Knowledge to Empathy: Shifting Epistemological Frames in an Engineering Course for Preservice Elementary Teachers

Amy Voss Farris and Gözde Tosun
amy@psu.edu, gjt5160@psu.edu
Pennsylvania State University

Abstract: Elementary teacher preparation commonly includes relatively few science and mathematics courses, and rarely do these have an emphasis on engineering (NRC, 2009). In this paper, we analyze data collected in an introductory engineering course for educators, taught during the Spring 2019 term. The participants are 23 preservice teachers (PSTs). We examine the changing epistemological frames (Hammer, Elby, Scherr, & Redish, 2005) through which students view their engineering work and describe how the PSTs talked and wrote about the relationships among engineering and their future practice as elementary and early childhood educators. Across the course, we see development from naïve notions of engineering's importance as "hands-on" and engaging to more robust epistemologies about engineering as design and *teaching engineering* as creating productive contexts for students' design processes. We focus on two students' accounts of their own experiences of the engineering design process as centrally relevant to their pedagogical practice with elementary students.

Conceptual and theoretical background

Since the release of the Framework for K12 Science Education (2013), engineering education has begun to find its place as central within curricular goals at the elementary level. An ambitious vision for engineering in elementary schools extends beyond superficial forms of making and design challenges and seeks to engage students in disciplinarily-deep processes of purposeful design. This is a high bar, as elementary teacher preparation commonly includes relatively few science and mathematics courses, and rarely do these have explicit emphasis on engineering (NRC, 2009) or portrayals of what high-quality engineering instruction looks like at the elementary level (Cunningham, 2018). In addition to these challenges, elementary education majors enrolled in STEM classes have long reported feelings of isolation and are often unsupported to connect their view of the disciplinary content to their developing pedagogical commitments (e.g., Bergman & Morphew, 1999). This context motivates the need for this study, an investigation of an engineering content course housed within a College of Education. We investigate how preservice elementary teachers develop epistemological frames through which to view their own engineering practice and envision productive forms of engineering for their future students.

We seek to extend the contributions of self-efficacy and teacher beliefs scholars (e.g. Bursal & Paznwkas, 2006), who argue that preservice teachers' attitudes and beliefs about learning science and mathematics predict their confidence for teaching these areas. Rather than beliefs, our approach here is concerned with fine-grain cognitive resources (e.g., diSessa, 1993; McCormick & Hammer, 2016). The engineering content class is a context in which students' uncertainty about the content is especially pronounced. Students' ideas are challenging to elicit, but are (often) productively rooted in their humble intuitions about engineering. Following other scholarship on resources-based views, our emphasis is to identify, recruit, and build upon the productive epistemic resources and representational competencies that learners bring with them to the classroom, rather than discarding their naïve knowledge and competencies. We find that this manifold view of knowledge allows for a more appropriate grainsize of analysis, and seek to identify the activation of small, localized, and highly contextualized cognitive resources (Hammer et al., 2005).

As argued by Elby and Hammer (2010), when a locally coherent set of resources "becomes is activated again and again, it can eventually become sufficiently established to act as a unit." (p. 12). This unit is called an *epistemological frame*. Epistemological frames answer the question "How should I approach knowledge?" (Hammer, et al. 2005, p. 12), or in a moment of teaching, "What is going on here?" (Elby & Hammer, 2010, p. 5). For learners, the epistemological frames through which they perceive their work shape their decision making about what is productive and worthwhile within a particular form of activity. Epistemological frames drive what teachers attend to (Russ & Luna, 2013). This is akin to what Ryan and Bourke (2013) have called reflexive mediation, in which professionals mediate among subjective concerns (e.g., priorities and values) with objective concerns (e.g., standards). Specifically, we are concerned with the following: (1) What broader epistemological frames for leading engineering instruction at the elementary level begin to emerge?, and (2) How do PSTs frame particular (local) engineering tasks as productive for learning?

Method

Data were collected in an introductory engineering for educators course taught in Spring 2019 at a large land-grant university in the northeastern United States. The course focused on the interaction among physical science concepts and engineering design principles. It included three science content modules (structures, simple machines, and electrical circuits), each of which had an associated engineering design project and an exam. In addition, there were problem sets associated with the physics content. A smaller component of the class was a series of six assignments designed to support teachers to think about elementary engineering education (e.g., reviewing lesson planning resources). Completion of the course fulfilled three science credit hours (including lab credit). All 23 students who completed the class elected to participate in the study. All 23 were undergraduate students (19 females and 4 males). Twenty-two students were classified as Pre-major Education, and one had begun the Elementary and Early Childhood B.S., which also leads to a state teaching licensure at the pre-kindergarten through 4th grade (PK-4) levels. Twenty students stated goals to enter the Elementary and Early Childhood major and become teachers at the preschool or elementary level. One student was considering secondary mathematics education. The first author instructed the course. Her scholarship concerns science education and the learning sciences but she has no formal training in engineering.

Throughout the course, the first author kept field notes with memos from class discussions and patterns in student work. Data sources include these field notes and all student products, including photographs, problem sets, and design sketches. Students were asked to respond to a reflective writing prompt in Weeks 1 and 15 regarding how they perceived the content was related to their future practice as teachers. The prompt asked, "How might fundamental knowledge about engineering and physical science become useful in your work with young learners?" To encourage honest and reflective responses, the instructor informed students that they would not be graded for the content of their responses in these reflections (mere completion was sufficient). The analysis began with the student responses to the reflection question, which were coded using open and axial coding (Strauss & Corbin, 1990). To aid in establishing trustworthiness, we triangulated those codes with student work, and considered the processes of change in individual students' approaches to the content of the course, both in written work and their engineered artifacts across the semester.

Data and analysis

Initial codes are shown in Table 1. At the outset of the course, only three students mentioned that greater knowledge about engineering and physics may prepare them to select, modify, or teach lessons about science and engineering in their future. Instead, students wrote generally about the desire to support students' interests in STEM and STEM-related careers (10) and enact instruction that supports student inquiry and agency (12). At the end of the course, students' reflections generally maintain desire to support students' emergent interest in STEM (7) and facilitate student-centered, active learning (12). However, participants' ways of discussing this aim becomes much more specific, with a small shift towards preparation to empathize with students amid a long and sometimes arduous design process (4) and increased connections among the course content and their own abilities to select, plan for, and lead classroom engineering instruction (10).

Table 1: Codes and Counts for Student Responses to Reflection Question

Question: *How might fundamental knowledge about engineering and physical science become useful in your work with young learners?*			
		Week 1 (counts)	Week 15 (counts)
Connections Related to the Preservice Teacher (PST)	Increasing confidence	3	8
	PST's content knowledge	10	14
	PST's social connectedness to people in the course	0	5
	Relevance to PST's everyday life	2	1
	Selecting or planning classroom engineering instruction, PST's potential for creative instructional design	3	10
	Learning about instructional and building materials for elementary engineering	2	2
	"Figure out" own career goals	1	1
Connections Related to Teaching, Students,	Importance of topics for students' (Ss') cognitive development	11	2
	Importance of science and engineering for Ss' fine motor development	1	0
	Student expression of creativity, connections between creativity and physical science	5	3
	Student-centered and active learning	12	12

	Participatory discussions of student work (presentations/whole class reflections)	0	3
	Students' participation in collaborative groups; social connectedness of the students	2	4
	Assessment through observation of collaborative groups	0	1
	Relevance to Ss' everyday life/ "basic skills" for everyday life	6	7
	Integration of other disciplinary subjects (e.g., mathematics)	2	2
	Supporting students' to grow in desire/curiosity for STEM and STEM careers	10	7
	Gender equity in STEM	1	3
	Understanding the hardship/reward of students' design process	0	4

PSTs' design process supports understandings about difficulties within children's design processes

In what follows, we focus on two students (S21 and S4), each who mention understanding the students' design process as a key way that they see their knowledge of engineering and physical science impacting their pedagogical practice. We report excerpts from their reflection and from a design memo about their design of loadbearing bridges during the first module of the course.

Week 1, Reflection	Week 8, Bridge Design Report	Week 15, Reflection
S21: With [background knowledge about physics and engineering] I will be more informed about simple things that go on around me every day. Another reason that knowing about physical sciences will help me in the future is the obvious point that I may be teaching it someday. Although the level of understanding may not need to be very high, the fact that I will know what I am talking about rather than reading it out of a textbook is extremely helpful.	**S21:** We found it **extremely stressful** at times, but we found it **extremely rewarding** when our design worked…. We knew that triangles were effective, but where in the bridge? Is most it important to have stable sides, bottom, or top? All of these were eventually answered… we do value the idea of learning on our own and found it extremely rewarding when we were able to figure out this information.	**S21:** I think that the setup of the course **encourages students to try without the fear of failing, which ultimately allows the students to be open-minded and try things different ways**. For many of the concepts and projects, there is not [one] certain way to do the work, but rather a multitude of possibilities, which allowed us to see others' ideas and work together to create the best possible solution.
S4: …If I could answer some of these questions for children, that could help broaden their personal view of what they know and how the world works. I could include lessons where we dig into how something they may use every day and discover how the individual parts work.	**S4:** The bridge snapped almost upward when it broke, telling us that the forces were pushing against each other (compression). Our bridge held half of the necessary weight without bending, so we were very optimistic. We decided that if we added more support to the middle of the bridge (where the force would be pulling it down), we would have a better chance of being able to hold the full amount of weight.	**S4:** My experiences during this class will be helpful when I am teaching elementary students because I went through the processes that I will be asking them to when I am teaching. **I learned the hardships that come out of designing and creating** the things we did in this class and I feel as if **working through them myself will help me better be able to understand my students or assist them when they face similar issues.**

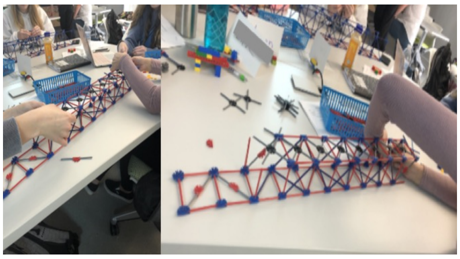

Figure 1. An early iteration of S4's bridge.

S21 shifts from an initial emphasis on content knowledge alone (Week 1) to perceptions of engineering that include aspects of the design process. His reactions are further reflected in a written design memo about a bridge built from micro K'Nex (early iteration of design shown in Figure 1), written in Week 8. S21 experienced the design process in a personal but conflicted way— "extremely stressful" and "extremely rewarding" —and continues to frame his learning about engineering as overcoming fear of failure. S4 shared a similar experience and also articulates how it may influence her teaching practice. Like S21, S4's initial reflection focuses on how engineering topics may be impactful for students.

Unlike S21, S4 discusses crafting student-centered experiences that build on children's own inquiries in her initial (Week 1) response, specifically by learning how everyday objects work. S4 found that her bridge design failed and continued to fail for several sessions. She, along with her three group members frequently worked beyond the scheduled meeting time of the course. There was a shortage of the K'Nex members that were the correct length to conventionally brace the weakest parts of their bridge. S4 relates her experience in the course to her empathy for students and her emergent competencies for leading elementary-aged learners in engineering design processes.

Conclusion and implications

In this paper, we've presented two different types of contexts for thinking about engineering within one course: introductory engineering content and elementary engineering pedagogy. Following Elby and Hammer (2010), the repeat activation of related resources may help in the maturation of epistemological frames and hopefully impact future teaching practice. We show evidence that the content course helped students interface among the complex relationships between their own emerging competencies in the content and their conceptions of teaching and learning in elementary classroom settings. Students' talk and writing shifted from folk notions of elementary engineering as "hands-on" and "engaging" to discussion of how to involve students in multifaceted processes of formulating problems and designing solutions. We have exemplified this shift with students' emergent visions for future practice, as shown in cases of S4's empathy for her own students' in the "hardships" of the engineering design and S21's coming to terms with the experience (and productive value) of uncertainty.

As teachers prepare to enter the profession, having more stable footing for responsiveness to student ideas in science and engineering is invaluable. How did the engineering course shape PSTs' epistemological frames for their own participation in engineering design within the course and in their future teaching practice? The data presented here suggest that the PSTs' (1) participation in introductory engineering practices as novices and (2) reflections about the relevance of the design process to children's learning experiences worked together to support them to frame engineering in productive ways. At the end of the course, students' dominant views of engineering were design-oriented, participatory, and suggested responsiveness to the needs of child designers.

References

Bergman, D. J., & Morphew, J. (2015). Effects of a science content course on elementary preservice teachers' self-efficacy of teaching science. *Journal of College Science Teaching*, *44*(3), 73-81.

Bursal, M., & Paznokas, L. (2006). Mathematics anxiety and preservice elementary teachers' confidence to teach mathematics and science. *School Science and Mathematics*, *106*(4), 173-180.

Cunningham, C. M. (2018). *Engineering in elementary STEM education: Curriculum design, instruction, learning, and assessment*. Teachers College Press.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, *10*(2-3), 105 - 225.

Elby, A., & Hammer, D. (2010). Epistemological resources and framing: A cognitive framework for helping teachers interpret and respond to their students' epistemologies. *Personal epistemology in the classroom: Theory, research, and implications for practice*, *4*(1), 409-434.

Hammer, D., Elby, A., Scherr, R., & Redish, E. (2005). Resources, framing, and transfer. In Mestre, J. (Ed.), *Transfer of learning from a multidisciplinary perspective* (pp. 89 - 119). Greenwich, CT: Information Age Publishing.

Harlow, D. B., Bianchini, J. A., Swanson, L. H., & Dwyer, H. A. (2013). Potential teachers' appropriate and inappropriate application of pedagogical resources in a model-based physics course: A "knowledge in pieces" perspective on teacher learning. *Journal of Research in Science Teaching, 50*(9), 1098-1126.

McCormick, M. E., & Hammer, D. (2016). Stable beginnings in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)*, *6*(1), 4.

National Academy of Engineering and National Research Council. 2009. *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12635.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, *50*(3), 284-314.

Ryan, M., & Bourke, T. (2013). The teacher as reflexive professional: Making visible the excluded discourse in teacher standards. *Discourse: Studies in the cultural politics of education*, *34*(3), 411-423.

Strauss, A., & Corbin, J. M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques.* Thousand Oaks, CA, US: Sage Publications, Inc.