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Elaine M. Silva Mangiante

Adam Moore

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Elaine M. Silva Mangiante
Salve Regina University, emangiante@gmail.com

Adam Moore
Roger Williams University, amoore@rwu.edu

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

Elaine M. Silva Mangiante
Salve Regina University

Adam Moore
Roger Williams University

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

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

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

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

Engineering DCIs	Low focus on student thinking	Basic focus on student thinking	Strong focus on student thinking
D-Defining and delimiting engineering problem	D1-Describes teacher presentation of criteria and constraints for solving the engineering problem. Does not address students' ideas of criteria/constraints.	D2-Describes how the teacher notes students' ideas about the criteria and constraints for solving the engineering problem.	D3-Describes how the students define criteria and constraints for solving the engineering problem, and how the teacher supports students with this DCI.
E-Developing possible solutions	E1-Describes teacher suggestions for design options. Does not address students' ideas of design options or choice of a design to pursue.	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.	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.
F-Optimizing the design solution	F1-Describes teacher suggestions for how to refine the design. Does not address students' identification of design features that need improvement.	F2-Describes how the teacher notes students' ideas of design features needing improvement and guides students to consider ways to refine the design.	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.

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

Levels of focus on student thinking	Idea units per category	Percentage	Examples of PST reflection comments for each category
<i>A-Attending</i>			
A1-Low focus on student thinking	82/235	35%	"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)
A2-Basic focus on student thinking	87/235	37%	"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)
A3-Strong focus on student thinking	66/235	28%	"Observing their diagrams, especially when they would draw arrows, was eye-opening. It allowed us to understand their thoughts." (Meg)
<i>B-Analyzing</i>			
B1-Low focus on student thinking	125/174	72%	"Student T said, 'Well, all bulbs lit a little bit, so that's good.' I [PST] agreed with him. (Ella)
B2-Basic focus on student thinking	34/174	20%	"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)
B3-Strong focus on student thinking	15/174	8%	"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)
<i>C-Responding</i>			
C1-Low focus on student thinking	46/80	58%	"They should be modifying the designs they already created... Perhaps, I will have ideas of modifications that they can make." (Anne)
C2-Basic focus on student thinking	24/80	30%	"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)
C3-Strong focus on student thinking	10/80	12%	"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)

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
AAR framework scores for individual PSTs’ reflective comments

PST	Pseudonyms	A1	A2	A3	B1	B2	B3	C1	C2	C3
#1	Anne	4	5	7	7	5	0	2	2	0
#2	Cari	4	6	6	2	7	2	0	6	1
#3	Ella	6	8	5	8	7	0	5	1	0
#4	Chloe	7	3	7	8	1	4	1	1	2
#5	Meg	7	5	4	7	3	2	2	1	2
#6	Rebecca	3	5	13	7	3	2	1	0	3
#7	Molly	11	5	2	14	0	0	4	2	0
#8	Sandy	6	7	4	8	2	3	4	0	0
#9	Val	3	9	4	11	1	0	5	1	0
#10	Dana	2	11	3	10	1	1	4	2	1
#11	Kelly	11	5	0	10	2	0	5	0	0
#12	Jean	2	8	6	9	2	1	3	4	1
#13	Codi	10	3	3	12	0	0	4	3	0
#14	Laura	6	7	2	12	0	0	6	1	0
Total		82	87	66	125	34	15	46	24	10

Table 5

Pre-service teachers' levels of focus on student thinking for engineering DCIs—the Engineering Design Framework

Levels of focus on student thinking for engineering DCIs	Idea units per category	Percentage	Examples of PST reflection comments for each category
<i>D-Defining and delimiting engineering problem</i>			
D1-Low focus on student thinking	23/44	52%	"I explained how the bulb brightness is affected by the number of batteries in a circuit and showed them how the circuit would be arranged around a field. They were not connecting the cost of the batteries in their planning." (Val)
D2-Basic focus on student thinking	20/44	48%	"Student N stated that 'we want to have the design be bright and cost the least money.'" (Rebecca)
D3-Strong focus on student thinking	0/44	0%	
<i>E-Developing possible solutions</i>			
E1-Low focus on student thinking	17/62	27%	"I would not allow them to have less than four lights because then they will just make two lights shine in a series circuit with all four batteries, and that will not be enough to light the entire field." (Ella)
E2-Basic focus on student thinking	33/62	53%	"Student Q's diagram had five batteries and four bulbs in series. Student B's diagram included six batteries with six bulbs in series." (Anne)
E3-Strong focus on student thinking	13/62	20%	"I asked students to tell something they liked about each person's design. Instead of assuming their design was best, by looking at other's ideas, they expanded their thinking and made adjustments to their own design. (Sandy)
<i>F-Optimizing the design solution</i>			
F1-Low focus on student thinking	16/55	29%	"I would be wise to train their thinking towards incorporating parallel circuits in their improved design." (Meg)
F2-Basic focus on student thinking	29/55	53%	"I asked how we could improve and I wrote their ideas on the whiteboard. Student D said, 'The bulbs could be brighter.' Student T agreed and said, 'Yes, we could come up with a different plan.' That is as far as we got." (Ella)
F3-Strong focus on student thinking	10/55	18%	"Students responded that using a parallel circuit [of bulbs] would allow them to have more bulbs lit with less cost to reach a higher brightness." (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

PST	Pseudonyms	D1	D2	D3	E1	E2	E3	F1	F2	F3
#1	Anne	1	3	0	0	3	0	1	0	1
#2	Cari	0	0	0	1	1	1	0	4	0
#3	Ella	5	0	0	3	3	0	1	5	0
#4	Chloe	2	4	0	0	0	2	0	4	2
#5	Meg	1	1	0	0	2	1	1	1	1
#6	Rebecca	2	2	0	0	4	5	0	1	5
#7	Molly	0	0	0	1	4	0	2	2	1
#8	Sandy	1	2	0	0	3	3	1	2	0
#9	Val	2	2	0	3	0	0	2	4	0
#10	Dana	1	2	0	2	4	1	1	0	0
#11	Kelly	4	0	0	1	2	0	3	2	0
#12	Jean	0	3	0	1	3	0	2	1	0
#13	Codi	3	0	0	2	2	0	1	2	0
#14	Laura	1	1	0	3	2	0	1	1	0
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 (Zemba-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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Authors

Elaine M. Silva Mangiante

Associate Professor

Salve Regina University, Department of Education

Email: emangiante@gmail.com

Adam Moore

Assistant Professor

Roger Williams University, Fienstein School of Humanities, Arts and Education

Email: amoores@rwu.edu