strong focus on student thinking. The results indicated that all the PSTs wrote some reflection comments that were at a low level of attending to student thinking (see Table 4, A1). In
these cases, PSTs wrote from a teacher-centered perspective detailing their own actions and decisions or noting students’ behaviors, attitudes, and motivation, or the environmental conditions. For example, Val focused on her own actions,

I created a model of the correct drawing of a closed circuit. I briefly showed it to them before quickly erasing it so that they would be able to draw it from their memory… I demonstrated with my arms how parallel lines will continue on a path without ever intersecting.

In addition, some reflections indicated assumptions about students’ understanding. Laura articulated her belief that students automatically understand concepts during lessons (see Table 3). Laura explained in her interview that she struggled with “getting questions to try to figure out what they’re thinking.” Thus, for PSTs with low attention to student thinking, they focused on their own performance, student behavior, class conditions, and their own assumptions about student understanding.

For noticing with a basic focus on student thinking, all the PSTs (see Table 4, A2) also attended with a procedural lens to student ideas from their series and parallel circuitry investigations, describing students’ abilities to distinguish, construct, and troubleshoot circuits. Furthermore, PSTs would note students’ conceptions about circuitry pathways, voltage, and bulb brightness for each circuit without noting how students applied these concepts to the lighting design problem.

Yet, some of the reflection comments from most of the PSTs (see Table 4, A3) also had strong attention to students’ engineering thinking when describing students’ design ideas and connections made between the engineering problem and their scientific understanding of circuits. With this student-centered focus, PSTs noted how students explained their thinking to each other. For example, Sandy’s reflection indicated that she observed not only student thinking for engineering design, but also student interactions in which students “tried to convince the other group members” of an alternative idea to solve the engineering problem. One PST, Rebecca, provided 13 comments that were coded as having strong attention to students’ engineering thinking. For example, she wrote, “To understand more deeply their thinking…I asked the students to explain to me why they thought using a parallel circuit of bulbs would be an improvement.” She frequently reflected on her students’ design ideas to understand the reasons for their choices.

Analyzing student thinking for engineering design. In contrast to results for attending to student thinking, the data from the PSTs’ reflections that addressed analyzing student thinking indicated that most of the comments had a low focus on analyzing their students’ thinking for the engineering design (see Table 4, B1). The reflection comments at this low level described students’ ideas with little or no evidence and without analyzing students’ conceptions of electric circuits or engineering designs. For example, Ella noted she agreed with Student T about the brightness of the bulbs after testing one prototype (see Table 3); however, she did not provide analysis of Student T’s thinking about the effectiveness of the design.

Fewer PST reflection comments provided a basic level of analysis of their students’ thinking for engineering design and some interpretation of students’ actions and ideas (see Table 4, B2); yet, the PSTs’ analysis did not identify fully students’ conceptions about circuits. For example, Anne attempted to analyze the student’s reasoning for not using a series circuit for the challenge (see Table 3); however, she did not note whether the student referred to bulbs or batteries wired in series or understood the difference in the circuits. Interview data provided some insight into this omission. Several PSTs commented on their limited understanding of circuits. Sandy explained
that she was “only one lesson ahead of the kids, so our knowledge is pretty much where theirs is” in understanding the differences in light intensity and electrical pathways for different circuits.

In contrast, the least number of comments had a strong focus on analyzing student thinking from seven PSTs (see Table 4, B3) including evidence to support the PST’s interpretation of a student’s conceptions. For example, Chloe analyzed Student M’s thinking about a design. We provide the entire comment that includes Chloe’s response in order to convey the progression of the analysis and response.

When I asked Student M what she thought would be the best circuit to design, she said, “series because it’s one path and we can make the bulbs really bright.” From this statement, it is evident that Student M understands that a series circuit has one path and also that the brightness of the bulbs can change. When Student M drew a diagram of her design, she drew 5 bulbs and 6 batteries. From this, I could see she believed that the more batteries you added, the brighter the bulbs would be, no matter how many bulbs there were. I saw this as a learning opportunity for her, so I had Students M and B create it. After they created it, they noticed the bulbs were dim. I asked Student M why she thought they were dim and she paused for a minute to think. She responded by saying, “Oh, there are too many bulbs. We should take some out.” They took two bulbs out and noticed that the bulbs were much brighter. I asked her why the bulbs were brighter and she said, “The bulbs are getting more energy from the batteries now.” By having Student M work through her misconception, she was able to solve it on her own.

Chloe was able to focus on the students’ thinking, analyze the event, and respond by facilitating the student’s understanding of the science concepts—evidence of her student-centered focus in professional noticing.

Table 4

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<th>A2</th>
<th>A3</th>
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<th>B2</th>
<th>B3</th>
<th>C1</th>
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<th>C3</th>
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</table>

**Examples of PST reflection comments for each category**

**D-Defining and delimiting engineering problem**

- **D1-Low focus on student thinking**
  
  I explained how the bulb brightness is affected by the number of batteries in a parallel circuit. (Rebecca)

- **D2-Basic focus on student thinking**
  
  Student N stated that “we want to have the design be bright and cost the least money.” (Rebecca)

- **D3-Strong focus on student thinking**
  
  Students responded that using a parallel circuit (of bulbs) would allow them to have more bulbs lit with less cost. (Ella)

**E-Developing possible solutions**

- **E1-Low focus on student thinking**
  
  “I asked how we could improve and I wrote their ideas on the whiteboard. I would be wise to train their thinking towards incorporating parallel circuits in their improved design.” (Sandy)

- **E2-Basic focus on student thinking**
  
  “I asked students and they made ideas to improve their own designs.” (Anne)

- **E3-Strong focus on student thinking**
  
  “Students responded that using a parallel circuit with all the bulbs was the best.” (Sandy)

**F-Optimizing the design**

- **F1-Low focus on student thinking**
  
  “I would be wise to train their thinking towards incorporating parallel circuits in their improved design.” (Meg)

- **F2-Basic focus on student thinking**
  
  “I asked how we could improve and I wrote their ideas on the whiteboard. Student D said, ‘The bulbs could be brighter.’ Student T disagreed and said, ‘Yes, that’s right.’ I asked how we could improve and I wrote their ideas on the whiteboard.” (Ella)

- **F3-Strong focus on student thinking**
  
  “Students responded that using a parallel circuit (of bulbs) would allow them to have more bulbs lit with less cost.” (Rebecca)
Responding to student thinking for engineering design. PSTs’ comments addressed responding and planning for next steps the least in their reflections. Most of the PSTs provided some responses for next steps with a low focus on student thinking (see Table 4, C1). The comments at this level provided a teacher-centered response by giving students ideas of how they could optimize their original design (see Table 3) and/or vague recommendations of how to help students make connections between their circuitry knowledge and potential design ideas.

Fewer reflection comments had a basic focus on responding to student thinking from most of the PSTs (see Table 4, C2) that suggested an awareness of students’ conceptions or struggles with engineering design; however, the responses did not make clear how the next steps could help students advance their engineering problem-solving. For example, Dana recognized Student W’s confusion about power generated from different circuits; yet, Dana’s response of using Christmas lights as a model of multiple bulbs was insufficient in helping Student W design a circuit with two power sources to solve the engineering problem (see Table 3).

The fewest reflection comments had a strong focus on student thinking from six of the PSTs (see Table 4, C3) who provided clear responses of how to scaffold students’ application of their growing understanding of circuits to solve the engineering problem. Chloe specified next steps to promote students’ engineering thinking, noting “another conversation about how series and parallel circuits of bulbs and batteries could help us determine a design. This was not clicking with my group and is crucial in understanding the best way to light the field.” Rebecca detailed how she planned to “get her students to engage in scientific discourse that is respectful and includes evidence to support their claims” as they “work together to create the second design.” Of note, when comparing scores between PSTs, the data indicated that PSTs who analyzed student thinking at a strong level were also the PSTs who gave strong responses to students’ ideas in their reflections.

Focus on Student Thinking for Disciplinary Core Ideas of Engineering Design

To answer the second question, we present results from an analysis of the focus on student thinking in their reflections using the Engineering Design Framework (see Tables 5 and 6). The PSTs’ reflections addressed the DCIs of defining and delimiting the engineering problem in 44 idea units, developing solutions in 62 ideas units, and optimizing the solution in 55 idea units.

Defining and delimiting the engineering problem. The findings indicated that the PSTs stressed defining and delimiting the engineering problem the least of the engineering DCIs with a low or basic focus on student thinking. No PST wrote a reflective comment with a strong focus on a students’ defining constraints of the problem and/or criteria for success.

The reflection comments with a low focus on student thinking from most PSTs (see Table 6, D1) were characterized by a teacher-directed role in providing students with the constraints or criteria for solving the problem. PSTs informed students of cost of materials, maximum budget allowed, location of the batteries, and maximum number of lights for the project (see Table 5) as well as information about how they could evaluate their prototype designs. In her interview, Val explained that this teacher-directed approach “saved a lot of time,” suggesting she provided the project parameters in order for students to move on to the design portion of the unit.

In the comments with a basic focus on student thinking about the criteria and constraints for solving the problem from the majority of the PSTs (see Table 6, D2), the PSTs noted students’ general ideas without promoting specificity in the student discussion. PSTs’ reflections at this basic level had a limited emphasis on students’ defining the criteria and constraints. For example,
Dana wrote that the students “saw the prices on the budget sheet and immediately thought that the price would be the biggest issue”; however, there was no mention of students discussing other constraints in designing a solution or criteria to judge success of a prototype.

Table 6  
Engineering framework scores for individual PSTs’ reflective comments

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<th>PST</th>
<th>Pseudonyms</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
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</table>

| Total | 23 | 20 | 0  | 27 | 53 | 20 | 16 | 29 | 10 |

Developing possible solutions to the engineering problem. The reflections addressed the engineering DCI of developing possible solutions the most frequently. Though the NGSS intent for engineering emphasizes student-centered idea generation for designs (NRC, 2012), the reflection comments addressing this DCI with a low focus on student thinking were teacher-centered; PSTs suggested or guided design options if they viewed students as “stuck” and unable to come up with their own ideas (see Table 5).

Approximately half of the comments for this DCI of developing possible solutions had a basic focus on student thinking from most of the PSTs (see Table 6, E2) in which the PSTs noted each student’s design ideas and group members’ final decision on a design to test. However, the PSTs’ comments did not address student discussions about pros and cons of proposed designs or if designs met the criteria or constraints. For example, Ann’s comment indicated that students proposed designs; yet, she did not mention students’ critiquing each proposal (see Table 5). The emphasis in the PSTs’ reflective comments at this basic level was on design generation rather than design evaluation.

Six PSTs’ provided comments with a strong focus on student thinking for the DCI of developing possible solutions (see Table 6, E3). These PSTs described how they facilitated students’ discourse to generate multiple designs, analyze pros and cons of each design, and engage in debate to decide on a design to test. Sandy’s statement illustrates a reflective comment that emphasized students’ making sense of designs together (see Table 5). Furthermore, Rebecca’s comments noted her students “reminded each other that their main goal was to have the brightest lights with the least amount of money spent. They wanted to think of the advantages and
disadvantages of each type of circuit.” The emphasis of these PSTs’ reflections was on the students’ active role in evaluating their designs.

**Optimizing the design solution.** For the engineering DCI, *optimizing the design solution*, PST comments with a low focus on student thinking described the PSTs’ own suggestions to students for how to improve the design (see Table 5). Interview comments from Meg suggested a possible reason for a PST’s choice of using a teacher-directed approach: “I think we [the PSTs] were really nervous about improving the design because we didn't think we’d get beyond the circuit we already made,” implying that she lacked confidence in her ability to help students improve their design on their own.

More than half of the reflection comments for this DCI from most of the PSTs provided a basic focus on student thinking for design optimization (see Table 6, F2). At this basic level, PSTs noted students’ ideas for improving their initial design without probing for reasons why a feature needed improvement. For example, Ella noted her students’ initial conversation about what could be improved, but the discussion did not continue to examine reasons for the potential change (see Table 5). Chloe described, “I am going to have to come in prepared with questions and suggestions that will help prompt my students to revise the plan.” From limited experience with facilitation for engineering design, Chloe’s general comments did not delve into each student’s ideas or how to help students negotiate their decision-making.

Reflection comments from five PSTs had a strong focus on student thinking for design optimization (see Table 6, F3). These PSTs addressed how they facilitated students in identifying design features needing improvement, providing reasons for their recommendations, and refining the design through iterative revisions. For example, Rebecca’s reflection indicated she encouraged students to explain the rationale for their ideas of why four bulbs wired in parallel with two batteries in series would be an effective solution (see Table 5). She attended to the students’ thinking about design components and reasons for their design changes.

**Limitations**

While the results provide insight into one cohort of PSTs’ professional noticing of student thinking during their initial attempt to implement an engineering design unit, we acknowledge that there are limiting factors that could affect the study. Although the findings are consistent with results reported in the literature on PSTs’ professional noticing and emphasis on engineering core ideas (Barnhart & van Es, 2015; Wendell, 2014), the small sample size reduces the generalizability of the claims and applicability to the broader community of elementary PSTs. The structure of the practicum teaching experience in which each PST worked with four students allowed the PSTs to experience an integrated science/engineering design STEM unit with a small group of students giving them the potential to focus their attention on student thinking. However, this small teacher-to-student ratio did not replicate actual conditions in which in-service teachers work with students.

Factors specific to the participants themselves, such as prior knowledge about science/engineering as well as disposition to writing also affected the nature of the individual reflections collected for the study. The PSTs experienced engineering design education for the first time during the methods course. Though some PSTs had prior knowledge of electricity concepts, many were learning about content for electricity and student-centered pedagogical approaches at the same time that they were expected to notice students’ ideas for science and engineering and reflect on their experience. Thus, some PSTs were able to provide more detailed...
reflections with this complex task than others. Davis (2006) notes that PSTs differ in their ability to reflect on their teaching and their students’ understanding. However, by analyzing the full range of all the written reflections, we were able to gain insight into the possible variation of how the PSTs noticed and made sense of their students’ engineering experiences and thinking at this early point in their teacher preparation.

Discussion

The findings from this study describe one group of elementary PSTs’ attention, analysis, and response to student thinking with engineering DCIs offering a window into their professional noticing of students’ thinking (Sherin, 2001) during their first experience teaching an integrated science/engineering STEM unit. These findings build upon the research on PSTs’ preparation for engineering design (Dalvi & Wendell, 2017; McCormick et al., 2014; Wendell, 2014). The analysis of the data suggests a number of factors affecting PSTs’ professional noticing of students’ engineering thinking and their promotion of the NGSS engineering DCIs that teacher educators can consider when developing their STEM methods courses.

First, teaching an integrated science/engineering design STEM unit was a new experience for the PSTs; one that they had not encountered in their own schooling. This pedagogical approach required multiple cognitive tasks: PSTs needed to understand not only the scientific mechanisms of the different electrical circuits, but also how to promote the engineering disciplinary core ideas for students to engage in design problem-solving. The results suggested that some PSTs were able to understand the circuitry concepts and, as a result, they were able to probe and analyze their students’ thinking about the circuits and proposed designs. However, other PSTs were still making sense of the science for themselves, and, thus, focused on describing students’ ideas and actions with nascent analysis of students’ thinking. For these PSTs, their limited knowledge of circuitry may have impacted their analysis of and responses to students’ engineering ideas, a common struggle for PSTs when trying to acquire subject-specific pedagogical knowledge during teacher preparation (Zembal-Saul et al., 2000). As the literature on professional noticing indicates, novice teachers require time and experience to acquire an ability to notice student thinking, and then interpret and make decisions for their follow-up response (Miller, 2011; Sabers et al., 1991).

Other factors also may have affected the PSTs’ level of professional noticing (Sherin, 2001). Most PSTs had experienced teacher-directed science instruction in their own schooling. Research has indicated the PSTs tend to teach the way they were taught and revert to didactic teaching approaches (Lemke, 1990), in spite of more reform-based, student-centered pedagogy presented in a teacher education methods course. The data indicated that when PSTs noticed student confusion or difficulty in generating design ideas, some PSTs stepped in and proposed possible ideas to their students, while other PSTs were able to implement student-centered pedagogies of questioning, facilitating discourse, and eliciting student ideas.

This tendency toward adopting a teacher-directed approach was also evident in the reflection comments for the engineering DCI of defining and delimiting the engineering problem. Most PSTs under-emphasized this DCI or provided students with problem constraints and criteria for judging success of the designs. It is possible that the teachers chose to deliver this information rather than to elicit students’ ideas of constraints and criteria to save time given the limited number of lessons. Alternatively, the PSTs may not have been aware of the value of students’ identifying constraints and criteria for themselves as a precursor to evaluating design proposals (Wendell, 2014). It is noteworthy that for the engineering DCI of developing possible solutions, a pattern
emerged in the reflections showing that most PSTs focused on students’ design ideas rather than on students’ evaluation of pros and cons of proposed ideas or tested prototypes. Since the PSTs in the study gave limited attention to defining criteria for success in solving the problem, this omission may have resulted in their under-emphasizing the practice of evaluating the degree to which designs met the criteria.

Similarly, for most of the PST reflective comments for the two DCIs of *developing possible solutions* and *optimizing the design solution*, the evidence indicated that the PSTs either made general note of students’ ideas (basic focus on student thinking) or described a teacher-directed approach of providing students with design or improvement ideas (low focus on student thinking). These findings are consistent with Sun and Strobel’s (2013) study of elementary teachers in their early stages of implementing engineering units; teachers had a low comfort level with teaching engineering and adopted a teacher-oriented approach.

Another factor affecting PSTs’ level of professional noticing may have been each PST’s frame of reference. Levin and colleagues (2009) contend that what a PST notices in the classroom depends on what they frame as their focus of attention. Often PSTs’ reflections focus on what may be challenging for them, such as student behavior or their own teaching performance, rather than student thinking. The findings from this study showed that all the PSTs focused in some of their reflective comments on these areas. When they did describe students’ ideas, some PSTs did so without taking an inquiring stance to analyze the student thinking. It is possible that these PSTs may not have been aware of student conceptions that needed further examination (Loughran, 2002; Schön, 1983). Likewise, without strong analysis of student understanding, these PSTs’ did not have a basis from which to provide specific responses for next steps that connected to particular students’ ideas.

However, it is encouraging that some reflections from seven of the 14 PSTs provided strong analysis of students’ thinking for the engineering challenge, describing how they would identify student conceptions or further elicit their ideas to analyze their thinking. It is noteworthy that six of these PSTs, who analyzed students’ thinking at a strong level in reflective comments, also provided strong level responses. This finding supports Barnhart and van Es’s argument (2015) that analysis may be “the bridging skill between attending and responding” (p. 91) and needed for sophisticated responses to students’ thinking. An informed response to students’ engineering problem-solving would need a more developed ability to analyze student thinking connecting science concepts and engineering design processes. Analysis and response to student thinking are complex skills for PSTs to acquire (Barnhart & van Es, 2015; Davis, 2006); yet, these PSTs exhibited evidence that they were beginning to develop these skills of professional noticing.

Furthermore, six of the seven PSTs who were able to reflect with a strong focus on analyzing student thinking were also able to reflect on the engineering DCI of *developing possible solutions* by describing students’ evaluation of designs and reasoned debate to determine a design to test. This finding is promising indicating potential for PSTs to acquire professional noticing skills within their practicum teaching that promote elementary students’ application of science learning to engineering problem-solving. Researchers in science and mathematics education have noted that PSTs need experience and explicit training in how to notice salient features of student understandings and interactions (Barnhart & van Es, 2015; Miller, 2011; Sabers et al., 1991). Following are possible implications from this study and suggestions for teacher educators.
Implications

The intent of this study was exploratory in nature to gain baseline information about the PSTs’ professional noticing of their own students’ thinking during an integrated science/engineering STEM unit. From that perspective, the findings suggest possible focus areas for teacher educators when introducing elementary PSTs to integrated science and engineering design pedagogy. We propose a number of strategies that teacher educators can implement in a methods course to provide PSTs with experience and explicit training in how to notice students’ thinking when solving an integrated science/engineering design challenge: video analysis, metacognitive discussions, enactment tools, student journals, and a social learning model.

The data indicated that some PSTs were challenged to notice and analyze their students’ thinking due to their own limited content knowledge. Video analysis is one approach that teacher educators have used to provide PSTs with opportunities to develop content knowledge and practice professional noticing of student thinking without in-the-moment pressures of teaching (Sun & van Es, 2015). By coupling content-specific videos of elementary students engaged in science investigations with videos of elementary students solving engineering design problems, PSTs can gain awareness not only of science pedagogical content knowledge (Schön, 1983), but also of students’ commonly held engineering and scientific conceptions. PSTs can view videos through different frames, making a distinction between the classroom frame of behavior management or environmental factors and the student thinking frame of students’ science ideas or engineering proposals.

Since the findings from this study suggested that PSTs need skill with analysis before being able to provide sophisticated responses to students’ thinking, we propose that PSTs first practice attending to and analyzing students’ scientific and engineering ideas. Teacher educators can reinforce these skills by facilitating pre-practicum discussions and post-practicum debriefing sessions that focus on students’ science conceptions and engineering design thinking. By sharing both their plans and experiences through this frame, PSTs can identify and analyze students’ thinking in connection with their pedagogical decisions as a foundation for making more informed responses that promote students’ engineering problem-solving.

With regard to the NGSS engineering DCIs, this study indicated that the PSTs focused the least on students’ thinking for defining and delimiting the engineering problem. We suggest that PSTs may need exposure to enactment tools to assist them in helping elementary students process their thinking for engineering design (Ghousseini, Beasley, & Lord, 2015). These tools can include question sequences and graphic organizers that prompt students to identify and record decisions about constraints of a problem and criteria to evaluate a design. Ghousseini et al. argue that before PSTs can enact complex practices with students, they need to experiment with these practices themselves. By posing an engineering challenge for PSTs in the methods course emphasizing, first, defining and delimiting an engineering problem, PSTs can implement these tools, gain awareness of this DCI, consider ways students might think about the problem, and explore how to respond to student ideas.

The results also indicated that PSTs’ reflections focused at a low or basic level on students’ evaluating possible designs or failure points of a tested design. Student engineering design journals can provide a means for elementary students to record and evaluate their ideas as they work through an engineering problem (Wendell & Rogers, 2013). Open-ended questions, graphic organizers, and prompts for visual representations that scaffold students in recording pros and cons
of proposed designs, failure points of tested designs, and improvements to optimize the design are tools that can encourage PSTs to focus on the often, under-addressed aspect of evaluating designs based on criteria (Lachapelle & Cunningham, 2014). A tangible written record of students’ engineering thinking allows students to make their reasoning visible when negotiating design decisions with peers. Teacher educators can employ these tools first in the methods course to build PSTs’ capacity in developing their own scaffolding tools for elementary students.

Finally, since some PSTs in this study demonstrated a strong ability to focus on students’ thinking in their reflections, we recommend implementing a social learning model in the methods course whereby PSTs work collaboratively to improve their ability to attend, analyze, and respond to student thinking with engineering design (Lave & Wenger, 1991). By positioning the methods course as a reflective learning community (Hammerness et al., 2005), PSTs can process their practicum experiences together, address content that confuses them or students, analyze students’ thinking, and generate ways to promote students’ design thinking.

As teacher educators seek to expand their pedagogical approaches in promoting PSTs’ understanding and experience with STEM education in the elementary grades (Daugherty, Carter, & Swagerty, 2014), results from this study may provide insight into elements needing further development in PST training. With attention to the professional vision needed for implementing integrated science inquiry and engineering design learning experiences with elementary students, teacher educators can shape a methods course to help make these complex skills of attending, analyzing, and responding to students’ thinking more apparent to the novice elementary PST when facilitating science/engineering design lessons.

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Fab Fridays: Fostering Elementary Teacher Candidate Preparation Through Informal STEM Events

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ABSTRACT

Informal STEM learning opportunities offered outside of the structured school day have been gaining popularity in today’s STEM-oriented culture. These are venues where children and their families gather to engage and explore in science, technology, engineering, and math —together. For a number of years, faculty from the College of Education at Tennessee Tech University have been promoting these events for the local community, free of charge, to encourage and foster a love for STEM Education. Methods professors recognize these events as golden opportunities for teacher candidates enrolled to learn about STEM content while aiding in the development of their pedagogy. In addition to the experience gained from working with the materials at various STEM stations, teacher candidates have the opportunity to interact with children and families. Furthermore, teacher candidates interact with faculty and students from other academic areas such as nursing, engineering, biology and physics, as well as content specialists from the community. These interactions help to bolster preservice teachers’ skills and feelings of self-efficacy toward communicating with families and teaching STEM concepts. The informal STEM learning events offer a variety of experiences often unavailable during the school day and promote the social, emotional, and intellectual skills of our teacher candidates, as well as, those of the children and families who attend.

*Keywords:* Teacher Preparation; Service Learning; STEM Education; Communication Skills; Pedagogical Content Knowledge; Informal STEM Learning; Reflection; Self-efficacy

Informal STEM learning opportunities taking place in settings such as libraries, museums, parks, STEM centers, and other out-of-school locations offer children and families freedom to explore science, technology, engineering, and math activities together. These events promote inquiry-based STEM experiences commonly unavailable in schools (National Research Council, 2015). By engaging children intellectually, socially, and emotionally, informal STEM learning opportunities support understanding as well as inspire further study for future careers (Heath & McLaughlin, 1994). Informal STEM learning experiences provide invaluable opportunities for teacher candidates to develop their teaching and communication skills prior to entering the classroom (National Research Council, 2015).
The essential skill of communicating with children and families should not be overlooked when preparing teacher candidates, however, opportunities for doing so can be limited. Informal STEM learning experiences provide the perfect venue for this to be accomplished. These authentic experiences build the confidence in the teacher candidates to develop a comfortable rapport with students and families. Ratcliff and Hunt (2009) found that, “Although strong evidence supports quality partnerships between teachers and their students' families, many teachers enter the profession with inadequate dispositions, skills, and knowledge needed to promote the partnerships that support students in the achievement of their educational potential” (p. 495). All too often the opportunity to engage with children and their families is lacking from teacher preparation (Brown, Harris, Jacobson, & Trotti, 2014).

Reflection is another vital skill needed for future educators. For most teacher candidates, traditional academic learning by way of reading, listening, and practicing is a comfortable and reliable set of strategies for acquiring knowledge. Learning to teach, however, should include constant reflections by way of analyzing and evaluating all teaching experiences. The practice of reflection provides teachers with the opportunity to develop their individual pedagogical beliefs and practices (Rodman, 2010). Reflecting on one’s personal teaching pedagogy also facilitates connections of practice to theory. (Calderhead & Gates, 1993; Korthagen, 2017).

The College of Education at Tennessee Tech University prepares approximately 250 undergraduate and 75 graduate students per year. Of this number, 160 are certified to teach elementary education. Other certifications include early childhood education, secondary education, special education, physical education, and fine arts education. All elementary education majors participate in two field placement opportunities during their junior year of coursework. One placement focuses on literacy instruction, while the other concentrates on content area instruction in math, science, and social studies. Both 60-hour field experiences take place in general education public school settings. During their senior year, elementary education teacher candidates are immersed in a residency placement that lasts the entire academic year. Teacher candidates stay in the same classroom to learn about beginning and ending a school year, as well as, the growth and transition that occurs in between.

While these classroom-based experiences help teacher candidates to prepare for their future teaching careers, they often lack diversity of setting and opportunities to communicate with families and caregivers. In an effort to fill those gaps, teacher candidates are also required to participate in informal STEM outreach events at the Millard Oakley STEM Center on the Tennessee Tech University campus. Teacher candidates choose two out of four events during their content block semester. At these events, candidates work alongside volunteers including engineering majors, nursing majors, local business and community members, and university faculty. Approximately 20 stations are set up in a space that includes four classrooms, a large lobby, an auditorium, and a virtual theater. The stations are planned by graduate students, university faculty, STEM center employees, and community groups. The free events are open to the public and average 200 attendees, which include children and their families.

At the Millard Oakley STEM center at Tennessee Tech University, we host eight informal STEM learning events per year. Fab Fridays are geared toward third through eighth grade students, while Safari Saturdays focus on activities appropriate for students in preschool through third grade. These events serve two purposes. First, we seek to benefit both elementary and middle school-aged students and their families participating in the events, as well as, the teacher candidates leading the activities. Secondly, our informal STEM learning events provide opportunity to
research the impact on teacher candidates’ content knowledge, pedagogical knowledge, and communication skills. Our research questions were specific to the teacher candidates as students enrolled in elementary education math and science courses. These research questions included:

1. How does required participation in informal STEM learning opportunities increase STEM pedagogical knowledge in elementary education teacher candidates?
2. How does required participation in informal STEM learning opportunities impact the content knowledge of elementary education teacher candidates?
3. How does required participation in informal STEM learning opportunities impact elementary education teacher candidates’ abilities to communicate with students and their families?

STEM Content and Pedagogical Content Knowledge

Both subject matter knowledge and an understanding of how to convey that knowledge in a meaningful way are essential for effective teaching (Darling-Hammond, 1999; Eckman, Williams, & Silver-Thorn, 2016; Grossman, Hammerness, & McDonald, 2009; Shulman, 1986; Shulman, 1987). Teacher candidates' STEM content and pedagogical content knowledge are enhanced through participation in our informal STEM learning events. Conceptual understanding of the content and practical application are concurrently achieved in a manner that allows teacher candidates to experience teaching while also learning from content and educational experts.

Shulman (1986) clearly defined both content knowledge and pedagogical content knowledge (PCK). Content knowledge is “the amount and organization of knowledge” (p. 9), while PCK refers to “the ways of representing and formulating the subject that make it comprehensible to others” (p. 9). Hill, Ball, and Schilling (2008) further developed our understanding of PCK by breaking it down into three distinct parts: knowledge of content and students (KCS), knowledge of content and teaching (KCT), and knowledge of curriculum (p. 377). The informal STEM learning events discussed in this article support all three components of PCK for teacher candidates, while KCS is particularly addressed. Teacher candidates practice KCS by relating to the way students interact with the content (Hill et al, 2008). This is evident in the questioning techniques practiced by teacher candidates as they discuss STEM content at their assigned stations. As the evening progressed, candidates revised their interactions based on what they noticed in common participant misunderstandings, individual participant responses, developmental levels of the participants (based primarily on age/grade level), as well as participant strategies in problem solving (Hill et al, 2008).

Communication Skills with Students and Families

Our informal STEM family events provide safe opportunities for preservice elementary education teachers to practice communicating meaningfully with both students and families. They must think on their feet and communicate in ways that engage, instruct, even entertain. While interacting with the students, the preservice teachers adapt their language and use kid-friendly definitions to introduce complex content vocabulary. They listen to the students, ask purposeful questions, connect to what the students know, and encourage ideas.

Preservice teachers regularly express concerns and feel ill-prepared to communicate with families (Brown, Harris, Jacobson, & Trotti, 2014; Hampshire, Havercraft, Luy, & Call, 2015). The STEM family events provide opportunities for our preservice teachers to confront their fears,
reflect on their communication moves, and connect with parents and family members. Graham-Clay (2005) explained, “Every communication exchange, regardless of format, should reflect a thoughtful, planned approach and should be viewed as an opportunity for teachers to promote parent partnerships and, ultimately, to support student learning” (p. 127).

Service Learning and Teacher Preparation

Jacoby (2015) described several models of service learning in higher education, including field work as service learning. But Jacoby clarified for field work to be considered service learning, it is essential that “reciprocal partnerships, critical reflection, and intentional integration with academic content” be addressed (p. 93). At the informal STEM events, our preservice teachers develop reciprocal partnerships with university students and faculty in other fields, and STEM professionals from the community. The teacher candidates work alongside and learn from students and faculty from other colleges including Arts and Sciences, Engineering, and Business. Occasionally, our teacher candidates also learn from and work alongside STEM professionals from the community, such as optometrists and a local anti-drug coalition. The teacher candidates participate in critical reflection as they engage in class discussions with their peers and write about their experiences after the Fab Fridays. Lastly, each Fab Friday event is themed on an area of academic content covered in the school-aged children’s state standards, so teacher candidates learn in-depth knowledge about academic topics they will be expected to teach in their classrooms.

There are several more benefits of field work as service learning. For example, the Fab Friday outreach events allow teacher candidates to work with populations (families) to which they may not otherwise be exposed. Teacher candidates have the opportunity to test the waters by communicating with school-aged children and their families. For many of our preservice teachers, this is a first. Fab Fridays are required field experiences in our methods courses. Because all candidates participate in the Fab Friday field experiences, there is common ground for reflection and discussion. Sometimes candidates have legitimate obstacles to participating in the outreach events (work, family schedules), but typically this issue is resolved because they can choose from two of four events to attend during the semester.

Fab Fridays

In this article, we discuss the findings from one of the four informal STEM family events provided during the spring 2018 semester. A total of 12 teacher candidates participated from the elementary math and science methods courses, along with university faculty, community members, and several undergraduate and graduate students from various majors with connections to STEM education, such as engineering and nursing. Teacher candidates arrived at the STEM center approximately one hour before the Fab Friday Human Body event to learn about the stations, and practice the activities before students and families arrived. During the event, teacher candidates guided students and families at each station. Possible questions for discussion at each station were provided to our teacher candidates. University faculty mingled and supervised during the event, checking in with teacher candidates at stations, and with students and families throughout the evening. After the event, teacher candidates reflected on their experiences in two formats, written and oral. Within one week of the event, teacher candidates completed a written reflection that required, at a minimum, to address the following prompts:

- What was your overall impression of the event?
- What was the name and description of your station?
• Thinking as a parent, was this event something that you would attend with your children? Explain.
• Thinking as a teacher, to what extent and how could this event be replicated in a classroom?

In addition to the written reflection, teacher candidates discussed the event in their following content methods class. During the discussion, candidates shared details of the event with the class, an audience that included peers who were not present at the Fab Friday Human Body event. They discussed what went well and what they would do differently at future events. During post-event discussions, candidates often shared their excitement about using ideas from the event in their classroom field experiences. Even though teacher candidates are only required to attend two events during the semester, they frequently request to volunteer at all four events due to the benefits they perceive from volunteering.

Each teacher candidate volunteering at the event was also asked three oral interview questions four to six days after the event. Their responses were recorded, transcribed, and analyzed. These questions were:

1. Tell me about your observations at the Fab Friday event. What will you take away from this event?
2. How did the Fab Friday event help to prepare you for future STEM experiences with students?
3. Looking forward, how did this experience help to prepare you for working with parents/families?

Human Body STEM Stations

In the following discussion, we address several of the stations that were at the Fab Friday Human Body event. We explain the organization and purpose of each station and highlight some of the insightful quotes we obtained from our teacher candidates who manned the stations during the event. This is a full list of the station titles:

- A Healthy Heart: Nothing Beats It!
- Brain Hat
- Build a Bone
- Build a Skeleton
- Can you Conduct?
- Get to the Heart of the Matter
- Healthy Choices Obstacle Course
- Heart-Rate Marshmallow!
- Hop ‘Till You Drop
- Mind Your Back
- My Heart is in Your Hands
- Race Through the Body!
- Robotic Hands
- The EYES have it!
- Virtual Reality Tour of the Human Body
- Weight, I’m an Astronaut?
- What’s Up With Those Lungs?
- You Make My Heart Skip a Beat
- You Take My Breath Away!
- You're Somebody's Type
- Your Brain Always Sees Straight

Your Brain Always Sees Straight

The physics club participated in the Fab Friday Human Body event with a station called Your Brain Always Sees Straight. Participants experienced strange optical effects that resulted from the brain’s faulty assumptions about how light rays behave. Using convex and concave mirrors,
participants moved backwards and forwards to determine at what point their image would be inverted. See Table 1 for connections to the Next Generation Science Standards. Initially, the teacher candidates were timid about working at this station. After talking with members of the physics club and their advisor (a professor in the physics department), one teacher candidate got so excited by what she learned that she wanted to learn more:

The concave refracts light so that, from a distance, objects look upside down—creating a real image. When the object is close to the mirror, it looks right side up, and enlarged—creating a virtual image. What we see in everyday mirrors in bathrooms and other places show us right side up, and we see our perfect reflection; this is also a virtual image. The upside-down version of the object from a distance reflected in the mirror, as well as movie projectors, and even our own eyes show real images. The actual concept of real versus virtual images is really cool, and leading this activity made me do my own research about it.

Table 1.
Station connections to Next Generation Science Standards

<table>
<thead>
<tr>
<th>Fab Friday Station</th>
<th>NGSS Performance Expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your Brain Always Sees Straight</td>
<td>□ 1-PS4-3 Waves and their Application in Technologies for Information Transfer: Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light.</td>
</tr>
<tr>
<td></td>
<td>□ 2-PS1-2 Matter and Its Interactions: Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.</td>
</tr>
<tr>
<td></td>
<td>□ 5-PS1-3 Matter and Its Interactions: Make observations and measurements to identify materials based on their properties.</td>
</tr>
<tr>
<td>Brain Hat</td>
<td>4-LS1-2 From Molecules to Organisms: Structures and Processes: Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways.</td>
</tr>
<tr>
<td></td>
<td>□ 1-LS1-1 From Molecules to Organisms: Structures and Processes Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.</td>
</tr>
<tr>
<td></td>
<td>□ 4-LS1-2 From Molecules to Organisms: Structures and Processes Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways.</td>
</tr>
<tr>
<td>What’s Up With Those Lungs?</td>
<td>□ K-LS1-1 From Molecules to Organisms: Structures and Processes: Use observations to describe patterns of what plants and animals (including humans) need to survive.</td>
</tr>
<tr>
<td></td>
<td>□ 2-PS1-1 Matter and Its Interactions: Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties.</td>
</tr>
<tr>
<td>You’re Somebody’s Type</td>
<td>□ MS-LS1-1 From Molecules to Organisms: Structures and Processes: Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.</td>
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<tr>
<td></td>
<td>□ MS-LS1-2 From Molecules to Organisms: Structures and Processes: Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.</td>
</tr>
<tr>
<td></td>
<td>□ MS-LS1-3 From Molecules to Organisms: Structures and Processes: Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.</td>
</tr>
</tbody>
</table>
Brain Hat

A station built upon a visual model, the Brain Hat station was one of the most popular. At this station, participants assembled the two hemispheres of the brain from black and white paper templates (See Figure 1). They could wear their new “Brain Hats” around all night! This activity relates well to NGSS 4-LS1-2. This visual model included labels for the parts of the brain as well as phrases that highlighted function examples associated with these different parts. For example, the logic section of the brain located in the frontal lobe is responsible for sequencing. The teacher candidates saw great benefit to this activity for future use in their classrooms. One of them stated the following during her interview:

I was just thinking about my event, a brain hat. I would definitely use this. If my students were really young, I would just have them color each section of each hemisphere a different color. If the students were older, we would talk about each section, like the temporal lobe, and go into detail about each. This would be a really fun and interactive activity, and it is better than a worksheet on the same topic.


The EYES have it!

An optometrist group located near campus volunteered to share information about eye health. Besides providing information, they also brought fun and interactive activities for participants. One of the activities tricked the eye to see something that was not there using Benham’s disks. They used circles with various patterns to make spinning tops (See Figure 2). A slit was cut in the middle of the circle with a penny inserted to provide the spinning base. As the top was spun, participants observed patterns and colors different from the designs on the resting circles. Participants also experimented with blind spots by moving a paper strip with a symbol at end (See Figure 2) through their field of vision to determine at which position one of the symbols disappears. As this occurred, the participants identified their blind spots. This station connects to NGSS 1-LS1-1 and 4-LS1-2 (see Table
1). Teacher candidates learned how the eyes work by volunteering at this station and talking with the optometrist. One teacher candidate shared:

The purpose of this station was to demonstrate the powerful effects that the brain can have on vision and how people perceive images. The activities involved with this station established the presence of the strong relationship between the brain and the eyes.

![Figure 2. Example of Beckham’s Disk retrieved from http://faculty.washington.edu/chudler/benham.html](http://faculty.washington.edu/chudler/benham.html)

![Figure 3. Blind Spot Test Strip retrieved from: http://brainu.org/sites/brainu.org/files/lessons/es_blindspot_teststrip.jpg](http://brainu.org/sites/brainu.org/files/lessons/es_blindspot_teststrip.jpg)

**What’s Up with Those Lungs?**

A local anti-drug coalition brought two sets of pig lungs to demonstrate the harmful effects of smoking. One set of the lungs was healthy, as seen by its bright pink coloration. The other set was diseased with a grayish appearance (See Image X). Both sets of lungs were attached to a pumping system made of PVC pipes. As air was pumped through the lungs, participants observed the diseased lungs inflated slowly and did not return to normal size between pumps. Observers were able to make strong, memorable connections to smoking and diminished lung function. This
demonstration supported NGSS K-LS1-1 and 2-PS1-1 (see Table 1). The teacher candidates quickly learned from the anti-drug coalition volunteers and were able to share their knowledge with participants. A member of the anti-drug coalition who worked the station shared his perspective of the event as a community stakeholder:

[Students] seemed to really enjoy almost all of the stations, especially the ones where they got to be interactive with things. I really enjoyed being able to explain things to them, and feeling like they really understood. I also really liked how the parents were involved and got to come be a part of the event. This makes for a successful learning experience.

**You’re Somebody’s Type**

Children and families identified the components of blood and their functions while participating in two blood simulations. First, participants created their own blood samples in small portion cups to take home. Cheerios pre-soaked in red food coloring served as the red blood cells. Water with yellow food coloring represented plasma. A few marshmallows were added as white blood cells and tiny purple pom-poms represented platelets. After creating small blood cups to take home, participants sank their hands into dish tubs filled with another blood simulation. In the tubs, red water beads were the red blood cells, white ping-pong balls were the white blood cells, and small strips of red foam paper represented the platelets. While children (and families) enjoyed feeling the slippery fake blood, the teacher candidates guided and asked them to recall the names and functions of the blood components. One teacher candidate commented on the practicality of the “You’re Somebody’s Type” activity:

There was a station focusing on blood where students learned about red blood cells, white blood cells, and platelets. Students were able to see, manipulate, and feel the “blood”. ... The students loved putting their hands in the box and observing the differences between the three materials. This would be an easy and cheap way to teach blood in the classroom and would definitely be more beneficial than giving students a worksheet.

**Research Findings and Project Evaluation**

The responses from the teacher candidates were positive and showed meaningful critical reflections. Candidates made comments indicating increases in their pedagogical content knowledge, STEM content knowledge, and confidence for communicating with students and their families. Responses indicated that teacher candidates saw the benefit of designing fun and interactive activities to teach STEM concepts.

- I have found that any activity that students can put their hands on, manipulate, or experience in some way is the best way to form a concrete connection between content knowledge and real-world applications.
- In my future classroom, I would try to implement some of these more hands-on activities when teaching my students. I think that some science concepts are harder to understand when just reading about them in a book. Showing a video can be helpful sometimes, but is still only a semi-concrete example of something.
- The whole event was a perfect way to use the resources that are more easily accessible to the school and share it with the community.

Many teacher candidates commented about learning STEM content. Some thought about their previous understanding or partial understanding gained in elementary and middle school.
• I feel like I learned a lot more than I did as a kid about the human body.
• Of each of the branches of science, I would say that I know the least about physics, so I learned some really great things to show my class about physics to get them [students] engaged.

Communicating with participants, both students and parents, was frequently mentioned in the teacher candidate reflections, interviews, and in class discussions. They expressed initial anxiety in working with families and a desire for more practice.

• I saw a lot of people who don’t normally work with children figuring out how to talk to the children in a way that the children would understand and I did notice how it adapted from the beginning where it was way too complex and they were losing kids to where it turned into them making it a lot simpler and they were able to keep the children's attention about it.
• Being able to communicate with the parents effectively, as to why you are doing these things, and what the purpose is, I think is something that I was able to learn from this experience.
• I have been in a practicum class but I haven’t really talked to the parents, so I think that talking with the parents really helped.
• I believe this is one of the best ways to get a child's interest sparked in STEM. All of these activities were super intriguing for the kids and even the parents. It got the students thinking outside of the required classroom curriculum and possibly opened their learning interests to new things.

Challenges noted by teacher candidates included difficulty engaging with reluctant students and families and anxiety about what to expect. Drawing on their own experiences as school-aged children, teacher candidates expected all participants and family members to react to the activities and respond to their communication in similar ways. These preconceptions were quickly disproven as a diverse group of participants visited their stations. Teacher candidates also expressed initial anxiety about the event due to inexperience working with students in informal settings as well as lack of opportunities to work with families prior to this event.

**Future Plans and Conclusion**

With almost 50 STEM family outreach events so far, each and every one provides new opportunities for insight into possible improvements. The research focus of teacher candidate preparation and intentional reflection has definitely illuminated the need for future modifications to the Fab Friday events. Actions for future informal STEM learning opportunities include:

• Boost parent engagement
• Include teacher candidates more in station planning
• Design explicit content training for teacher candidates
• Consider station budget with teacher candidates
• Work towards accommodating diverse learners and their families (English learners & students with disabilities)

Teacher candidates noticed that some parents were eager to be involved with their children, while others were more timid and stood back as observers. One way to encourage more parental involvement would be to give parents written station guides. These guides would include questions
parents could ask their children, as well as, explanations of the content and links to further activities they could do at home. These guides (created by the teacher candidates) could be referenced at each station.

Currently, Fab Friday stations are prepared by university faculty, graduate students, and community members who are experts on various topics. By pairing the teacher candidates with content experts in the planning process, teacher candidates may better understand the specific station directions and content. This collaboration in planning would require time, but would offer greater learning for the teacher candidates. In reflections, several candidates made suggestions for general event logistics and modifications for station activities. By being involved in the planning, the teacher candidates could see why decisions are made (often due to budget restrictions), and offer their perspectives as well. Some candidates commented that they would have liked to have had more time to learn about the content specifics at their assigned stations. This could be achieved by meeting with the content expert and also by reading/viewing related online resources prior to the event. Preparing a training manual, role-play opportunities, and training videos are also areas of interest for our team.

Another concern of the teacher candidates that came up multiple times was lack of preparation to work with diverse groups of students and families. The informal STEM learning opportunities are open to the public. Participants come from the local schools, surrounding districts, homeschool groups, and more. Teacher candidates noticed that some participants were accustomed to the STEM Center and the format of the activities, while others reacted differently. There were students with varying needs: some that spoke different languages, and some that needed special accommodations. In the planning, these differences should be considered and prepared for with appropriate accommodations for all participants to benefit fully from the event. This would be a great way to collaborate with the special education department and to help the teacher candidates to prepare for their future classrooms of diverse learners.

For future research in improving teacher candidate preparation, the reflection and interview questions will be modified to more closely align with our research questions. These new questions will include:

- What specifically did you learn about how to teach STEM concepts? Give examples.
- In what ways did your STEM content knowledge increase? What from the event impacted your knowledge?
- How did you interact/communicate with students? Give examples.
- How did you interact/communicate with family members? Give examples.

These reflection questions will be kept to a minimum. Teacher candidates will be encouraged to share as much specific detail from the event as possible along with any improvement suggestions for both participants and for their own learning.

Along with a focus on elementary education teacher candidate preparation, this type of informal STEM learning opportunity is rich in potential for research. Future research projects may focus on:

- Student learning
- Family perspectives
- Communication with families
- Similar events for the disability community (Kahn & Samblanet, 2018)
• How participation in informal STEM teaching transfers to formal STEM classroom teaching

Informal STEM learning events such as the one discussed in this article provide valuable opportunities for participants to be actively involved in inquiry-based learning (National Research Council, 2015). Students interact with community members and teacher candidates with activities that boost their understanding about STEM concepts and increases awareness of STEM careers (Heath & McLaughlin, 1994). In addition to the benefits to STEM learning for the participants, teacher candidates are able to practice communication skills with students and families often lacking in teacher preparation programs (Brown, Harris, Jacobson, & Trotti, 2014).

Final Thoughts

The Fab Friday events held at our university’s STEM Center have provided us with an opportunity to immerse our teacher candidates in informal STEM learning. During the events, candidates interact with school-age children and their families, university faculty and students from other academic areas, and content specialists. These experiences provide a rich learning environment for our teacher candidates, wherein, they can practice the essential skills of communication while learning about specific content and the best practices for teaching the content. It is often said that experience is the best teacher. We feel confident that this preparation will help them hit the ground running in an age when STEM is so important in K-12 education.

References


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Full STEAM Ahead: Creating Interdisciplinary Informal Learning Opportunities for Early Childhood Teacher Candidates

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**ABSTRACT**

Early childhood teacher candidates benefit when presented with opportunities to engage meaningfully with their clinically-based school community. Informal learning events that are hosted after school hours but within school settings present a valuable way to provide these opportunities. Too often, content areas exist in isolation in classrooms, a stark contrast to the real world where content is connected and overlapping. Additionally, while many early childhood teachers express insecurity about their ability to teach STEM content, an integrated STEAM (STEM + Arts & Humanities) approach may help to promote comfort with STEM content and presents an authentic example of content integration. This article presents a model of informal STEAM learning that capitalizes on collaborative school-university partnerships to improve both teacher candidate development and student learning outcomes. The model described provides practical ideas for facilitating successful informal STEAM events at local schools and is of value to a variety of educational stakeholders.

*Keywords:* Informal STEAM Learning; School-University Partnerships, Teacher Candidates, Professional Development School, Clinical Model of Teacher Preparation

In K-3 classroom settings, content areas too often exist in stark isolation from each other, yet, in the real world, science, math, literacy, social studies, and the arts are naturally connected in meaningful ways. Presenting content areas in an integrated STEAM (STEM + Arts & Humanities) manner provides children with authentic learning experiences and activities that are relevant to them (NSTA, 2009; Sharapan, 2012). Authentic learning activities allow children to develop understanding of ideas and relationships in real-world contexts; mimic the work of professionals; involve presentation of findings to audiences beyond the classroom; require exploration, inquiry, thinking skills and metacognition; and engage communities of learners in discourse and self-directed project work (Donovan, Bransford, & Pellegrino, 1999; Rule, 2006). Authentic learning experiences with real-world connections offer valuable learning opportunities for children in formal and informal contexts.

Despite the many benefits for children’s learning that STEM and STEAM-based approaches offer, initiatives that implement them are more prevalent in middle and high schools across the United States (Bencze, 2008; Dejarnette, 2012). Proposed reasons for the slower rate of implementation in elementary schools include teachers’ lack of pedagogical expertise and self-
efficacy for scientific inquiry and technological design, which result from fewer opportunities to experience these in teacher preparation programs and the small amount of time dedicated to STEM teaching in the elementary classroom (Bencze, 2008; Ross, 1998; Smith & Soutether, 2007). In response to calls for better integration of these approaches into the elementary teacher education curriculum (Bencze, 2008; Dejarnette, 2012, Dani, Hartman, & Helfrich, 2018) reported the value of informal events as spaces for developing teacher candidates’ pedagogical expertise and self-efficacy for teaching STEM disciplines. Situating STEAM learning within an informal learning event planned and implemented by early childhood teacher candidates who are completing elementary clinical experiences in grades K-3 can create meaningful learning opportunities for all involved. In this article, a rationale and two examples for using informal STEAM learning events in early childhood teacher education are described. Ideas for helping early childhood teacher candidates plan and implement informal learning events as part of their teacher preparation programs are also provided.

**Background**

**The STEAM Approach**

In response to the recent emphasis on STEM (Science, Technology, Engineering, & Math), early childhood educators are adopting a STEAM approach to integrate the arts and humanities into the early childhood curriculum (Chesloff, 2013). Although STEM educators have long emphasized the need for an integrated approach to STEM education (Bybee, 2010; Claymier, 2014; Dejarnette, 2012), a STEAM approach takes this a step further to promote integration beyond STEM disciplines. This approach is of particular relevance to early childhood educators because integrated and authentic learning is a hallmark of developmentally appropriate practice, and it allows children to see content areas as inter-connected (Ceschini, 2014; NSTA, 2009; Rich, 2010; Sharapan, 2012). From an instructional perspective, the goals of the STEAM approach are to purposefully present the content and practices of mathematics and science through the lens of technology, engineering, arts, and humanities; anchor the content in the design process; and situate learning within the present needs of students (Claymier; 2014; Gess, 2017).

Several conceptualizations of the integrated nature of STEAM teaching have been described, including transdisciplinary, interdisciplinary, multidisciplinary, and content and context (Herro, Quigley, & Dsouza, 2016; Moore et al., 2014). The transdisciplinary method uses the collective expertise of multiple disciplines to present and solve a problem and may incorporate all aspects of the STEAM acronym (Dyer, 2003; Henriksen, 2014). The interdisciplinary method draws from more than one discipline by emphasizing the similarities between the selected disciplines (Kim & Bolger, 2017). The multidisciplinary method to integration allows for the exploration of a common theme from the perspective of multiple disciplines (Kim & Bolger, 2017). In the context and content method of integration, a STEAM lesson emphasizes the content from one discipline and uses the context of another discipline to add relevance and facilitate the design or problem-solving process (Moore et al., 2014). Of importance, individual STEAM experiences or lessons may not incorporate all of the content areas represented by the STEAM acronym. For example, using the context and content method, teachers may emphasize a geometry concept using art and design principles. While the transdisciplinary approach to STEAM integration may be possible for larger problem-based projects that take place during the academic year, interdisciplinary and context-based approaches to integration between at least two disciplines are desirable for lessons and activities that span shorter periods of time (Moore et al., 2014).
Using STEAM in the early grades encourages learners to be creative, independent thinkers who are able to innovate and shift perspectives to discover new ways of viewing familiar things (Ceschini, 2014; Rich, 2010; Sharapan, 2012). It promotes students’ ability to think divergently and problem-solve, both of which are key skills for the 21st century (Trilling & Fadel, 2009). When used in early elementary grades, the STEAM approach resulted in increases in students’ achievement, motivation, and engagement in STEM learning, improving access to a wider audience of students (Becker & Park, 2011). For example, a STEM unit situated within the arts can scaffold meaningful learning for students with disabilities, creating connections that are missing from a STEM-only approach (Hwang & Taylor, 2016). STEAM-based learning can promote students’ ability to transfer knowledge learned in school to out of school contexts (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005). It offers opportunities for teachers, students, families, and community members to collaboratively engage in a sustained investigation to solve a community-identified problem, such as building a tree house at the school (Weatherly, Oleson, & Kistner, 2017).

Perceptions and Challenges of the STEAM Approach

Despite the benefits of a STEAM approach, research finds that early childhood teachers and teacher candidates report challenges in implementing it. To start, elementary teachers and future teachers often express insecurities about their knowledge of and ability to teach STEM content (Bencze, 2008; Bursal & Paznokas, 2006; Murphy, Neil, & Beggs, 2007; Schneider et al., 2007). Building on Bandura’s (1977) work on perceived self-efficacy and its impact on effort, persistence, and motivation to engage in particular tasks, several researchers have investigated elementary teachers’ self-efficacy for teaching science (Riggs & Enochs, 1990), mathematics (Enochs, Smith, & Huinker, 2000; Tapia & Marsh, 2004), and engineering (Yoon Yoon, Evans, & Strobel, 2014). Findings of these studies consistently indicate that preservice and new elementary teachers exhibit low self-efficacy in their ability to teach STEM content areas (Bursal & Paznokas, 2006, Hammad & Ivey, 2017; Riegle-Crumb et al., 2015; van Aalderen-Smeets, Walma van der Molen, & Asma, 2012).

Other challenges for implementing the STEAM approach are based in elementary teachers’ reports about the little time they spend teaching STEM content (Schneider et al., 2007). The isolated way they learned this content during their own educational experiences makes it difficult for them to identify natural connections between content areas. While some early childhood teachers do not view themselves as artists and share apprehension about teaching arts-based curricula (Battersby & Cave, 2014; Davies, 2010; Oreck, 2004; Russell-Bowie, 2012), others tend to feel increased confidence surrounding literacy, social studies, and art (Chesloff, 2013; Sharapan, 2012). Some express doubt that a STEAM approach can be used to achieve curricular and standards-based goals (Jamil, Linder, & Stegelin, 2017; Kim & Bolger, 2017).

Taken together, these challenges can impact early childhood and elementary teachers’ ability to plan and engage students in authentic STEM and STEAM teaching. They highlight the need for providing teacher candidates with opportunities to engage in STEAM teaching to develop their self-efficacy for using the approach and support them to create STEAM-based lessons and experiences for children (Donahue & Stuart, 2008; Kim & Bolger, 2017; Zimmerman, 2016). A variety of programs and strategies have been used to increase early childhood teachers’ STEM teaching self-efficacy (Deehan, Danaia, & McKinnon, 2017; Cone, 2009; Jarrett, 1999; Wingfield, Freeman, & Ramsey, 2000). For example, researchers Duran et al. (2009) found that interacting
with an informal science organization increased inquiry-based science teaching self-efficacy. Early childhood teachers who participated in a one-day workshop focusing on STEAM found the STEAM approach valuable for their development (Jamil et al., 2017). Similarly, teacher candidates who created STEAM lesson plans developed positive attitudes toward the approach and self-efficacy for designing STEAM materials (Kim & Bolger, 2017). In short, developing and implementing STEAM curriculum in formal and informal settings supports teacher learning about the STEAM approach. In the next section, we describe the affordances of informal settings as places of learning for children, caregivers, and teacher candidates.

Impact of Informal Settings

Informal settings are places where learning occurs outside a formal classroom. These places can include museums, discovery centers, zoos and aquaria, clubs, libraries, online forums, and homes. Informal settings present a variety of content through displays, activities, and objects, cater to diverse learners of all ages, and invite voluntary attendance that results from intrinsic motivation (Bell et al., 2009; Koran, Koran, Foster, & Dierking, 1988; National Research Council, 2009). Not surprisingly, informal settings offer a learning environment that is beneficial to children’s development. They allow children to actively construct meaning of new knowledge through hands-on, interdisciplinary, play-based, real-world, and authentic contexts (Bell et al., 2009; Brooks & Brookes, 1993; Gibbons, 2003; Migus, n.d.). Access to STEM and STEAM experiences in the early years contributes to children’s increased interest in STEM disciplines (Bybee & Fuchs, 2006), yet access to these experiences is often limited for elementary aged children (Dejarnette, 2012; Hartman, Hines-Bergmeier, & Klein, 2017). As such, informal learning settings offer increased opportunities for children to engage in STEAM learning.

Informal settings also allow children and their caregivers to interact and learn together. Caregiver involvement in informal learning settings supports children’s development (Olson & Drake, 2009), learning of STEM content (Bell et al., 2009), learning of history and art (Riedinger, 2012), and is essential to children’s academic success (Buxton & Provenzo, 2011; Geerdts, Van de Walle, & LoBue, 2015; NSTA, 2009). Caregivers tend to direct children to notice physical characteristics of exhibits, help them comprehend information and instructions, and model appropriate ways for interacting with materials. Caregivers also ask children to make predictions about unobservable information, encourage scientific reasoning and causal inferences, elaborate on content by connecting it to past experiences and knowledge, and model interest for learning the content (Geerdts et al., 2015; Riedinger, 2012; Zimmerman, Reeve, & Bell, 2009).

Hosting events that offer developmentally appropriate informal learning experiences within a child’s school but outside the formal classroom makes them more accessible to children and their caregivers (Bell et al., 2009; Bevan et al., 2010). The practice bridges formal (school-based) and informal learning, creating cross-contextual learning spaces (Fallik, Rosenfeld, & Eylon, 2013; National Research Council, 2009; Russell, Knutson, & Crowley, 2013). By attending a rich curricular event at a local school, caregivers may develop a better understanding of class content and may discover ways to make school content relatable to their children in out-of-school settings. Providing ways for caregivers to see the natural connections between school learning and out-of-school learning increases the chances that caregivers will seek additional informal learning opportunities for their children, many of which may support classroom learning topics (Bell et al., 2009).
Hosting informal events within school walls is also of value to the development of teacher candidates (Bottoms, Ciechanowski, Jones, de la Hoz, & Fonseca, 2016; Dani et al., 2018; Duran, Ballone-Duran, Haney, & Beltyukova, 2009; Harlow, 2012; Jamil et al., 2017). Informal learning events create service opportunities for teacher candidates to engage in meaningful ways with their clinically-based school communities, interact with caregivers and families from diverse racial, ethnic, and socioeconomic backgrounds, and provide a context for discussion of culturally relevant teaching practices in methods courses (Bell, Lewenstein, Shouse, & Feder, 2009; Bottoms et al., 2016; Dani et al., 2018; Harlow, 2012; Rennie, 2007). As communicating with caregivers and families is an area of heightened anxiety and low self-efficacy for new teachers (Hartman, Kennedy, & Brady, 2016; Melnick & Meister, 2008), creating opportunities for interactions with caregivers and families is important for teacher candidates’ development.

Research also documents that informal learning events provide a way to increase early childhood teacher candidates’ STEM knowledge and self-efficacy with STEM topics (Dani et al., 2018; Harlow, 2012). Applying what is known about the benefits of informal learning events and the importance of providing experience in implementing the STEAM approach in early childhood contexts, we used informal STEAM events to provide teacher candidates an opportunity to practice STEAM teaching. Informal STEAM learning events create an integrated twist to traditional STEM events. The practices presented in this article offer accessible ways to provide these opportunities for early childhood teacher candidates.

Context

The informal STEAM learning events described in this article occurred in the context of an Early Childhood Education program at Ohio University, a large university in the midwestern region of the United States. The program enrolls over 400 teacher candidates and provides licensure from age 3 to grade 3. Via Professional Development School (PDS) partnerships, the program utilizes a Clinical Model of teacher preparation (AACTE, 2018; NAPDS, 2008; NCATE, 2010). The PDS collaborative model creates unique partnerships between local PreK-12 schools and the university community that involve public school leaders and teachers, university faculty and administrators, and teacher candidates. Such partnerships create a rich community of learners that is able to positively influence both PreK-12 student learning and teacher candidate development (NAPDS, 2008).

The Clinical Model at Ohio University is focused on preparing teacher leaders through sustained clinical experiences with integrated co-teaching, extensive school-based mentoring, and a programmatic emphasis on advocacy and social justice (AACTE, 2018; NCATE, 2010). At the junior level, the early childhood program has PDS partnerships with six local elementary schools from three districts. Each PDS partnership has a university-based faculty coordinator and school-based teacher liaison who are an integral part of the junior year clinical experience. During their junior year, early childhood teacher candidates spend two full days each week in their PDS school. Teacher candidates are supported and supervised by mentor teachers, the school’s teacher liaison, and the university’s faculty coordinator, both in classrooms and through a weekly seminar held at their elementary school. In their PDS cohort group, early childhood candidates also take coursework (content, pedagogy, and content-specific pedagogy) on the university campus.

The sustained nature of the early childhood PDS partnerships has allowed for the incubation of innovative ideas to further promote student learning. One of these ideas involved helping candidates plan and host STEAM-focused informal learning events at their PDS partnership
schools. Nearly all PDS partnership schools host informal learning events one to two times per year that are planned by teacher candidates. Each semester, if a school does not host its own event, the teacher candidates placed at that school are required to assist at informal learning events happening at other PDS sites. In this way, all early childhood teacher candidates at Ohio University gain experience in hosting informal learning events. The events allow candidates to interact with their students and students’ caregivers in out-of-school events that promote family engagement and cross-contextual learning. The events also support candidates’ development as early childhood teachers by providing them with authentic opportunities to present interdisciplinary content. As the STEAM events grew from idea to reality, teacher candidates also pursued partnerships with community entities, including public libraries, museums, environmental agencies, and local businesses. The collaboration among these multiple stakeholders, together with the existing collaborative school-university partnerships, contributed to the success of the two STEAM events described in this article.

The STEAM Events

To illustrate the types of integrated events that early childhood teacher candidates are capable of planning and hosting, two STEAM events are described. The first, World Market$^1$, combined Social Studies and Math content, and the second, Reading & Science Night, integrated literacy, science, and art content. For each informal STEAM event, teacher candidates created both an interactive, hands-on activity and a content focused poster. The posters provided background knowledge about the STEAM content of the activity, directions for participating in the activity, and learning standards for each content area (Figure 1).

![Figure 1. An example of an accompanying STEAM poster.](https://ir.library.illinoisstate.edu/jste/vol54/iss1/5)

$^1$ Pseudonyms are used for event names.
Both events were conducted at one PDS school where early childhood candidates were completing their junior year clinical placement. Between 18 and 21 ECE partnership teacher candidates facilitated the STEAM stations at each event. The school is classified as a high poverty, rural school with approximately 400 children attending in grades K-6. Over 125 children, ages kindergarten-sixth grade, their siblings, and families/caregivers attended each of the events. As the school typically struggles to attract student attendance and parent/caregiver engagement at after-school events, this is a very large attendance number. During each event, caregivers were encouraged to actively participate in the stations with their child. Additional participants included teachers, administrators, and university faculty. Following each event, teacher candidates reflected on their experiences. In the remainder of this paper, we use quotes from these reflections to provide more context and a better feel for the type of learning environments generated by these events.

**World Market**

*World Market* was inspired by a desire to make family nights at the candidates’ school more interdisciplinary and to create natural connections to teacher candidates’ methods courses. Each fall semester, candidates take math and social studies methods courses, so it was important to see both of these content areas reflected in the informal learning event’s content. Art provided another natural connection to each content area. The faculty coordinator at the teacher candidates’ school, who was also their social studies methods instructor, first proposed the idea of integrating the two content areas for the informal event. *World Market* was the first event in Ohio University’s PDS network to be developed specifically to have an interdisciplinary, STEAM focus. Previously, all informal events were solely STEM focused. At first, early childhood candidates were nervous about finding a connection between the STEAM content areas and expressed trepidation about stations that made this connection. However, with modeling, many examples, and support from their teacher liaison, math methods instructor, and mentor teachers, teacher candidates began to develop ideas for their interactive stations and began to see the natural, real-world connections between math and social studies (see Table 1 for examples of the math/social studies stations). For example, a teacher candidate developed the Peruvian “Pan” Flutes station, which used concepts from social studies (geography), mathematics (measurement), and music (instruments) to design, create, and learn about pan flutes. The name of the event emerged as ideas began to take shape and excitement about the event was building. *World Market* was very well attended and was met by extremely enthusiastic reviews (Figure 2). Children also carried a “passport” around and received stamps as they visited each station. Reflects a teacher candidate, “I think *World Market* went really well. I was not sure what to expect, so I was very nervous. I was really engaged the whole night, and I think it was great for kids to see the connection between math and social studies.” Based on the reactions of children, families, and teacher candidates, the teacher liaison and faculty coordinator decided to embrace a STEAM approach for the spring informal event, too. This is described next.

**Reading & Science Night**

As science content methods courses are sometimes challenging for teacher candidates, for *Reading & Science Night*, teacher candidates were asked to start the planning for their station by identifying a picture book that inspired a science connection through art or literacy. As part of their weekly seminar class, the faculty coordinator and teacher liaison also set up four examples of stations that modeled science, reading, and art connections. One example involved using the wordless picture book, *Journey* (Becker, 2013), as a launching point for a discussion of how art
can tell a story without words and for creating science connections to buoyancy and floating. Creating aluminum foil boats with the goal of carrying as many pennies as possible (i.e. penny boats) was presented as the station’s activity.

Table 1.
*Market Around the World Stations*

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer’s Market</td>
<td>This station allowed children to purchase fruits or vegetables for a healthy snack. Upon arriving, each child was given $2.00 in play money to use to purchase fruit and vegetables at the “Farmer’s Market.”</td>
</tr>
<tr>
<td>Kongki Noli</td>
<td>A traditional Korean math game that uses stones and is similar to “jacks.” After tossing and catching their stones, children and caregivers added their scores after each round of play.</td>
</tr>
<tr>
<td>Terrific Timelines</td>
<td>Each visitor to the event had the opportunity to add an important event to the school timeline. After that, they could use an array of art materials to create their own timeline. Children and caregivers chose to work individually or together to create their timelines.</td>
</tr>
<tr>
<td>Tangrams</td>
<td>The ancient Chinese puzzles became life-size floor puzzles. Children and caregivers worked together to arrange the pieces to match templates or create their own seven-piece puzzle.</td>
</tr>
<tr>
<td>Peruvian “Pan” Flutes</td>
<td>First, visitors found Peru on a map. Second, they learned about Pan, the Greek god of nature who was often depicted holding a flute. Third, children and caregivers measured and cut straws to make their own pan flutes, which originated in Peru. Finally, visitors created music with their pan flute.</td>
</tr>
<tr>
<td>Jobs in Our Community</td>
<td>Children and caregivers chose a job and then collectively created tally marks and a bar graph with their chosen professions.</td>
</tr>
<tr>
<td>Life-Sized Shisima</td>
<td>This math game from Kenya allowed up to six players at a time to become life-sized game pieces. A game of strategy, Shisima invited children and caregivers to use collaboration and advanced planning to assemble three people in a line to win the game.</td>
</tr>
</tbody>
</table>

From there, teacher candidates began bringing picture books to school to share with each other and began developing their own science activity that connected to their book (see Table 2 for examples of picture books with science station connections). Candidates were encouraged to choose books from a variety of genres and to not limit themselves to nonfiction science-focused books. In total, teacher candidates created 21 science stations for the event, which was attended by over 100 children and their caregivers. To illustrate, visitors to the *Rosie the Raven* (Bansch, 2015) station were encouraged to read the book (literacy) and use key details to the life cycle, basic needs, and adaptations of ravens (literacy and science) to design and create an aesthetically pleasing raven bird feeder (science and visual arts). Each picture book was displayed with the station’s activity and was available for reading during the event (Figure 3). Teacher candidates also invited local
organizations to partner in the event. The small town’s public library set up a reading station, and two science-focused and one STEAM focused organization also created stations for the event. Even though teacher candidates had an extremely busy semester, all felt the informal event was worthwhile and appreciated the real-word model that the STEAM approach created. Illustrating this, one teacher candidate says, “One of my big take-aways was just seeing how much fun everyone was having. There were so many integrated stations, and everyone who came to the event and worked the event seemed to have an awesome time while learning.” The following section presents facilitating factors that may be useful to other stakeholders who wish to plan and host a STEAM event with their early childhood teacher candidates.

Table 2. Reading & Science Night Picture Books and Activities

<table>
<thead>
<tr>
<th>Picture Book*</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Diary of a Worm</em></td>
<td>This station allowed children and caregivers to get up close and personal with worms. They were encouraged to identify the different parts of worms’ bodies, as well as discuss their diets and habitats.</td>
</tr>
<tr>
<td>By Doreen Cronin</td>
<td></td>
</tr>
<tr>
<td>Illustrated by Harry Bliss</td>
<td></td>
</tr>
<tr>
<td><em>Rosie the Raven</em></td>
<td>Children and caregivers worked together to make homemade birdfeeders that they could hang in their yard or community. Sun butter was made available for visitors with nut allergies.</td>
</tr>
<tr>
<td>Written and Illustrated by Helga Bansch</td>
<td></td>
</tr>
<tr>
<td><em>Dannie and the Monarch Butterfly</em></td>
<td>All four cycles of butterfly development were explored at this interactive station. Visitors created representations of all four cycles that they could take home with them.</td>
</tr>
<tr>
<td>Written and Illustrated by Helga Bansch</td>
<td></td>
</tr>
<tr>
<td><em>The Man Who Walked Between the Towers</em></td>
<td>Using straight and/or bendy straws and playdoh, children and caregivers worked together to create and build their own tower.</td>
</tr>
<tr>
<td>Written and Illustrated by Mordicai Gerstein</td>
<td></td>
</tr>
<tr>
<td><em>One Plastic Bag: Isatou Ceesay and the Recycling Women of Gambia</em></td>
<td>Children and caregivers upcycled plastic grocery bags by weaving them into jump ropes. Then, they could practice jumping rope with their creations.</td>
</tr>
<tr>
<td>By Miranda Paul</td>
<td></td>
</tr>
<tr>
<td>Illustrated by Elizabeth Zunon</td>
<td></td>
</tr>
<tr>
<td><em>The Turnip</em></td>
<td>With many real life examples, children and caregivers examined and drew the parts of a plant.</td>
</tr>
<tr>
<td>Written &amp; Illustrated by Jan Brett</td>
<td></td>
</tr>
</tbody>
</table>

*Each book was available at the corresponding station. Caregivers and children were encouraged to read them together.
Figure 2. Graphing and communities creates a math/social studies connection.

Figure 3. A book about worms encourages worm exploration at the station.
Facilitating a STEAM Event

Content Connections and Idea Formation

Methods Courses. Each STEAM event was designed to complement the content methods courses that teacher candidates were taking in the corresponding semester. As such, math and social studies were grouped, as were literacy and science. The arts, which are infused throughout much of early childhood classroom activities, provided a natural companion to both events. Creating clear content connections to the methods courses teacher candidates are currently taking is highly recommended. A teacher candidate emphasizes this saying, “It was helpful to us to have the content match our methods courses. It gives us an opportunity to see how they are related.” This also creates natural connections between teacher candidates’ university coursework and their clinical placements.

During weekly seminars, the faculty coordinator and teacher liaison introduced STEAM pedagogy and offered considerable support to candidates as they developed their ideas and allowed time to discuss ideas and test activities with each other. During the content-specific methods courses, university faculty discussed readings about hosting informal events. For example, science educators facilitated discussions around articles from publications of the National Science Teachers Association (e.g., McCubbins, Thomas, & Vetere, 2014; Sutton & Hatton, 2011). Teacher candidates received feedback on their initial ideas and activity summaries from the faculty coordinator and teacher liaison. To best facilitate this process, frequent communication and dedicated class time to develop ideas is essential.

Station Requirements. Each station that teacher candidates designed had to: 1) Be interdisciplinary with a real-world connection; 2) Be interactive and hands-on; and, 3) Foster collaboration between children and caregivers. Integrating grade appropriate standards with each content area was also expected, and standards for content areas were displayed on each station’s accompanying poster. For each station, teacher candidates connected the activity to students’ prior knowledge, whether it was something they learned in school or an activity they participated in on a field trip, or something that related to what was happening in their life outside of school in their family or the community. For example, one station at World Market was focused on a Farmer’s Market and connecting it to the local farmer’s market was important. Making authentic connections to children’s communities made the stations more relevant to young learners. For Reading & Science Night, teacher candidates spent time reading the accompanying picture books to the students in their classrooms. Creating these requirements for stations is recommended for those who develop their own informal STEAM events.

Planning and Preparation

Committees. Teacher candidates took the lead on planning all the logistical details associated with each STEAM event. They formed committees for advertising, fundraising, refreshments, materials and supplies, volunteers and many others. For example, the budget committee was responsible for making sure the costs associated with each committee fit within the allotted budget for each informal event. Table 3 lists the types of committees and a description of their duties. Teacher candidates also coordinated with community agencies, school personnel, and PTOs throughout the planning process. Adopting a committee system is recommended to ensure all candidates are responsible for planning some part of the informal event’s logistics and for making sure the workload is evenly distributed. As a teacher candidate describes, “It helps to have the
work spread out. That way no one is responsible for too much, and we can also focus on our stations.”

Table 3. Committee Types and Assignments

<table>
<thead>
<tr>
<th>Committee Title</th>
<th>Description of Duties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteers</td>
<td>The volunteer committee recruits, schedules, and supervises volunteers during the event.</td>
</tr>
<tr>
<td>PTO Communications</td>
<td>This committee communicates with the PTO to arrange possible collaborations for refreshments and school-wide notifications (e.g. School newsletter).</td>
</tr>
<tr>
<td>Advertising</td>
<td>This committee notifies local media outlets and communicates event information to important stakeholders, such as the superintendent and school board.</td>
</tr>
<tr>
<td>Theme/Decorating</td>
<td>Creating a festive atmosphere is important to the overall look of the event. This committee is responsible for designing and implementing the event’s theme.</td>
</tr>
<tr>
<td>Family/Caregiver Notifications</td>
<td>Teacher candidates in this committee wrote paper notifications and emails to notify families about the upcoming informal STEAM events.</td>
</tr>
<tr>
<td>Fundraising</td>
<td>Members of this committee contacted local business to solicit both monetary and in-kind donations of supplies and/or equipment.</td>
</tr>
<tr>
<td>Supplies</td>
<td>Each teacher candidate communicated their supply needs to the members of this committee. Once supply lists were received, committee members organized the lists and searched for affordable vendors to purchase needed supplies.</td>
</tr>
</tbody>
</table>

**Materials and Equipment.** Implementing each event required teacher candidates to acquire materials and equipment. Some supplies were consumable and had to be purchased in advance of the event (e.g. glue, dirt, paper plates, beads, stickers, straws, cornstarch, … etc.) To raise money for these supplies the following funding sources are recommended, 1) The school’s Parent-Teacher Organization; 2) Local businesses (e.g. a local grocery store donated fresh produce and bottled water); and, 3) Small university-based grants. Some supplies and equipment were borrowed from the candidates’ mentor teachers (e.g. markers, scissors, and stamps), while others were borrowed from university faculty and university laboratories (e.g. black light for the Germ Station). A week before each event, the faculty coordinator took candidates who needed consumable materials shopping at local stores. The teacher candidates picked out the materials they needed, the faculty coordinator paid for them, and then the candidates took the supplies with them. In that way, candidates were responsible for preparing and stocking their own station. It should be noted that a
large budget is not needed to facilitate an effective STEAM learning event. The events described in this article were each implemented for around $150.

**Volunteers.** Each STEAM event was supported by volunteers who served as material managers at some stations, monitored attendance and sign-in, and helped with cleanup. Volunteer support during the events was essential to helping the events run smoothly. Having volunteers available to help staff stations provided additional help for messy stations (e.g. Oobleck) or those that were creating intricate products (e.g. life cycle of a butterfly). Teacher candidates should utilize their networks to attract volunteers to their informal events. For the STEAM events described here, volunteers included teacher candidates from other early childhood PDS partnership schools, student organizations, and from other majors. Reflects a teacher candidate, “I am very grateful that candidates came from other schools, because it gave us extra help at our stations. If I hadn’t had help, I wouldn’t have been able to get kids in and out of my station efficiently.” Facilitating events of this nature requires some degree of volunteer recruitment and engagement and should be planned for early as the STEAM event is developing.

**Advertising.** To ensure attendance at the STEAM events, the planners should consider an advertising strategy. At the events described here, teacher candidates were innovative in their advertising plans. The events were advertised in the school newsletter, in the morning announcements, by stapling reminder bracelets on each child on the day of the events, in a promotional video that was shown in each classroom, and via signs posted around the school (Figure 4). Before Reading & Science Night, teacher candidates also read the accompanying picture books to their classes. In this manner, they generated a lot of enthusiasm and excitement about the events. Advertising may also be done with the help of the PTO. Teacher candidates should work together to advertise in a way that best suits the needs of their school, whether it be in print form, such as a printed flyer, or through an electronic message on the school’s website, email, or social network sites.

*Figure 4. Posters advertising the events were displayed around the school.*
During the Event

**Active Engagement.** Each of the STEAM events lasted for one and a half hours, and active engagement from teacher candidates was expected the whole time. Maintaining focus and enthusiasm during informal learning events is essential (Dani et al., 2018). This presented a unique opportunity for teacher candidates to interact with children and families in a non-threatening and fun manner. Speaking of her station about moon phases, a teacher candidate shares:

> I tried to be open, positive, and engaged. I think being open and positive is important for creating a safe space and feeling comfortable. Being engaged in your station and being able to discuss the different moon phases with your students is important so they aren’t only having fun but learning something as well.

Teacher candidates were encouraged to come out from behind their station’s table, to greet each visitor enthusiastically, to help children use the manipulatives and supplies, and to ask inquiry driven questions. Teacher candidates got on the floor to help children count with manipulatives, helped them measure and pour ingredients, and interacted with families throughout each of the events. This type of engaged behavior was necessary for truly inclusive events and aided greatly in their success.

In order to help teacher candidates be ready for the event, it is recommended that the events be held in the early evening. The STEAM events described here were held from 5:30-7:00, which allowed teacher candidates to set up after school at a leisurely pace. Making sure candidates know the importance of active engagement before the event begins is of paramount importance. During the event, it is helpful if university and school-based instructors are present and encouraging teacher candidates to be actively participating with the children and caregivers at their station. Teacher candidates may need to be reminded to ask children and caregivers to join them at their station and to present a welcoming and approachable demeanor. Creating an expectation of active engagement helps greatly in facilitating a successful event.

**Encouraging Caregiver Involvement.** Child/caregiver collaboration at an informal event can also lead to continued learning in the home (Bell et al., 2009; Olson & Drake, 2009). One challenge for schools and informal learning providers is bridging the gap between school learning and out-of-school learning (Voss, 2011). Stations that encourage collaboration between children and their families/caregivers create important opportunities for in-school learning to continue outside the school walls. As such, teacher candidates should be prepared to encourage children and caregivers to engage together in the station’s activities. Sometimes, this requires a teacher candidate to gently encourage a caregiver/parent to get involved by asking a question or welcoming them to the event. It also requires teacher candidates to plan activities that provide accessible and fun ways for caregivers to participate in the station (Figure 5). While this does not always result in a caregiver getting involved, it does frequently result in more active caregiver engagement. Reflecting on the value of caregiver involvement during the STEAM events, a teacher candidate expressed:

> I believe it is so vital to interact with families in this type of setting. Although you see families during conferences, it can be a totally different situation because you may have to touch on some difficult topics when meeting. To be able to interact with them in a fun and carefree area, allows me as a teacher candidate to get to know who the parents are and what they want for their child.
After the STEAM Event

Facilitating an informal STEAM event should also involve documenting and reflecting on the event. For the STEAM events described here, teacher candidates reflected on their experiences via discussions during seminar and through written reflections. Additionally, both the faculty coordinator and the teacher liaison sought feedback from the school’s mentor teachers and principal. As ascertained via these discussions, the school’s principal recommended that all future informal events adopt an interdisciplinary STEAM focus. As a result, a future informal event also incorporated Physical Education content. Teacher candidates may also want to contact a local newspaper so that pictures and/or a story about the event can be featured within the community. Finally, encouraging teacher candidates to share the success of the event to the school’s school board and superintendent provides a very valuable opportunity for candidates to both celebrate their success and gain a better understanding of the organization of a school system. If a group of candidates uses a committee structure as described here, dissemination can be a committee assignment.

Final Thoughts

The success of the STEAM events was predicated on a strong collaborative and community-based approach to planning. Using this STEAM model, collaborations can be sought, nurtured, and leveraged to advance the real-world, authentic learning of children using similar events. In the model presented here, the time and space afforded by the early childhood PDS partnership was utilized to engage teacher candidates in the design and development of the events. The process requires a time commitment from both school and university-based partners and will work best in contexts where teacher candidates have the time and space to engage in similar processes (e.g., dedicated course time, student professional organization activity, or service learning project). Collaboration between school, university, and community participants was paramount in the
delivery of each STEAM event. If adopted as part of clinically-based teacher education programs, this model can lead to an institutionalized, cyclical approach to interdisciplinary informal learning events within school settings. When implemented twice a year, the success of each informal event then carries forward to the next event.

Teacher candidates who facilitate informal STEAM events can benefit in many ways. Prior research indicates that informal STEM events provide clinical opportunities for teacher candidates to teach science in authentic settings, interact with children and their caregivers, and gain much needed confidence about STEM content (Dani et al., 2018; Harlow, 2012). Informal STEAM events can provide teacher candidates with similar opportunities to gain confidence about STEM/STEAM content. However, utilizing a STEAM approach, as opposed to a STEM focus, creates more real-world, integrated experiences. Describing her penny boat design station, a candidate reports:

One thing that I learned about my experiment was that objects stay afloat when they have a greater ratio of empty space to mass than fluid. I thought this was beneficial for me as a future teacher, because I was able to better explain density and mass to the students who came to my station, which impacted the artistic design process of their boats.

Whereas a STEM approach may further the impression that STEM content exists in isolation from the arts and humanities, a STEAM approach models real-world integration of content areas (NSTA, 2009; Sharapan, 2012).

Teacher candidates’ involvement in STEAM events can also contribute to their development as leader educators who will be able to design and implement community-engaging events at their schools. Emphasizing this, a teacher candidate states, “The STEAM nights made me see how I want to work in a school setting very similar to my partnership school and to be able to collaborate with future coworkers to make fun family nights.” Such involvement provides much needed real-world experience about their role as a teacher outside of the formal classroom and allows them to witness the importance of a community coming together to promote student learning. As testament to this, a teacher candidate relays, “For me, the most beneficial part of these events is seeing the school community come together to create an amazing night for students and families.” Facilitating informal STEAM events promotes teacher candidates’ learning about the many logistical details that are needed to make informal learning events a success and the value of investing their time to engage with their school community.

While informal conversations with all stakeholders involved in the STEAM events described in this article support our belief that these events are impactful, formal research to investigate the benefits of STEAM events is needed. Future research should focus on the impact of facilitating STEAM events on teacher candidate development and self-efficacy. Future research should also investigate the benefits of informal STEAM events to children and caregivers. Informal STEAM events that are located within school settings create meaningful opportunities to bring together university, school, and community stakeholders in ways that enhance children’s knowledge. Informal STEAM events provide important ways to bridge the learning that happens within formal school classrooms and the interdisciplinary learning that happens during out-of-school hours. Stakeholders in other locales may take the practices presented in this article to plan and implement their own successful informal STEAM events.
References


Zimmerman, A. S. (2016). Developing confidence in STEAM: Exploring the challenges that novice elementary teachers face. The STEAM Journal, 2, Article 15. doi: 10.5642/steam.20160202.15


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The Impact on Technology and Engineering Education Programs Based on their Academic Homes

Ryan A. Brown
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ABSTRACT

Technology and Engineering Education programs are housed in a number of different types of colleges and departments. This paper explores the curricular impact on technology and engineering programs based on the college and department that are the academic home for the program. The study found that there were four categories of colleges (Education, Technology, Engineering, and Arts and Sciences) and departments (Education, Technology, Technology Education, and Engineering) that serve as the academic homes of the 40 technology and engineering education programs that were examined. The plans of study for each program were examined and courses were divided into 12 codes within the categories of general education, content courses, and education and methods courses. An ANOVA was used to determine if any significant differences existed between the quantity of credit hours in each code and whether the program was housed in an education or non-education department. No significant differences in the coursework were found between programs housed in education departments and programs in non-education departments.

Keywords: Technology and engineering education; pre-service teachers

Over the past 20 years the literature has presented the reality of technology education programs closing at a worrying pace (Volk, 1997; Litowitz, 2014). In some cases, those programs that have remained open have shifted academic homes as they have moved from a technology department to a consolidated program within a college of education or otherwise. However, some programs have always lived in a variety of academic homes across college campuses in the United States.

The purpose of this paper is to explore the impact that the academic home has on technology and engineering education programs. To explore this topic, research has been conducted to compare the programs of study for active undergraduate technology and engineering education programs in relation to their academic home on their respective campuses. This study will help technology and engineering educators understand the relationship that exists between a technology and engineering education program and the college and department in which it resides.

Research Question and Methodology

The guiding question in this study is:

Are technology and engineering teacher education programs more appropriately located in pure teacher education departments, or departments where the primary focus is not on teacher education?
Many approaches could have been taken to determine appropriateness, as it is both relative and subjective. Appropriateness could have been viewed through the eyes of students/graduates or faculty members or explored using graduate success and placement rates. This study, however, used coursework to provide a foundation for appropriateness and a source of comparison between the academic homes of technology and engineering education programs.

The resulting study is a quantitative analysis of the variances that exist in the plans of study of technology education programs based on their academic home. To conduct the study, a list of existing technology and engineering education programs was created. Each program was then researched to find the program name and their academic department/school and college (or similar depending on the institutional structure). Programs of study, course lists, and advising documents were then located and coded into 3 different categories (General Education, Content Courses, and Education and Methods) with several codes in each category (see Table 1). After all programs were coded and the quantity of credit hours in each code were calculated, a One-Way Analysis of Variance (ANOVA) was used to determine if there were any significant differences between the programs based on their academic home.

Table 1
Categories and Codes Used in the Analysis

<table>
<thead>
<tr>
<th>General Education</th>
<th>Content Courses</th>
<th>Education and Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Education</td>
<td>Technology Content</td>
<td>Technology Education</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Methods</td>
</tr>
<tr>
<td>Directed General Education</td>
<td>Industrial Technology Content Design</td>
<td>STEM Methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Education Methods</td>
</tr>
<tr>
<td></td>
<td>Engineering Content</td>
<td>Education Foundations</td>
</tr>
<tr>
<td></td>
<td>Technology and Society</td>
<td>Student Teaching</td>
</tr>
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</table>

The sample in this study includes 40 programs that certify teachers at the undergraduate level for technology and engineering education (or related) certification. Initially, 53 programs were examined. However, six of the programs on the initial list were either closed or are no longer accepting students and seven programs were MAT or Certification-Only programs. MAT or Certification-only programs were excluded from the study because the entire plan of study would not have been able to be determined and the program would not have been able to be analyzed in comparison with the full undergraduate programs.

Limitations

There are several limitations to this study that include:

- Only undergraduate programs in which all degree coursework could be determined were used in analysis. There may be different and innovative programs that were excluded from this study that reside at the Master’s or Certification-Only level.
- The analysis is based solely on the coursework titles. The courses were coded based only on the titles in either the plan of study or the undergraduate catalog.
- No interactions were had with program faculty or students.
- While an attempt was made to include all technology and engineering education (or related) programs, some may have been unintentionally left out of the analysis.
Findings

The findings for this study include both the academic homes and their use as a factor of analysis in relation to the coding categories.

Academic Homes

The first tier of the academic home was determined for each program. This was the first level of division of the institution and in most cases, was either a college or school. This tier was grouped into four categories; Education, Technology, Engineering, Arts and Sciences. The quantity of each category and the titles it contains can be found in Table 2.

The second tier of the academic institutions was typically the department level. The following categories were created for second tier for each program: Education, Technology, Technology Education, and Engineering. The organization of the second tier can be seen in Table 3. The major analysis in this study was completed at the second-tier level by comparing the Education category with a master category that combined the other three non-education categories.

The last tier of the academic home that was examined was the program level. The names of each of the 40 programs were organized into four categories: Technology Education, Technology and Engineering Education, Industrial Technology and Career and Technical Education, and Engineering Education. Table 4 lists the categories and titles of the programs.

Table 2
First Tier Categories and Titles

<table>
<thead>
<tr>
<th>Education (N=13)</th>
<th>Technology (N=15)</th>
<th>Engineering (N=7)</th>
<th>Arts and Science (N=5)</th>
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<tr>
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<td>Business and Technology Division</td>
<td>College of Engineering</td>
<td>College of Agriculture and Applied Sciences</td>
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<td>College of Education, Health, and Human</td>
<td>College of Applied Science and Technology</td>
<td>College of Engineering and Technology (x2)</td>
<td>College of Arts and Sciences</td>
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<td>Development</td>
<td>College of Business and Applied Sciences</td>
<td>College of Science and Engineering</td>
<td>College of Arts, Sciences, and Professional Studies</td>
</tr>
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<td>College of Education, Health, and Human</td>
<td>College of Business, Industry, Life Science,</td>
<td>College of Science and Engineering Technology</td>
<td>College of Humanities, Arts and Sciences</td>
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<td>Sciences</td>
<td>and Agriculture</td>
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<tr>
<td>College of Education and Health Professions</td>
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<td>School of Professional Studies</td>
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<td>College of Education, Hospitality, Health</td>
<td>College (or School) of Business and</td>
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<td>Teachers College</td>
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Table 3
Second Tier Categories and Titles

<table>
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<tr>
<th>Education (N=7)</th>
<th>Technology (N=17)</th>
<th>Technology Education (N=6)</th>
<th>Engineering (N=10)</th>
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<td>Department of Curriculum and Instruction (x3)</td>
<td>Applied Technology Division</td>
<td>Career and Technology Teacher Education Department (x2)</td>
<td>Applied Engineering, Safety, and Technology</td>
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<td>Department of Education</td>
<td>Department of Applied Technology</td>
<td>Department of Family, Consumer, and Technology Education</td>
<td>Department of Agricultural Sciences and Engineering Technology</td>
</tr>
<tr>
<td>Department of Middle, Secondary, and Adult Education</td>
<td>Department of Industrial Studies</td>
<td>Department of STEM Education</td>
<td>Department of Applied Engineering and Technology (x2)</td>
</tr>
<tr>
<td>Department of Secondary Education and Foundations</td>
<td>Department of Technological Studies</td>
<td>Department of STEM Education and Professional Studies</td>
<td>Department of Applied Engineering and Technology Management</td>
</tr>
<tr>
<td>School of Education</td>
<td>Department of Technology (x6)</td>
<td>Department of Teaching Leadership and Innovation</td>
<td>Department of Technology and Engineering</td>
</tr>
<tr>
<td></td>
<td>Department of Technology &amp; Workforce Learning Environmental and Technological Studies Industrial Technology Department School of Applied Sciences, Technology and Education School of Technology Tech and Applied Science Department Technology and Applied Design Department</td>
<td></td>
<td>Engineering Engineering Technologies, Safety and Construction Engineering Technology School of Engineering (x2)</td>
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</table>
Table 4

Program Categories and Titles

<table>
<thead>
<tr>
<th>Technology Education (N=18)</th>
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<th>Industrial Technology and CTE (N=4)</th>
<th>Engineering Education (N=1)</th>
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<td>Career and Technical Education</td>
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<td>Technology Teacher Education</td>
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</table>

Coursework Analysis

The coursework was analyzed and will be presented in three categories: General Education, Content Courses, and Education and Methods Courses.

**General Education.** General education courses were present in each program that was analyzed. Two codes were used to analyze general education courses. The first code “GE” was used for general education courses that were required for all Bachelor’s degree students at each institution. In most cases these were not specific courses but were categories in which the students were required to earn a specific amount of credit hours. The second general education code was “GE+” which was used for directed general education courses. GE+ courses were typically specific math, science, or psychology courses that were required general education courses for education majors. Table 5 provides descriptive statistics related to GE codes. The ALLGE code is a code that was created by combining GE and GE+ to determine the total of GE courses required in that program.

Table 5

**General Education Descriptive Statistics**

<table>
<thead>
<tr>
<th>Codes</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GenED</td>
<td>40</td>
<td>22</td>
<td>55</td>
<td>38.65</td>
<td>6.439</td>
</tr>
<tr>
<td>GenEDPlus</td>
<td>40</td>
<td>0</td>
<td>18</td>
<td>4.93</td>
<td>5.609</td>
</tr>
<tr>
<td>AllGE</td>
<td>40</td>
<td>34</td>
<td>55</td>
<td>43.58</td>
<td>5.344</td>
</tr>
</tbody>
</table>

The GE codes were analyzed using an ANOVA to determine if there was a significant difference between the number of general education courses taken in programs housed in education departments compared to non-education departments. As seen in Table 6, no significant differences were found.
Table 6

One-Way Analysis of Variance of General Education Codes by Department

<table>
<thead>
<tr>
<th>Code</th>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>GenED</td>
<td>Between Groups</td>
<td>1.126</td>
<td>1</td>
<td>1.126</td>
<td>.026</td>
<td>.872</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>1615.974</td>
<td>38</td>
<td>42.526</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1617.100</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GenEDPlus</td>
<td>Between Groups</td>
<td>3.468</td>
<td>1</td>
<td>3.468</td>
<td>.108</td>
<td>.745</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>1223.307</td>
<td>38</td>
<td>32.192</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1226.775</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AllGE</td>
<td>Between Groups</td>
<td>8.546</td>
<td>1</td>
<td>8.546</td>
<td>.294</td>
<td>.591</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>1105.229</td>
<td>38</td>
<td>29.085</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1113.775</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Content Courses.** The content courses category was used for courses that were non-general education courses that provided content knowledge to students, but that were not educational methods or clinical courses. Five different codes were used in this category to differentiate between the types of content courses that were required in each program. When a program required content area electives in which students could select from a list, the number of credit hours required were coded as “TE/C” which served as both a code for any technology content course and a content elective course. Specific courses that were coded as TE/C included courses such as Transportation Systems, Construction Systems, Manufacturing Systems, and Communication Technology. Content courses that were more traditional in nature, such as Metals Technology, Welding, and Ag. Mechanics were coded as Industrial Technology Content (IT/C). Courses that involved design, such as CAD, Architectural Drawing, and Engineering Graphics were coded as Design Courses (TE/D). Engineering content courses (E/C) included courses that are traditionally taught in engineering programs such as Statics, Dynamics, and Thermodynamics. The final content code was Technology and Society (TE/S) which included Technology and Society and Technology and the Future course titles. Table 7 provides descriptive statistics related to Content codes.

Table 7

Content Course Descriptive Statistics

<table>
<thead>
<tr>
<th>Codes</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC</td>
<td>40</td>
<td>2</td>
<td>39</td>
<td>24.73</td>
<td>7.867</td>
</tr>
<tr>
<td>ITC</td>
<td>40</td>
<td>0</td>
<td>32</td>
<td>4.80</td>
<td>7.697</td>
</tr>
<tr>
<td>TED</td>
<td>40</td>
<td>0</td>
<td>18</td>
<td>7.75</td>
<td>3.801</td>
</tr>
<tr>
<td>EC</td>
<td>40</td>
<td>0</td>
<td>38</td>
<td>1.88</td>
<td>6.178</td>
</tr>
<tr>
<td>TES</td>
<td>40</td>
<td>0</td>
<td>9</td>
<td>1.52</td>
<td>2.172</td>
</tr>
<tr>
<td>AllC</td>
<td>40</td>
<td>15</td>
<td>55</td>
<td>31.40</td>
<td>8.022</td>
</tr>
</tbody>
</table>
The Content codes were analyzed using an ANOVA to determine if there was a significant difference between the types of Content courses taken in programs housed in education departments compared to non-education departments. As seen in Table 8, no significant differences were found.

Table 8

One-Way Analysis of Variance of Content Course Codes by Department

<table>
<thead>
<tr>
<th>Code</th>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC</td>
<td>Between Groups</td>
<td>.148</td>
<td>1</td>
<td>.148</td>
<td>.002</td>
<td>.962</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>2413.827</td>
<td>38</td>
<td>63.522</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2413.975</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITC</td>
<td>Between Groups</td>
<td>42.140</td>
<td>1</td>
<td>42.140</td>
<td>.706</td>
<td>.406</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>2268.260</td>
<td>38</td>
<td>59.691</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2310.400</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TED</td>
<td>Between Groups</td>
<td>3.128</td>
<td>1</td>
<td>3.128</td>
<td>.212</td>
<td>.648</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>560.372</td>
<td>38</td>
<td>14.747</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Total</td>
<td>563.500</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>Between Groups</td>
<td>11.431</td>
<td>1</td>
<td>11.431</td>
<td>.294</td>
<td>.591</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>1476.944</td>
<td>38</td>
<td>38.867</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1488.375</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TES</td>
<td>Between Groups</td>
<td>9.291</td>
<td>1</td>
<td>9.291</td>
<td>2.021</td>
<td>.163</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>174.684</td>
<td>38</td>
<td>4.597</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>183.975</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AllC</td>
<td>Between Groups</td>
<td>90.016</td>
<td>1</td>
<td>90.016</td>
<td>1.414</td>
<td>.242</td>
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<tr>
<td></td>
<td>Within Groups</td>
<td>2419.584</td>
<td>38</td>
<td>63.673</td>
<td></td>
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<tr>
<td></td>
<td>Total</td>
<td>2509.600</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Education and Method Courses.** The Education and Method courses category was used for courses that focused on classroom instruction. Five codes were used in this category to differentiate between several types of Education and Methods courses. The first code, Technology Education Methods (TE/M) includes courses in technology education, technology and engineering education, and career and technical education that focus on classroom teaching methods and/or have clinical hours in technology classrooms. Course titles in this code included Curriculum in Technology Education, Technology and Engineering Education Methods, and Teaching Engineering and Design. The STEM Methods code (STEM/M) was used for methods and/or clinical courses that specifically listed STEM education in the title. Only 8 of the 40 programs had at least one course that met the requirements of this code. The Educational Methods (ED/M) code was used for courses in general methods, assessment, and classroom management that were not content-specific such as Educational Evaluation and Strategies and Teaching Literacy in Secondary Schools. Educational Foundations (ED/F) courses included non-clinical diversity courses and educational psychology courses. The Student Teaching code (ED/ST) was used for student teaching hours and any related seminars that occurred in the student teaching semester. Table 9 provides descriptive statistics related to Content codes.
Table 9
*Education and Method Courses Descriptive Statistics*

<table>
<thead>
<tr>
<th>Codes</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEM</td>
<td>40</td>
<td>3</td>
<td>21</td>
<td>10.70</td>
<td>4.778</td>
</tr>
<tr>
<td>STEM</td>
<td>40</td>
<td>0</td>
<td>11</td>
<td>12.02</td>
<td>5.859</td>
</tr>
<tr>
<td>EDM</td>
<td>40</td>
<td>0</td>
<td>24</td>
<td>4.57</td>
<td>2.827</td>
</tr>
<tr>
<td>EDF</td>
<td>40</td>
<td>0</td>
<td>12</td>
<td>4.57</td>
<td>2.827</td>
</tr>
<tr>
<td>EDST</td>
<td>40</td>
<td>6</td>
<td>19</td>
<td>11.75</td>
<td>2.488</td>
</tr>
<tr>
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<td>40</td>
<td>9</td>
<td>42</td>
<td>28.35</td>
<td>7.499</td>
</tr>
</tbody>
</table>

The Education and Method codes were analyzed using an ANOVA to determine if there was a significant difference between the types of Education and Methods courses taken in programs housed in education departments compared to non-education departments. As seen in Table 10, no significant differences were found.

Table 10
*One-Way Analysis of Variance of Education and Methods Codes by Department*

<table>
<thead>
<tr>
<th>Code</th>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEM</td>
<td>Between Groups</td>
<td>34.426</td>
<td>1</td>
<td>34.426</td>
<td>1.528</td>
<td>.224</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>855.974</td>
<td>38</td>
<td>22.526</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>890.400</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STEM</td>
<td>Between Groups</td>
<td>1.507</td>
<td>1</td>
<td>1.507</td>
<td>.342</td>
<td>.562</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
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<td>38</td>
<td>4.410</td>
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<td></td>
<td>Total</td>
<td>169.100</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDM</td>
<td>Between Groups</td>
<td>38.057</td>
<td>1</td>
<td>38.057</td>
<td>1.112</td>
<td>.298</td>
</tr>
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<td></td>
<td>Within Groups</td>
<td>1300.918</td>
<td>38</td>
<td>34.235</td>
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<td></td>
</tr>
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<td></td>
<td>Total</td>
<td>1338.975</td>
<td>39</td>
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<td></td>
</tr>
<tr>
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<td>Between Groups</td>
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<td>2.805</td>
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<td>.560</td>
</tr>
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<td></td>
<td>Within Groups</td>
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<td>8.131</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDST</td>
<td>Between Groups</td>
<td>1.310</td>
<td>1</td>
<td>1.310</td>
<td>.207</td>
<td>.652</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>240.190</td>
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<td>6.321</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>241.500</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AllED</td>
<td>Between Groups</td>
<td>31.793</td>
<td>1</td>
<td>31.793</td>
<td>.559</td>
<td>.459</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>2161.307</td>
<td>38</td>
<td>56.877</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2193.100</td>
<td>39</td>
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</tr>
</tbody>
</table>

**Conclusions and Implications**

This study provides information regarding the location of technology and engineering teacher education programs in pure teacher education departments, or departments where the primary focus is not on teacher education. The study was approached through use of programs of study as a representation of the experiences that students have in each program. In terms of the courses that
students in technology education (and related) programs take, there is no significant difference between programs housed in education departments and programs in non-education departments.

This may be due to the amount of control that institutions and state licensing boards have on degree programs. Most, if not all, institutions have a set number of general education courses that students must take. While, at the same time programs must make sure that they are meeting the credit hour requirements that are placed on them from the state level. That leaves very few credit hours to use in innovative ways and still make sure that the students meet both the general education and certification requirements so that they can both graduate and be certified to teach.

One implication of the conclusions, however, is that in an era of consolidation and movement of programs (often making the choice to restructure over closure) the academic home of the program does not make a significant difference in terms of the types of courses that students complete in their technology teacher education program. This is certainly not to say that there are not challenges or impacts on other aspects of the program or faculty (i.e. resources, tenure, faculty morale). I recommend that additional research be conducted to examine other aspects of appropriateness in relation to the academic home of technology and engineering education programs. Studies of resource allocation, faculty expertise, and graduate retention could all be potential avenues for additional research.

References


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