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Less is More: Balancing Tradeoffs in an Engineering Design Task During a Teacher Workshop

Abstract: Despite the recent emphasis on the importance of K-12 students engaging in engineering content and practices, there has been little research done about how teachers learn engineering practices through teacher workshops and even less on how they utilize those experiences to teach engineering in their classes. Using methods of interactional ethnography, we analyzed data from an online teacher workshop in which elementary teachers engineered solutions to a multi-criteria problem in which balancing tradeoffs was a key practice. We found that teachers tended to focus on one criteria rather than both and lacked strategies to consider balancing these tradeoffs. We also found that a second iteration afforded all groups to demonstrate learning through improvement. Implications are discussed related to the importance of a focus on balancing tradeoffs in teacher learning and on pedagogy of engineering projects.

Engineering practices in Elementary Science Settings

Using engineering practices to teach K-12 science concepts is a relatively new paradigm (NRC, 2012) but offers many potential benefits as reviewed by Cunningham and Carlsen (2014), such as enhanced motivation to learn science, cognitive gains resulting from iteration (Capobianco, 2011), and enhanced problem-solving skills. Cunningham & Carlsen (2014) also advocated better understanding of how the practices manifest differently in science and engineering. A review of studies about engineering led Cunningham and Kelly (2017) to propose sixteen *epistemic practices of engineering* that are used to propose, communicate, assess, and legitimize knowledge. Among these practices are persisting and learning from failure, envisioning multiple solutions, and **making trade-offs between criteria and constraints** (Cunningham and Kelly, 2017).

Teachers trained before the *Framework for K-12 Science Education* (NRC, 2012) have no engineering experience, so they require professional learning opportunities. Particularly in engineering, it is recommended that teachers first experience design activities as a learner (i.e. "the student hat") and then have time to reflect on the problems and opportunities teaching it may present (i.e. "the teacher hat") (Sargianis et al., 2012). Changes in teacher practice have been demonstrated when science professional development has been focused on pedagogy (Enderle et al., 2014). Increases in teachers' learning about nature of science, self-efficacy for teaching and improvements in teaching have also been shown when teachers engage in the science practices (Sadler et al., 2010). However, teacher learning of the practices of engineers has so far been understudied.

Theoretical Framework

We approach this study with a sociocultural understanding of classroom work. It is guided by empirical studies of professional scientists and engineers. We also view the teacher learning through the lens of professional vision, where they develop their ability to teach through interactions with instructors and as they get practice in the classroom.

Studies looking closely at the professional practice of STEM professionals (i.e. "science studies") give us insight into the ways in which disciplinary experts create knowledge. These epistemic practices are constructed socially, are situated in activity, rely on prior discourse and/or artifacts, and matter to what counts as knowledge (Cunningham & Kelly, 2017). Teacher learning is also sociocultural as they develop a professional vision. Goodwin (2015) describes how members of a profession learn discursive practices by observing phenomenon in a specific context, then marking or highlighting the specific aspects that are salient and producing representations of these practices. In learning to teach, teachers must first notice what is important in a teaching situation and understand why it is important. Particularly as these teachers learn new content and practices, they must consider these interactions in classroom environments and reflect on them as they gain experience teaching. Our r**esearch question was,** How and in what ways did the teachers collectively **balance the trade-offs between criteria and constraints of a multi-criteria engineering problem**?

Methods

This is the first study of a larger funded project that seeks to understand how teachers from rural school districts learn about engineering through professional learning opportunities and how they utilize local funds of knowledge to help their students make connections between their own lives and engineering. For this study, four pairs of teachers from three different buildings within two small, rural school districts in the mid-Atlantic region (~80 students per grade level) were observed engaging in engineering practices during one four-hour session of a 16 hour long professional development series. These teachers were selected for the study because they attended the school district in which they now teach, have at least 5 years' experience in teaching elementary school, and had not previously taught engineering.

Due to the COVID-19 pandemic, the workshops were changed from two days in-person to four remote, half-day sessions covering the same topics. The teachers were in pairs in a school conference room with the materials they needed to construct and test their prototypes. However, the workshop was conducted over Zoom, using Google Classroom for distributing the course materials (other than the physical material, which were delivered) and for collecting evaluation data, photos, and videos from the teachers. Our data collection and analysis are described below, but can be read in greater detail (Johnson, 2021).

On Day 1, teachers engaged in an activity called, "Perspiring Penguins" (Schnittka & Bell, 2010) to introduce them to engineering practices. The teachers designed an enclosure given a variety of materials to protect a penguin ice cube from mass loss during a five-minute exposure to a heat box, attempting to **minimize cost** and **minimize percentage of mass (of the penguin ice cube) lost**. The materials that can be more easily used to protect the penguin cost more money. Trying to <u>minimize both cost and mass loss are in direct conflict and require balancing tradeoffs</u>. The cost and percent mass loss were graphed, and teachers went through a second design iteration after discussing how to improve their designs. They then reflected on the steps they took to design the best enclosure possible through discussion and in an engineering journal given the criteria and constraints to consider engineering practices.

We chose to use interactional ethnography (IE) as an approach to study our research question. IE is an approach that borrows from sociolinguistics, cultural anthropology, ethnomethodology, and critical discourse analysis and is used to study cultures-in-the-making to consider the use of discourse, and actions in the co-construction of the participants' reality (Kelly & Green, 2019). This is useful in addressing socially situated talk and action, and is also a systematic approach to observational data collection that enables the analysis of locally defined and enacted roles and responsibilities that are difficult to identify using experiments, pre/post, or other techniques (Watkins et al., 2014).

To analyze, we made event maps (Kelly et al, 2001; Author, 2019) to understand the overall activity of the teachers and to identify episodes for more detailed analysis. Then transcripts were compiled by using the transcription capabilities of Zoom and YouTube and then cleaning the word-by-word transcripts by fixing mistakes and assigning speakers to the lines of text. Using the event maps to identify the interactions of interest, we then compared the interactions between the four groups to find patterns and differences. As participant observers, we got to understand the norms of the groups and typical interactions, and using audio-visual recordings, we were able to reduce the dependence on premature interpretation and reducing the importance of the observer. Discourse analysis of this type is useful for not only generalizing classes of phenomena, but also about the unique properties of individual instances (Lemke, 1998). A more detailed description of methodology can be found (Author, 2019).

Findings

Based on the interactions we analyzed relating to balancing trade-offs, we argue two potentially important claims.

1. In the first iteration, none of the groups demonstrated strategies for, or an emphasis on balancing tradeoffs, as they focused either on cost or performance, but not both.
2. In the second iteration, they were able to compare their designs to others, and all demonstrated improvement through a focus on balancing tradeoffs between criteria and constraints.

Designing an enclosure for an ice cube penguin that prevents melting but minimizes cost is fundamentally at odds. We were interested in how the teachers approached this challenge and which strategies they used to balance these competing criteria. During the initial design, the four groups exhibited three distinct approaches. Nikki and Heather focused almost exclusively on keeping cost as low as possible. They decided they only wanted to use a reflective "roof" to protect the ice. They tested each of the materials to see which would be the most effective at reflecting the incoming radiation from the heat lamps. After comparing aluminum foil and mylar, they decided to compare the relative value of adding a second layer of foil. In this interaction with the facilitator (Walter), Nikki emphasizes this point:

24:11 – Heather: So one liner is 125 [dollars] and two for 250 [dollars]. So if one layer is best, that's what we want to go with.

After testing, they determined that there was minimal value to a second layer and used one layer for a total of $125.

27:44 – Walter (facilitator): Alright, so you're going with a pretty minimal design trying to benefit most on cost, right? And that was based on the evidence you collected?
27:54 – Nikki – Yes. Less is more.
27:56 – Walter – Less is more in your test. Okay.

However, in the group from the other school in the same district, Jared and Bea emphasized the criteria of preventing the penguin from melting. Their design cost $700 (compared to the first group's cost of $125).

35:45 – Jared – You want a piece on the box. Something on the bottom because that felt that's in there is going to be hot and we're going to set it [the device] on it [the felt]. So you don't want a piece of foam or something on the bottom. Yeah, maybe this is going to be pricey. We're going to be expensive, but we're going to save our penguin!

The other two groups focused more on function than Nikki and Heather, but more on minimizing cost than Bea and Jared. In fact, an interesting conversation between Paris and her facilitator Wendy arose about the relative cost of their device. (Note: It is important to keep in mind that there was no maximum cost of the device, and the groups were in different locations so they were unable to compare their costs.)

46:55 – Paris – We're expensive. Yeah. 192[$] Okay, so we were. We just had to measure everything and calculate everything out and we're expensive!
47:07 – Wendy (facilitator) – It's ok, sounds good. I don't know. You'll like compare your costs versus how much your penguin lives and you'll see that there's like a balance and then you'll try to improve your balance when you get to the next iteration, so it's all good.

After testing the four initial prototypes and plotting them on a scatterplot (Fig 1), groups were given the opportunity to improve their design. Three of the groups focused on finding ways to decrease the cost of their original design without sacrificing much in its ability to save the penguin. Group 2 from Athens focused on ways to decrease the cost by identifying expensive materials while still providing insulation for the ice cube. Jared described the process:

56:50 – Jared – So, um we're going to try to eliminate the things that we think probably were not as effective, but also the things that were expensive. We lined the bottle on the bottom with the cotton balls. We put 10 cotton balls in the bottom to try to keep some of that heat from coming up. Uh, but they're 30 dollars a piece so we ten of those so that's three hundred dollars, so if we can get rid of a few cotton balls maybe, and maybe make our base that [the penguin] is sitting on a little smaller that could decrease our cost.

Figure 1 is a graph showing the changes for each of the four groups. With a multi-criteria problem like this with even emphasis placed on both cost and percent loss, improvement is shown by any movement that decreases the distance to the origin of the graph (i.e., $0 and 0% is the theoretical best score). All four groups improved, although Athens2 improved the least. The arrows point from the first iteration to the second.

Conclusions and Implications

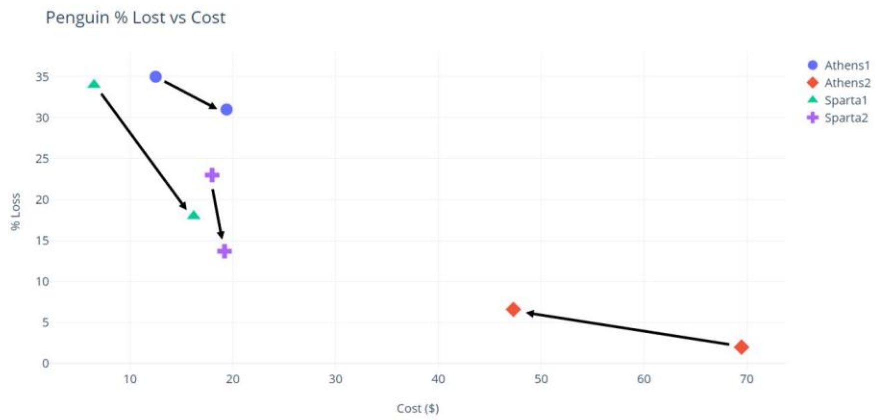
Our findings suggest that without an emphasis on and strategies for balancing tradeoffs in teacher workshops, both teachers and their students will miss a key practice of engineers (Cunningham & Kelly, 2017; Madhavan, 2015). Three of the four teacher groups focused on cost, and three of those groups thought their designs were "expensive" because they did not know what the other groups spent and were not given a maximum cost. However, when given the opportunity to improve, each of the groups' designs better balanced the tradeoffs, a demonstration of learning. This strengthens the argument that learning can be demonstrated through improvement in engineering (Capobianco, et al, 2011; Author, 2019), and that this learning should be assessed because most engineering education projects do not provide reliable evidence of learning (Svihla & Petrosino, 2008)

Among the many engineering practices outlined by Cunningham and Kelly (2017), the idea of balancing tradeoffs is among the most consequential from a pedagogical standpoint. As opposed to scientific inquiry, where the goal is progress toward "truth" (Cunningham & Carlsen, 2014), the contextual nature of engineering design means that there is not one correct answer. Further, the teacher or curriculum designer can completely change the activity by altering the criteria/constraints. Performance can be weighted more heavily than cost. Cost can be limited by a maximum amount in which students might use extraneous materials as long as they don't reach that maximum, but cost can also be minimized. However, to be able to lead engineering activities in elementary settings, teachers need to first experience this practice, reflect on it as a teacher, and develop strategies to support student learning

(Sargianis et al., 2012). Our next analyses will investigate closely these workshop teachers as they teach engineering and help their students navigate the engineering practices like balancing tradeoffs.

Figure 1

Each group improved in the second iteration because the points are closer to the graph's origin



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