”I understand their frustrations a little bit better.” – Elementary teachers’ affective stances in engineering in an online learning program (FUNDAMENTAL)

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“I understand their frustrations a little bit better.” – Elementary teachers’ perceptions of the impact of meaningful engineering experiences on their epistemic empathy (FUNDAMENTAL)

Introduction & Framework

Teacher preparation in engineering is a focus for research and practice discussions as engineering becomes more ubiquitous in K-12 (e.g., [1], [2]). A range of work has tackled teacher preparation with respect to engineering content, practices and pedagogy. While standards have emerged [3], teacher preparation in engineering education is still a nascent and dynamic area of study. We are particularly interested in the teachers’ own understanding of engineering design practices.

Within teacher education, research has attended to characterizations of K-12 teachers’ stances toward engineering design within their classroom and how teachers’ stances impact students’ experiences [4][5]. In our own work, we saw that teachers, who had been prepared solely by enacting the same student activities as they would use in their classroom, often enacted engineering design as a linear process [6]. However, to date there has been little focus on understanding which professional development approaches are particularly impactful for shifting teacher practices and ideas about engineering. If we look within the broader field of engineering education, there has been significant discussion about what informed engineering designers do (e.g., [7]–[9]) with respect to engineering design practices. Studies have correlated sophistication in design practice to experience in doing engineering [8], [9], suggesting that university-based design projects and real world challenges support engineering students and professionals in transforming their understanding and use of engineering practices.

Based on current research and our own work, we hypothesized that for teachers, as adults with significant experience with mechanisms and materials, practices of engineering design might *seem* more linear because individual elements may not be explicitly necessary for them to complete a challenge. For example, when building a windmill from craft materials, drawing before making may serve little purpose for teachers, as they have seen windmills in different contexts. Likewise, they might not need to test which shapes are sturdy before deciding on a configuration for a bridge, as they have prior experience with triangles or structural building challenges. In another example, teachers might not need to do multiple iterations of prototyping a chair for a teddy bear, as they can quickly and easily envision a functional solution.

Following this reasoning, we conjectured that, to understand the complexities and nuance of engineering design, teachers need to be engaged in doing engineering that challenged them as adults, similar to the types of experiences that have been proposed to shift practice for undergraduate engineering students and engineering professionals [8][9]. Shifting practice and understanding through thoughtful experiences that are “meaningful” to the learners has been discussed within research in science education (e.g., [10]). *Meaningfulness* grounds what happens in instruction with the learner’s sensemaking in both the professional disciplinary and classroom context and foregrounds how the learner experiences the activity. We take this up within engineering to mean that participants experience the need for engineering practices and tools. In contrast to when teachers are enacting a challenge that their young students are doing that might not necessitate planning or iteration – we propose that teachers engage in engineering activities that challenge them as adults. We call this approach *meaningful engineering*.

We explored our conjecture related to meaningful engineering within the Teacher Engineering Education Program (TEEP), our online teacher certification program in engineering. TEEP is an 18-month program where participants take two engineering content courses and two engineering pedagogy courses. The TEEP program separated content and pedagogy courses so that educators could experience learning engineering as adults, independent of their role as teachers.

The graduate level TEEP content courses use LEGO robotics materials to engage teachers in the doing of engineering. In this paper we focus on elementary teacher participants engaged in learning paradigms for programming (Sense-Think-Act) and structures for coding with sensors. The course addressed content related to particular mechanical mechanisms (gears, pulleys, motors) and higher-level engineering design (design process models, tools for evaluating solutions, failure analysis). Throughout the semester, participants do weekly readings on engineering and engage in hands-on design challenges (described in Appendix A). The course culminated with a final project that tasks participants to solve the problem of feeding Agnes's fish while she is away. Figure 1 is an excerpt from the open-ended design brief students receive. The project is scaffolded (Figure 2) with design deliverables (drawings, first prototypes and final prototypes) over the final weeks of the course.

Design Brief: Agnes is retired and lives alone outside of Boston. She has a fish tank with three fish. She often goes away to visit her grandchildren in New Jersey for long weekends. She needs a solution to feed her fish while she is gone.

Constraints:

- Must use your LEGO EV3 kits and at least 1 motor and 1 sensor
- Other materials (craft supplies, Tupperware, etc.) are allowed

Your challenge is to PROTOTYPE a solution. You will need to make assumptions and create a testing environment.

Figure 1: Design brief for final project in first elementary content course in TEEP

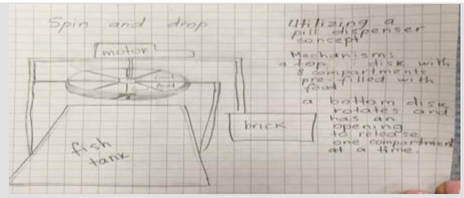
Week	Task	Example of teachers' work
12	Share brainstormed ideas and initial sketches Receive feedback and support from classmates & instructor	
13	Build and share first prototype, showing two elements of functionality Receive feedback and support from classmates & instructor	
15	Present photos and videos showing device functionality, share programming code, and post a reflection on their design process	

Figure 2: Tasks and sample student work from final design project of first elementary content course

Our research questions for exploring this conjecture with TEEP program asked:

1. How did teachers respond to engaging in meaningful engineering for teachers in the TEEP program?
2. What did teachers identify as important things they learned about engineering content and pedagogy?

METHODS

Participants

In this exploratory study, we analyzed the transcriptions of semi-structured interviews of eleven elementary teachers and specialists in the 2017-2018 TEEP program. The group of teachers, 10 females and 1 male, held a broad spectrum of teaching positions, teaching experiences, and prior experience with teaching engineering (Table 1).

Table 1: Eleven elementary research participants backgrounds

Teacher	Years Taught	School Type	Teaching Position	Prior Experience with Engineering
Alma	21	Public	Science specialist, grades 3-5	Extensive
Brad	13	Public	Classroom teacher, grade 3	Minimal
Bryn	10	Public	Gifted and talented teacher, grades 4-8	Extensive
Daphne	11	Public	Classroom teacher, grade 4	Minimal

Denise	16	Public	Library media teacher, grades K-5	Minimal
Jamie	15	Public	STEM Integration Specialist, grades K-8	Extensive
Marlene	2	Private	Science teacher, grades 3-4	Minimal
Margaret	32	Private	Classroom teacher, grade 3	None
Remi	1	Public	Science and social studies teacher, grade 5	Extensive
Shannon	9	Public	Classroom teacher and math specialist, grades 3-4	Minimal
Vanessa	2	Public	ELL Specialist, grades K-5	Extensive

We analyzed interviews that took place immediately following the first content course, in Fall 1 (Figure 1). We focused on their responses to the prompt of "What have been some of the significant things you've learned so far in TEEP?"

Fall 1	Spring 1	Summer 1	Fall 2
Content Course 1	*Pedagogy Course 1*	*Content Course 2*	*Pedagogy Course 2*

Figure 3*: The (BLINDED) online graduate certificate program has a 4-course, teaching-level specific, sequence.*

Participants' responses to the prompt were first selected and sorted for those that attributed their learning to the physical engineering design tasks in the course that were designed for participants to experience as *meaningful engineering* (the course contained other readings and interaction components that participants also attributed learning to). Responses about physical engineering design tasks were then grouped by emergent themes. The first author wrote memos about the themes emerging from the data (Braun & Clarke, 2006) and discussed and refined the themes with the research group.

Findings/Analysis

In our analysis, we found that teachers talked about several different themes related to their understanding of engineering design practices (non-linearity of engineering design, the need for iteration) and engineering as a discipline that were similar to the themes we identified in their written coursework reflections. A new theme that emerged was one we labeled as *Affective Experiences*. In *Affective Experiences*, teachers identified how the experience of doing engineering helped them to understand or empathize their students' experience in doing engineering. Marlene's quote below shows an example of this:

> **"**And then I've been definitely thinking about, and I wrote about how as a teacher, how do I get to the belief that you've learned more from failure than you do from success and how that drive to get it right feels really great. That feeling of 'I did it' is fantastic, but then how do you take what you're learning and the failure and continue to push through and not just give up and be frustrated. Because even for myself it was the third or fourth time that the scoop [on her final project's robotic fish feeder] wasn't going around right, I was like, 'Ugh,' **and I had to walk away from it. And I was having like real fourth grade feelings and I was like, okay, so now I see where they [students] come from**"

Marlene talks about how she values failure and iteration in her classroom but that her own experience designing the robotic fish feeder was frustrating at points, and how feeling and acknowledging that frustration helped her understand her own fourth grade students' experience in similar situations.

The *Affective Experiences* theme emerged in four of the eleven interviews. Within those four responses we identified two patterns related to their experiences in meaningful engineering that participants linked to new understandings of their students.

Table 2: Patterns within Meaningful Engineering & Epistemic Empathy

Participant	Affective Experience	Student Connection
Alma & Marlene	Frustration with building & redesign in engineering	Empathy for students' frustration in the classroom
Brad & Shannon	Frustration or insecurity about using unfamiliar materials or new programming concepts in service of engineering	Empathy for how students approach materials and unknown tasks

Like Marlene, Alma also talked about how she felt frustrated during two projects and how as a result of that "I understand their frustrations a little bit better, of what I've asked them to do before."

Brad and Shannon both talked about how the course's LEGO robotics materials were new to them and how that made them think about how some of their students felt when using novel materials. Brad said "So I kinda was in the disadvantage [being less familiar with materials than other course participants], but I saw it in a weird way as an advantage and saying OK, when I put this out to one of my student's desks, they're looking at it the same way I'm looking at it right now. So that was really cool for me." Similar to Brad, Shannon shared that she often didn't know where to start with particular engineering challenges:

> "Some of the weeks when I was like 'I have no idea to program this, my programs not working', and I would go on a discussion board, and I could actually see some of the other programs and I'm like oh, okay this is what I'm doing wrong and I would be able to go and make that change. **I felt like those students sometimes that we have in our classrooms, that they have no idea where to start and they just want to watch everybody else before they dive in.**"

Like Alma and Marlene, Shannon shares that her own affective experience in the course gave her a shared experience with her students that impacted her perception of her students.

Discussion

This study adds to a growing body of work studying teacher learning in engineering, highlighting a new theme in what teachers might gain from engaging in "doing engineering" themselves. In our previous analysis [6], we have shown how teachers can shift in their understandings of engineering as result of a course that ask them to engage in *meaningful engineering*. Reported shifts included an enhanced understanding of the dynamic and non-linear nature of engineering design, importance of improvement and iteration, social need for engineering, and how problem scoping and materials knowledge drives engineering prototyping. These findings (Table 2) add to our previous work by identifying affective dimensions to teacher learning.

These affective findings, while relatively small in number of cases, are significant for two reasons. First, they suggest that *meaningful engineering* engages teachers in experiencing engineering in different ways. While all of the identified participants had some experience with teaching engineering in their classroom, they still identified their experiences in the courses as consequential. Second, the findings suggest that the challenge of meaningful engineering experiences give teachers analogous affective experiences to their students, and that in recognizing those experiences teachers empathize with their students own affective experiences within engineering.

Teachers developing empathy for their students' affective learning experiences has been introduced in science education literature as *epistemic empathy* – "the act of understanding and appreciating someone's cognitive and emotional experience within an epistemic activity." for students [11]. Jaber, Southerland and Dake differentiate it from general empathy for students and their well-being, in that *epistemic empathy* is directly connected to disciplinary activity, with disciplinary goals foregrounded. They posit that epistemic empathy is significant as it allows teachers to attend to students' emotional well-being, while still considering learn and teaching goals. For example, during a science activity, a teacher may empathize with a student who is struggling to explain an idea like evaporation and may have fears about being wrong or embarrassed. Epistemic empathy supports teachers' instructional moves to make the student comfortable, without taking away the powerful experience of students' sensemaking about the phenomenon.

The idea of *epistemic empathy* seems equally consequential for engineering, where failure and iteration and exploring new materials for design are often necessary for engineering solutions. In parallel to science, we don't want teachers to dismiss student affect or to design learning experiences that prevent affect related to iteration and learning new materials. We want to support educators in helping students to manage affect in engineering much as they learn how to use engineering design practices responsively.

In addition to adding to the body of work on teaching engineering, our work also adds to the overall conversation about epistemic empathy. To date, prior studies have looked to develop epistemic empathy by having K-12 teachers watch videos of students or reflect on events in their classrooms. Currently, emergent work focuses on how epistemic empathy interacts with K-12 teachers' own disciplinary experiences. Our study suggests a connection between teachers having *meaningful engineering* experiences with their development of epistemic empathy that adds to the conversation about productive learning experiences in K-12 teacher preparation in engineering.

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APPENDIX A: Overview of First Elementary Content Course

Week 1:
- Become familiar with course-related technology
- Personal Introductions

Week 2:
- What is Engineering? What do Engineers do?
- LAB: Shopping Bag Redesign Project
- LAB: Lego Free-Build

Week 3:
- Using Different Materials: what are the tradeoffs and how do they manifest?
- LAB: Building Chairs

Week 4:
- What is the difference between science and engineering?
- How do engineers use science?
- LAB: Robot Car

Week 5:
- What is the engineering design process (EDP)?
- What are sensors?
- LAB: Light Sensor and Loop Car
- LAB: Touch Sensor Car

Week 6:
- How do engineers use mathematics?
- LAB: Obstacle Avoidance (Ultrasonic Sensor)

Week 7:
- How do robots use sensors to act intelligently?
- LAB: Line Follower

Week 8:
- How do we analyze, evaluate, and communicate mechanism in engineering?
- How do we productively notice and engage with other engineers' work?
-LAB: WIND-UP CAR EVALUATION

Week 9:
- What are gears for and how do they work?
LAB: Initial Thoughts on Final Design
LAB: Wind Up Car - Take Apart

Week 10:

- What are different kinds of gears?
- How do you mathematically calculate gear rations?

LAB: Penny Lifter

Week 11:
- How can gears be used to change direction and provide more or less torque?
- What is a nested loop in programming?

LAB: Robotic Mixer

Week 12:
- What kind of planning is necessary in engineering?
- Ways to use Decision Matrix

LAB: Final Project (Robotic Fish Feeder) proposal & sketches

Week 13:
- What is an engineering prototype?
-Providing critique for engineering design projects

LAB: First Prototype

Week 14:
LAB: Final Project Check-in

Week 15:
Final Project Report, Documentation and Videos.
Final Course Reflection on Engineering Design.