# Board 123: Engaging Teachers in Authentic Engineering Design Tasks to Refine their Disciplinary Understandings (Work In Progress)

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# Exploring how engaging in-service teachers in authentic engineering design tasks refine their understanding of engineering design (Work In Progress)

## Introduction and Background

As K-12 engineering education becomes more ubiquitous in the U.S [1, 2], there is increased attention on preparing teachers to lead engineering learning experiences in their classrooms. With the relative newness of engineering in the K-12 level, it is unsurprising that a majority of K-12 teachers report not feeling prepared to teach engineering [3, 4]. While the field has had nearly two decades of efforts at preparing teachers in engineering [e.g. 5, 6, 7], design principles and guidelines are just beginning to emerge for teacher education in engineering. Most teacher education initiatives emphasize familiarizing teachers with engineering concepts and helping them implement given curriculum [4, 8].

While there is a general agreement in the literature that elementary teachers need to gain more familiarity with engineering and the engineering design process [e.g. 8, 9], there is a need to better specify what exactly is important for teachers to learn. For instance, while teachers should be familiar with the steps of an EDP, research suggests that this is not sufficient to productively facilitate students' engineering. In a prior project [10], we documented how teachers' attention to steps of an EDP can be a barrier for their meaningful engagement with their students' engineering. When a teacher focused solely on students progressing through each step of the EDP, she missed productive aspects of students' thinking that deviated from the linear process she had planned [11]. These findings motivated us to consider how to support teachers in seeing the EDP not as an exact roadmap, but a set of tools that students can use to develop their designs. Part of this work involves helping teachers develop an understanding of the process as fluid and dynamic, reflecting the complex practice exhibited by engineering practitioners [12-14].

The question then is how to support teachers in developing an understanding of the complexities of the EDP. Recent work [8, 15] calls for teachers to be engaged in the *"doing"* of engineering to facilitate this learning. However, to date, there is limited information about what those engineering experiences for educators should look like. Many programs, due to limited time and constrained resources, engage teachers in the same engineering activities they will enact with their students. While this approach is useful so that teachers can gain familiarity with curriculum and anticipate students' ideas and approaches, there is reason to believe that these experiences may not be authentic enough to support teachers to develop new understandings of the EDP. Given teachers' greater familiarity with materials and designed solutions as adults, these tasks may not be challenging enough; teachers may be able to develop solutions using a more linear manner, reinforcing this linear perspective on the EDP. Therefore, we conjecture that engaging teachers in more rigorous engineering challenges designed for adult engineering novices, would more readily support teachers developing understandings of the ways in which professional engineers move through the process.

In this paper, we explore this conjecture in the context of an online graduate course for in-service teachers in engineering education. We share preliminary analysis of eleven elementary teachers' reflections on the changes in their understanding of engineering design after engaging in authentic engineering design challenges developed for adult learners. We ask:

1) What changes do teachers express in their understanding of the design process after participating in this course? What are differences in teachers' representations of the engineering design process from the start and end of the course?
2) How do these changes correspond to their prior experiences with engineering?

Description of Teacher Engineering Education Program (TEEP) Content Course 1

We explored these questions in a design-based research study in a new asynchronous online graduate program at Tufts University's Center for Engineering Education and Outreach (CEEO). In this program, teachers take four graduate-level courses over 18 months. Two of these courses focus on engineering content, while the other two focus on engineering pedagogy.

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

*Figure 1: The TEEP online graduate certificate program has a 4-course, teaching-level specific, sequence,*

Content course 1 for elementary teachers is entitled *Engineering and Science for Elementary School Educators I*. It focuses on teachers learning about the practice of engineering, understanding concepts central to engineering, and engaging in authentic design tasks. Teachers read seminal papers on professional engineering, including works from, Clive Dym, Natasha McCarthy, Donald Norman  and Henry Petroski. Teachers also watch videos presenting examples of the engineering design, including the IDEO shopping cart video, a TED talk on the leveraged freedom wheel chair, and Dean Kamen's work building a prosthetic arm. The course teaches conceptual ideas central to engineering, including computational thinking, basic programming structures, sensors, simple machines, and engineering design process skills. Teachers post weekly written reflections on the readings and complete assignments related to the core concepts.

For the lab portion of the course, participants are provided with a kit of LEGO EV3 Robotic materials and supplemental materials to engage in weekly hands-on engineering design challenges, including designing a simple chair for a stuffed animal, a device that could lift a roll of pennies, and a robotic car. The course culminates in participants designing, building and documenting a solution to an ill-defined problem: developing an automatic fish feeder that can deposit food when owners are away on vacation. This final task is scaffolded over four weeks (Figure 1) and is designed to leverage expertise teachers developed related to structures, gearing, simple machines, and coding. For all labs, teachers post photos and videos of their designs, along with written reflections on their process.

## Research Study

Participants

In this study we analyzed the coursework of eleven elementary teachers and specialists in the 2017-2018 program.  By focusing the qualitative analysis on a single cohort, we are able to share more rich and nuanced understandings around teachers' emerging practices in engineering education [16]. These teachers, 10 females and 1 male, had 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 |

All but one teacher had some engineering experience prior to starting the program. Teachers labeled as minimal had tried implementing engineering in their classroom, but had not engaged in coursework or formal professional development related to engineering. Teachers labeled as extensive had done formal coursework or professional development and had been teaching engineering in their classroom, often supported by or in collaboration with university programs.

Data & Analysis

This paper looks at teachers' reflections in their final assignment: designing an automatic fish feeder. For this paper, we focused on teachers' response to the prompt: "*Reflect on how your ideas about engineering design have evolved from the start of the course to after you have completed your final project*." Teachers were also asked to create a graphical representation of their design process, comparing to the representation they posted early in the course.

We first read through all participants' written reflections and viewed their graphical representations of their design process at start and end of the course. For each reflection, we segmented teachers' text to parse potential changes in their understanding of the EDP. Each participant reflected on at least one and as many as three aspects of engineering that they viewed differently after engaging in the course. Using open coding [17] of these segments, we identified four patterns across the teachers' responses. One researcher compiled all the segments for each pattern and the team met to discuss and refine descriptions of these themes. We then checked for consistency of these themes in teachers' graphical representations.

Findings

In Table 2 we present four themes identified from our coding of teachers' representations of the engineering design process and their reflections on changes in their understanding of the design process over the course of the program.

*Table 2: Emergent themes in teacher reflections in their changing understanding of engineering design*

| Theme | Description | Example |
|---|---|---|
| Dynamic nature of engineering design | Change noted understanding of engineering design from a linear model of engineering to a more dynamic one; or unexpected interplay and movement between multiple aspects of engineering design | *"My idea of the Engineering Design Process has also been on a journey. It was hard not to see the design process working in a specific order every time. When I designed my EDP representation in week 5 I knew that it wouldn't flow in a perfect circle and there would be some feedback and redesign, but I don't think I realized quite how much I would be moving around"* |
| Importance of improvement and iteration | Change noted around the role of improvement and iteration in engineering design | *"At the beginning of the course I had the belief that when building something to solve a design problem the final product would be the end, that would be the solution. Throughout this course, I have learned the importance of prototyping and how even when you think you've found a solution there can always be more changes made."* |
| Social nature of engineering | Change noted in understanding of why teamwork and feedback from others play a significant role in engineering design | *"I did struggle with idea creation and working on new ideas to improve my designs. I think if I had a partner or two in this process, that would not have been an issue at all…. I needed someone to bounce ideas off of as I was building, not once I was done… So as a result of this coursework, I am now convinced in the power of teamwork for the engineering design process!"* |
| Problem scoping and materials exploration | Change in where to spend time in the engineering design process | *"In reflecting upon this project, I am now a firm believer in the necessity to put in the adequate time to research the problem and understand the materials. designs that could actually function and meet and the criteria of the challenge."* |

In Table 3, we show how teachers' responses were distributed across the four categories. Nearly half of the teachers expressed changes in their understanding of the *dynamic nature of engineering* and the *importance of improvement and iteration*, while only a couple teachers reflected on problem-scoping or the social nature of engineering design. Three of the six teachers who didn't discuss the dynamic nature of engineering design had already indicated, in an earlier assignment for the course, that they saw the EDP as flexible and dynamic.

*Table 3: Distribution of teachers' responses amongst themes*

| Theme | Number of teachers | Teachers (Prior engineering experience) |
|---|---|---|
| Dynamic nature of engineering design | 5 | Denise (Minimal)<br>Jamie (Extensive)<br>Margaret (None)<br>Alma (Extensive)<br>Shannon (Minimal) |
| Importance of improvement and iteration | 5 | Brad (Minimal)<br>Bryn (Extensive)<br>Marlene (Minimal)<br>Jamie (Extensive)<br>Vanessa (Extensive)<br>Regan (Extensive) |
| Social nature of engineering | 2 | Daphne (Minimal) |

| | | |
|---|---|---|
| | | Vanessa (Extensive) |
| Time spent on problem scoping and materials exploration | 1 | Regan (Extensive) |

## Discussion

We observed that teachers in our program exhibited changes in their understandings of the EDP, even those with extensive prior engineering experiences. Furthermore, these changes indicate progress toward understanding the sophisticated design processes that characterize the work of professional engineers [12-14], including greater appreciation of the importance of problem-scoping, iteration, and the social nature of engineering.

Notably, one of our goals for engaging teachers in rigorous and authentic design tasks is to support them to see the EDP as fluid and dynamic. Our findings suggest that almost half of the teachers—including those new to and experienced in teaching engineering—expressed changes in how they understood the nature of the EDP. For instance, Alma, a long-time elementary science specialist, had taught engineering in her classroom for several years and attended multiple engineering professional developments. At the start of the course, however, she had presented a depiction of the design process as a set of linear steps. Her final representation of her design process with the fish feeder challenge showed how she "*was jumping from one stage to the next*." She reflected that by doing this project, she "*changed my mind of how the process actually works. It can skip from one step to another, go backwards, go forward, and so forth*."

## Implications & Future Directions

A central objective of our research is to refine and implement design principles for preparing teachers to teach engineering. Others have pointed to the need for teachers to engage in engineering design themselves; teachers' epistemic understandings of a discipline shape how they plan and implement disciplinary activities [18]. While other professional development programs have engaged teachers in the same design tasks that their students will tackle, our work looks at the outcomes of teachers' engaging in rigorous engineering tasks designed for adult learners. Our findings show teachers expressing more sophisticated understandings of non-linear design, iteration, teamwork, and initial problem scoping; these are similar to findings from research on differences between beginning and advanced undergraduate students [12, 13]. This suggests that the experience of having an engineering challenge designed for an adult learner can contribute to teachers' understandings in meaningful ways.

Future directions will explore how these experiences impact teachers' pedagogical practice. We acknowledge that this study took place in a graduate course focused solely on teachers learning about engineering design. This leaves questions for professional development with tighter time constraints on how to balance familiarizing teachers with the design curricula they will teach and deepening their understanding of engineering design through more challenging tasks. We also note the variability among our teachers, both in their prior experiences and in what they gained from the course. So far, much of the literature has treated elementary teachers as a homogeneous group with little experience with engineering. Our findings motivate challenging this assumption and studying more carefully the variability in teachers' experiences and progress, including through detailed case studies to understand the contextual dynamics in teachers' learning.

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