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A Balancing Act: Elementary Teachers and their Students Balancing Trade-offs in Engineering Design Projects (Fundamental)

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Introduction

Young learners naturally do engineering as they play and solve problems in their daily lives. But until recently, children have not been encouraged to do engineering design in schools. In the United States, the *Framework for K-12 Science Education* changed this perspective and promoted the inclusion of engineering in science classroom settings for elementary and secondary students [1] Also unique to the most recent science education reforms in the United States is the notion of engaging students in the *practices* of experts as a way to learn disciplinary content.

The *Framework* and *Next Generation Science Standards* identify eight knowledge creating ("epistemic") practices of scientists and engineers, only two of which are unique to engineering (defining problems and designing solutions)[1], [2]. However, engineering is different in many ways when compared to science, and those differences in the disciplinary practices should be recognized and emphasized [3]. A review of the literature identified sixteen practices of engineers that were both unique to engineering and relevant to K-12 teaching [4]. Of particular interest to our group has been *persisting and improving from failure* [5], *assessing implication of solutions*, and *building and using models* [6]. Recently, we have become particularly interested in the ways groups of students and teachers approach *balancing tradeoffs between criteria and constraints* in multi-objective problems [33].

Few teachers have experience learning engineering [7], and even fewer with teaching engineering through engaging their students in epistemic practices while solving multi-objective problems through multiple iterations of design. For teachers, especially those who teach younger learners, to be able to be effective in teaching engineering, they will require professional learning opportunities. It is important for teachers in these workshops to: 1) participate in hands-on, active learning; 2) participate as learners first; 3) have facilitators who model effective pedagogical strategies; 4) establish foundational knowledge like “what is technology” and “what is engineering;” and, 5) iteratively wear the “student hat” (experience first as a learner) and “teacher hat” (reflect on the challenges and opportunities in teaching the unit) [8]. It has been well-established that teacher learning experiences should be job-embedded and content-focused [9], [10]. It is also important to focus the trainings on how to teach specific curricula rather than on general pedagogy skills (i.e. learning styles)[11].

The goal of virtually all teacher professional development programs is to improve student outcomes by helping teachers to be able to teach better. However, measuring these improved outcomes is challenging, and establishing causation between these outcomes and the training is extremely difficult. Of those studies interested in changes in teacher outcomes, some rely on self-reported changes (e.g., [12]). Other have measured increases in engineering-related content knowledge like science or mathematics [13], [14]. But few (if any) studies look closely at teachers while they are acting as learners and then follow them into the classroom to look closely as them as they teach the same curriculum they just learned.

Theoretical Framework

We approach this work through two theoretical lenses. Engineering studies are the investigations about the professional practice of engineers to better understand how they create knowledge. These “epistemic practices” [4], [15] are theoretically tied to the practices and/or habits of mind of engineers and related to the activities students do when doing classroom engineering. The epistemic practices are socially constructed, situated in activity, rely on prior discourse and artifacts, and are consequential to what “counts” as knowledge [15]. We view the work of the student and teachers doing engineering as doing their best understanding of high-quality work

[16], and their interactions are important in understanding how and why they do and say the things they do in accomplishing their goals [17].

Consistent with our sociocultural view, we view our work through the lens of sociomaterialism, where the materials used in engineering as important participants in the social discourse [18]. And the classroom engineering should also be understood to be sociomaterial bricolage [17], because they are limited by the materials they have access, so as *bricoleurs*, they make do with the materials they have [19]. So the people and the materials are both significant and should be studied together [20].

Study Setting

PERSIST in Engineering is a project that seeks to make recommendations about teacher professional development and pedagogy that are best suited for engineering in rural elementary schools. To do that, we are investigating how teachers learn about engineering through formal professional learning workshops and then watching closely as a subset of those teachers implement engineering design units in their classes.

Bea and Jared - This study is a pilot of our first investigation that takes an ethnographic approach to better learn how teachers who recently learned about engineering teach engineering to their students. We focus specifically on two teachers who teach the same grade in the same school. Bea and Jared also worked in the same group. We chose to focus this study on Bea and Jared because they were the only two teachers in the cohort who were able to implement the engineering unit in their class. We investigated how they learned engineering in a workshop and then how they taught that unit in their 4th grade classrooms.

Setting 1 – The Teacher Workshop

A workshop for eight teachers was held virtually over four half days. Four pairs of teachers attended from their respective schools. Materials were sent to them ahead of time. Two school districts were chose based on their geographic location, their high percentage of students receiving free or reduced lunch prices, and high percentage of students who are potential first-generation college graduates. Teachers were selected to participate only if they had more than five years of teaching experience, attended the same district in which they now teach, and had never taught engineering before.

Table 1-A description of the teachers attending the workshop series

	Teacher Name	**Grade Level**	**Years' Experience**	**School District**
Group 1	Nikki	4	7	Athens
	Heather	4	6	Athens
Group 2	Bea	4	12	Athens
	Jared	4	13	Athens
Group 3	Christina	5	21	Sparta
	Juan	5	21	Sparta
Group 4	Paris	5	10	Sparta
	Tony	6	15	Sparta

Originally planned as a two-day in-person workshop, the resulting workshop was a four-part series of half-day, synchronous meetings with eight rural teachers from three schools in rural areas in the Mid-Atlantic region. All participating teachers had attended the same school in which they teach, have greater than five years of classroom experience, teach about the environment and ecology in their science curriculum, and have never learned about or taught engineering before. The teachers were situated in 4 pairs of teachers who teach in the same grade at the same school. During the workshop, each pair was physically located within their schools in private conference rooms wearing masks and the workshop was facilitated by the instructors via Zoom. Materials needed to participate in the hands-on designs were packaged into kits and delivered to each school. The overall objectives were to introduce teachers to engineering and engineering practices through participation in design and reflection activities as a "student" engaged in engineering as well as time as a teacher to reflect on teaching the activities with their students.

Day 1 introduced teachers to the concept that a technology can be an object, system, or process that solves a problem or makes life easier and that engineers design or improve technologies. Then, teachers participated in the activity called "Perspiring Penguins" [21]. In it, teachers designed a habitat using materials given to them for a penguin (ice cube) to survive in a Phoenix Zoo (heat box), attempting to minimize both cost and the percentage of mass loss during the five-minute exposure. We reflected on the ways they engineered by identifying the NGSS [2] and epistemic practices of engineering [4] used, and discussed ways to assess students' engagement in the practices using a continuum based on the NGSS practices [22] adapted to engineering. The teachers also watched video of teachers and students engineering in the classroom and identified practices they observed.

On Day 2, teachers identified several examples of engineering they encounter in their lives. Photos provided by the participants led to discussions about why it was an example of technology and how effective it might be to use as examples with their students [23]. Then, using the engineering design project from Day 1 as well as classroom video, teachers identified and discussed the different types of failure and their consequences [5]. They also used an analytic rubric [6] to quantitatively assess improvement and reflected on the needs to use this approach in the classroom.

During days 3 and 4, teachers piloted a new curricular unit, “The Problem with Plastics,” [24] as students and reflected on each of the eight lessons as teachers, including which of the 16 epistemic practices [4] were prominent. Significant time was included to discuss logistics of working through the lessons with students and to answer any questions they have before implementing the unit in their classes. Table 1 summarizes the workshop agendas.

Table 2- Workshop series goals and activities

Day	Learning Goals	Activities
1	Describe features of technologies Engage in an engineering project Reflect on engineering practices they used Observe and reflect on students and teachers engaged in engineering practices	“Tech in a bag” “Perspiring penguins” Engineering practice rubric, epistemic practices of engineering Classroom video
2	Identify and reflect on examples of engineering in their area Consider the role of failure and improvement in engineering Describe the role of teacher feedback in classroom engineering	Photodocumentation Classroom video Classroom video
3	Experience first half of environmental engineering unit as a “student” Reflect on first half of environmental engineering unit as a teacher Make connections between the unit and local ecosystems, trash/recycling, and pollution	“Engineering Plastic Filters” Unit
4	Experience second half of environmental engineering unit as a “student” Reflect on second half of environmental engineering unit as a teacher Make connections between the unit and local ecosystems, trash/recycling, and pollution	“Engineering Plastic Filters” Unit

Setting 2 – Bea and Jared’s classrooms

Bea and Jared have 12 and 13 years of elementary classroom teaching experience. Athens School District (pseudonym used) is in a rural mid-Atlantic town with a population of approximately 3,500 people. They both attended Athens School District and prior to this study had never taught engineering.

Description of "Engineering Plastic Filters" Unit

This unit is a part of a collection of elementary-focused curriculum collection from Youth Engineering Solutions. Each of their units focus on producing equitable educational in four ways. First, they socially engage the students in engineering by situating engineering in real-world context, introducing multiple perspectives and possible impacts of technology, and by connecting engineering to students' family, community, and cultures. Second, units engage students in authentic engineering practices. Key to this element is to ensure designs have multiple solutions, cultivate collaboration and teamwork, and scaffold students through persisting, risk-taking, and productive failure. Third, the kits utilize asset-based pedagogies to support students. Each unit leverages students' prior knowledge, sets aside time to ensure students develop familiarity with materials, tasks, and terminology. Last, the curriculum seeks to have students develop their engineering identity by using low-cost materials (so designs could continue at home), by providing role models with diverse demographic characteristics, and by fostering students' engineering identities and mindsets.

The *Engineering Plastic Filters*, like all YES for Elementary units is broken into eight units. A brief description can be found in Table 3.

Table 3-A description of the goals and guiding questions of the Engineering Plastic Filters unit

Unit	Learning Goals	Guiding Questions
1	Students learn that the water in Mobile Bay is polluted with plastics. In order to help clean up the Bay, students learn how various members of	What is the problem in Mobile Bay and how does it affect

	the community are unequally harmed by plastic pollution and consider how this will inform their solution.	different groups in the community?
2	Students learn how plastics break down in the ocean over time and how different sized pieces of plastic in the ocean affect the wildlife living there. Using a set of illustrated information cards, students identify, sort, and review how plastic pollution negatively affects living things in the ocean.	What happens to plastic waste in the ocean and how does it affect the animals living there?
3	Students learn about how plastics are used and how plastic pollutants get into the ocean. Students consider the benefits of plastic over other materials as they realize many of the items they use every day contain plastic. Students watch a video of a plastic bag moving "in the wild" to learn how plastic is carried by wind, water, animals, and people to different areas of an environment, including into the ocean.	How and why do people use things made of plastic? How does macroplastic waste get into the ocean?
4	Students are introduced to the model plastic pollutants and consider how these pieces move in the model bay and river. Students establish criteria for a successful design and consider the ways they will be limited. In their design groups, students examine how materials for their filters behave in water.	What does our plastic filter need to do? What properties of various materials make them useful in a plastic filter design?
5	Students are introduced to the scoring criteria that they will use to evaluate their plastic filters. Each student imagines two designs independently and works in their design groups to collaboratively plan one design for a low-cost plastic filter.	How can we use what we have learned to imagine and plan a plastic filter?
6	Students then follow their plans and use collaborative skills to create their own solution to the problem. They evaluate their plastic filters using the scoring system and begin to assess which areas of their design work well and which need improvement.Working in a group to design a solution to the problem gives students the opportunity to apply all they have learned and develop their social skills.	How can we create and test our plastic filter?
7	Students analyze their test results from the previous lesson to identify areas where they can Flip the Failure. They work collaboratively to imagine, plan, create, and test a plastic filter that will better meet the community's needs.	How can we engineer improvements to our plastic filter?
8	Groups share their designs with their peers by participating in a gallery walk and reflect on the impacts of their plastic filter designs on the Mobile Bay community and beyond. Students also learn more about the field of engineering they have engaged in throughout this unit—environmental engineering. The unit culminates with students reflecting on their growth as engineers.	What are the impacts of our plastic filter on the Mobile Bay community and beyond?

Description of the Designed Technology and How it is Assessed

In lessons 4-8, students design a floating filter to capture plastic pollution in a model bay. In the model, after designs are in place, students pour a mixture of water and plastic down a "river" and count how many of the 30 pieces of plastic are caught.

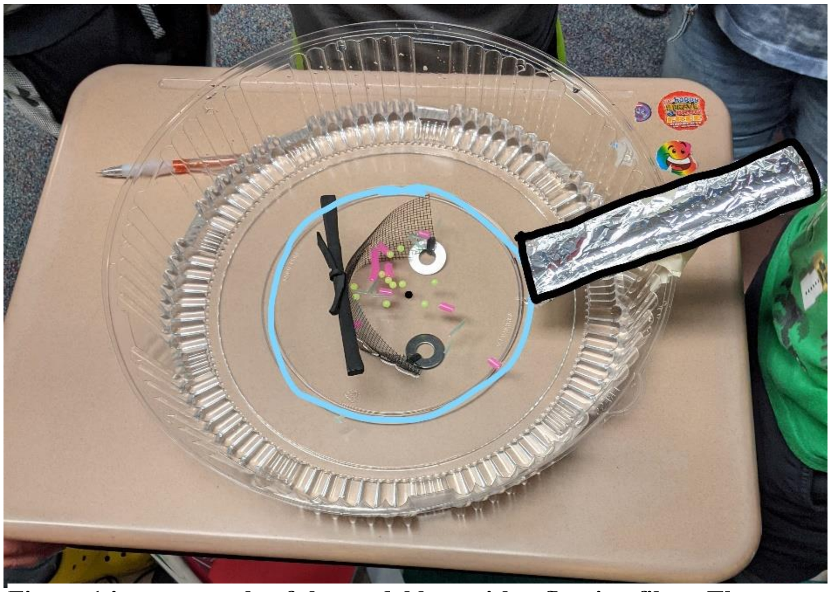

Figure 1 is an example of the model bay with a floating filter. The "river" is outlined in black.

The criteriafor the design are that the filter must be visible above the water surface, it much catch plastic as it enters the bay, it may not be attached to any surface (like the river), and it must fit inside the circle in the middle of the model bay (Figure 1 – outlined in blue). The constraints are that student only have certain materials to use and can only use up to $5,000 for the design. However, students can gain points on their overall score by decreasing their cost. A maximum of five points can be obtained for the cost score by keeping expenses below $1,000, with a stepped scoring system up to $5,000 (i.e., 4 points for $1,001-$2,000, etc). A maximum score of 38 is possible. In addition to earning points for cost (a maximum of five) and for each piece of plastic (a maximum of 30), designs earn addition points for being removable and detached, for fitting within the inner circle (outlined in blue), and for being visible above the water.

Rationale

Both the elementary teachers and their students have little experience in engineering [7]. To maximize their score, designers must balance tradeoffs between criteria (e.g., the ability to catch plastic) with the constraints (e.g., the cost of the materials). For example, a filter that catches all the plastic but that is very expensive would not score well. Similarly, a very inexpensive design that does not catch many plastic pieces would be judged as ineffective. Balancing tradeoffs between criteria and constraints is considered to be an important practice of engineers that is relevant to elementary engineering settings [4]. It is of interest to us for several reasons. First, a project that is evaluated on several metrics requires a more complex design strategy to complete, and we are interested in how teachers collectively approach this design. Second, we are interested in how their learning at workshops manifest itself in their classroom. Third, we are interested in the kinds of feedback the teachers give their students as they design these filters.

It is difficult to attribute causality in small qualitative studies, and indeed it is not our intention to do that here. But this was an opportunity to pilot an approach of looking at teachers learning engineering activities and then following them into the classroom to look for connections between them as learners and teachers to better understand teachers' needs in this area and to improve engineering education of elementary teachers through thoughtful inquiry.

Interactional ethnography, described in greater depth in the methodology section, is a way to systematically look closely at classroom activity [25]. However, the approach of studying teachers in workshops and then their classrooms, particularly in this way, has rarely been done (if ever – we were unsuccessful in finding an analogous approach). Due to COVID-19, only two of the eight teachers who attended the online workshop were able to teach the engineering unit in their class during the last academic year. For that reason, we approached this study as a pilot of a method we will expand on as more data become available this year.

Methods

Our method borrows from a host of researchers who have analyzed discourse in classrooms [26]–[28]. Interactional ethnography (IE) is an approach to studying cultures-in-the making, borrowing from research and philosophical traditions like sociolinguistics, cultural anthropology, and ethnomethodology [6]. Important to analyses in IE are the ways that social groups use talk, action, texts, and signs and symbols to construct the reality within social groups [5]. It is a useful way to better understand students and teachers during engineering design projects in classrooms because it is generally done in small groups, relies on talk and action focused on several design artifacts that becomes a character in the group. This approach captures details in the experience of students and their teachers doing engineering in ways that other methods cannot [29].

Video and audio recordings of engineering activities are a common data source for IE, but video data alone cannot tell the whole story. IE normally involves at least one researcher in the role of participant observer to better understand the norms of that classroom culture in the ways they talk and act [30]. It is through this careful assessment of the norms of the setting that enables the analyst to contextualize the events of interest with respect to their antecedents and outcomes. This "zooming in and out" is similar to the way Polkinghorne [31] describes the *hermeneutic circle*. Additionally, the participant observer role coupled with the video recording increases the capacity for completeness of analysis [32]. In other words, the video is limited because it cannot observe everything that an observer in the classroom can. However, the ability to revisit the instances helps the analyst see things he may not have seen and because it can be replayed, it reduces the dependence of the observer on premature interpretation.

In addition to video and audio recordings, other data sources can serve to triangulate findings. These sources can include artifacts (e.g., the designed technologies), interviews, or written texts (e.g., engineering journals). Author [6] found that video and journal data support each other in analysis. Sometimes classroom discourse occurs within groups but does not appear in journals because the non-verbal nature of the communication or because the outcome was obvious and did not warrant a discussion [5].

Due to COVID-19, we had to deliver the first workshop via Zoom with teachers in pairs at their respective schools. Then, Bea and Jared taught the engineering unit in their school and we collected data during those eight lessons. The data collection and analyses for those two settings are described here. A more detailed account of this method can be found in [33].

Data Collection at Teacher Workshop

During the four half-day sessions, all Zoom sessions were recorded. During times when teachers worked in pairs, a separate facilitator opened a breakout room, recorded the session, answered questions, and kept the teachers on pace. For the sessions in the main room, Zoom automatically transcribes the talk and saves all the comments in the Chat as a text file. For breakout rooms, videos were saved to a private YouTube channel that no one had access to except the researchers. YouTube automatically transcribes talk in these videos for closed caption purposes. We used Google Classroom as a class management system, enabling us to provide course materials, assign evaluations, and collect photos and engineering journals from the teachers. We shared our Google Slide deck with the teachers during each session. After each lesson, there were times for the teachers to reflect on slides made specifically for their groups. Since the slide deck is a shared document, those reflections serve as data from all the groups, rather than simply the response of the first group to answer.

Data Collection in the Classroom

Video and audio recordings were collected in Bea and Jared’s classrooms each of the 8 lessons as well as for two lessons introducing engineering before Lesson 1. In each classroom, one video camera was fixed on the whole class to capture movement of the teacher and whole-group activities. A lavalier microphone was worn by the teachers to capture all their verbal interactions.

Two additional video cameras and tabletop microphones were fixed on individual small groups to capture their talk and action regardless of whether the teacher was present. Photos were taken of each floating filter, and engineering journals were collected from each student. Parental consent forms were collected for every student.

Event maps

An important tool for our work is the event map. Event maps are time-stamped, descriptive records [34]. They allow for several hours of video recordings to be organized in several ways. The descriptions in the event maps can enable the analyst to quickly find events of interest to transcribe word-by-word while still considering the context in which they occurred. Lessons were also represented in the event maps as coordinated phases and within these phases smaller units of activity called sequences. Phases were based on goals of the curriculum developers and used in framing the lesson (e.g., "construct and test"). Sequences were developed *post hoc* through semantic and context clues [35]. Interaction units [36] surrounding balancing tradeoffs were also noted to consider in future analyses. Event maps were constructed in spreadsheets with each row representing one minute, to enable comparison between time spend on phases and sequences based on the number of minutes each activity lasted.

Research Questions

This theoretical framework guided the research questions, methods, and analytic decisions. Since classroom engineering projects are usually completed in small groups of students and involve collective thinking, negotiating, and problem solving, classroom ethnography, informed by discourse analysis [6], was chosen to investigate the following research questions:

1. How do teachers and students make decisions about making trade-offs between criteria and constraints.
2. What types of feedback do teachers give students to help them balance tradeoffs, and how is it related to their workshop experience?

Analysis and Findings

RQ 1 - In total, 65 event maps were created for the 4 teacher workshops (with 4 breakout rooms) and Bea and Jared's classes (with multiple camera angles recording different talk/actions). From there, we identified the sequence units from Bea and Jared's breakout room event map to identify the video episodes and isolate the YouTube transcript for closer analysis. We used a constant comparative method [37] to characterize the ways in which they talked about and designed and constructed their filters in order to take the criteria and constraints. Then, we found those sections of the engineering notebooks to look for supporting (or contradicting) evidence.

After characterizing the teachers approach to balancing tradeoffs, we used the event maps from Bea and Jared's classrooms to identify analogous activities to compare with the teachers. Using our understanding of the approach Bea and Jared took when designing their filter, we compared that with the four groups from their classrooms. Again, we used the engineering notebooks collected from the students to supplement the data from the recordings and event maps.

Finding #1 – Bea and Jared focused primarily on function and not cost

During their workshop design, Bea and Jared focused primarily on the performance of their filter. The talk and action during their initial design, construction, and testing suggested that they viewed the $5000 limit for receiving points for cost was the only threshold to consider. As a reminder, figure 2 shows the scoring for the design cost.

Table 2 Keeping the cost of the filter down earns the group's design more points, as long as it catches an equal amount of plastic

		Our score
5	$0 — $1,000	
4	$1,001 — $2,000	
3	$2,001 — $3,000	
2	$3,001 — $4,000	
1	$4,001 — $5,000	
0	$5,001 and above	

Three separate conversations lead us to this conclusion. The first episode can be found in table 3. In it, Jared makes the first reference to their design being "under budget" According to the scoring table (Figure 2), their design only earned a score of 2 because it cost $3,200. Saying "were under budget" suggests to us they were not trying to minimize cost to increase their score. It seems they were interested primarily in the fact the filter worked, and only that the design earned two points for cost. According to their description and their engineering notebook, the team's design earned 33 out of a possible 38 points.

Table 3 Bea and Jared consider their design (which only earned 2 points for score) to be "under budget"

Time	Speaker	Word by word transcript
16:20	Jared	1 That kind of works. That would work.
	Bea	2 How much is that?
	Jared	3 I don't know because a quarter…if we say each one of those pieces are
		4 about a
17:01		5 quarter screen, that's six, eight, ten, twelve hundred plus your twisty
		6 ties. How many twisty ties do you have? Right, I think we're all right.
		7 That's 400, 1800, 200. 3200. We're under budget!

The second discussion that strengthened our interpretation that Jared and Bea did not actively seek to minimize cost came during the improvement lesson, where teachers were given time and scaffold to improve upon their previous designs and attempt for a higher overall score. Table 4 is Jared's response to the group facilitator asking about the cost.

Table 4 - Jared again characterizes the design as being "under budget"

Time	Speaker	Word by word transcript
24:49	Facilitator	1 Is the cost of your improved version more or less?
	Jared	2 it's a little bit [less] but *we're still under budget* because when we tied
		3 our anchors on we only used a piece of the pipe cleaner and we counted
		4 in a whole piece of pipe cleaner okay so then we used just a couple
25:08		5 small pieces to tie it together a little better

Jared misspoke, as their cost *decreased* somewhat, but again the cost score did not seem to be a priority for him as long as their overall cost remained below $5,000. Again, he uses the term *under budget* to describe the filter but did not mention that they *increased* their device score from 33 to 36 out of a possible 38 because the second device caught two more pieces of plastic and earned an extra point. Jared further emphasized this emphasis when he presented their design to the other teachers in Table 5.

Table 5 - Jared and Bea describe their design to other teachers

Time	Speaker	Word by word transcript
3:14:08	Jared	1 They [the plastic pieces] kind of they stayed within our walls um so we were 2 able to capture pretty much all of them and then what was our cost?
	Bea	3 2600
	Jared	4 Yeah, 2600 was our cost so i mean we might be able to look at different
3:14:26		5 materials and make it go down but it worked pretty well

Bea and Jared's Classrooms

Based on the analysis of Bea and Jared's design, we looked closely at the ways four groups in their classes dealt with the same design. First, we looked at the process of planning, constructing, testing, and improving. As a pilot test, we wanted to see the range of designs students develop and compare them to the teachers we are beginning to analyze from our workshops. Second, we looked at the interactions and feedback the teachers gave to see potential connections between their workshop experience (RQ2).

Bea's room had only 14 students in person. She told me she typically has 25, but many were taking cyberschool due to COVID-19. We used video and audio recordings of both the talk and action from the small group work and the teacher camera when there were interactions. The public testing and reflections also occurred in whole group settings. We also used the engineering notebooks to verify the reported scores from the video. Figure 1 summarizes the designs.

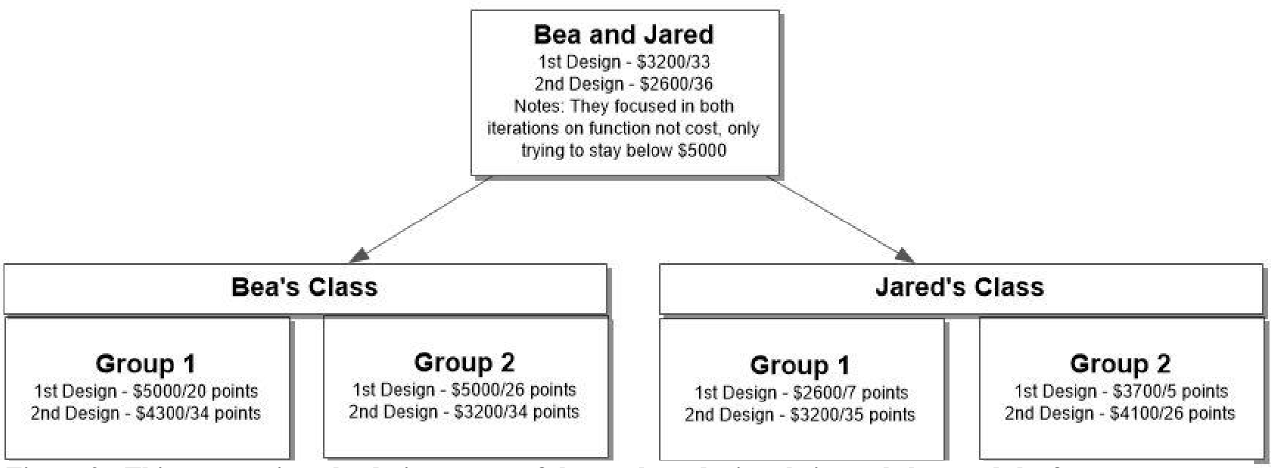

Figure 2 - This summarizes the design scores of the teachers during their workshop and the four groups studied in their class

Finding #2 – All five designs were improved through re-design, but in different ways

The two groups in Bea's class followed a similar path to Bea and Jared. They focused initially on the function of the filter and used $5000 as the maximum. Group 1 was able to decrease their cost from $5000 to $4300 but also increased their score to 34 because their filter caught all 30 pieces. Group 2 was also able to catch all but one of the 30 plastic pieces, but they were also able to decrease their cost by $1800. Both groups learned from watching the tests that the filters had to be wide enough to catch the pieces as the turbulence from the water scattered them and that the designs needed a way to prevent them from floating away.

The groups in Jared class started out with designs that did not perform very well. Like the groups in Bea's class, they learned from watching other groups test and were able to get ideas for their revisions. Jared's Group 1 went from a design that only scored 7 to catching all 30 pieces and scoring 35 out of a possible 38. But to accomplish this improvement, they spend more money, decreasing their cost score from 3 to 2. Their classmates in Group 2 also improved significantly, going from a score of 5 to a score of 26. They too increased their budget to do so and went from a cost score of 2 to 1.

RQ 2 -What types of feedback do teachers give students to help them balance tradeoffs, and how is it related to their workshop experience?

To address this question, we focused on the event maps from the workshop and the event maps from the classroom when students and their teacher talked about their design, particularly in those conversations that had to do with design decisions having to do with cost and the performance of the filter. After identifying those episodes, we used word-by-word transcripts for microanalysis.

Finding #3 – Teachers refrained from providing feedback that would affect the student designs

One style of feedback teachers give is based in their need to keep class moving smoothly and manage the students. Another type of feedback is based in the goal of teachers to help their student learn [6]. During the duration of the time students were designing, building, and improving, Bea was making sure students were staying on task, had all the supplies they needed, understood the assignment. To do this, she moved quickly from group to group, helping some with getting materials and making sure students were being safe (e.g. tipping back on a chair). The following is a summary of the feedback Bea gave to her students, including a summary to contextualize the response

Table 6 – Representative feedback from Bea during the design and the improvement phases from the unit

Antecedent	Bea's feedback
Student shows they have changed material and it costs $500	Yeah, so it's pretty durable.
Student told her their price increased to $2100	Ok, so the change to the cheese cloth did increase your price
A group shows her a design	What I worry about here is that you cannot see it from above the water. Remember the bay back there [back of the room] is the model bay
Student: We're not really gonna change much, but we need 5 more inches of tape, and that's going to put us at $5000.	Uh-oh!

These examples of feedback could plausibly be attributed to multiple causes. One might reason that the teacher is conducting a project-based unit for the first time and she is trying to make sure everything goes smoothly. Or it might be that the teacher does not want to influence the design. She may want the students to have full agency in their design and is leery of affecting the decisions she makes by interacting with them about design decisions or strategies.

In Jared's class, we found a similar pattern of feedback. He spent most of the time where students were designing in small groups managing the room. He made sure students had the right materials, he helped students find the correct engineering journal page, helped students with arithmetic as they added their materials' costs, and he addressed discipline issues. However, he showed tendencies to wanting to avoid influencing the students' design choices. At one point, he was helping Mitch and Abe cutting some materials.

Table 7 - Jared avoids answering Mitch's question

Time	Speaker	Word by word transcript
39:33	Abe	1 We need the pipe cleaners. I wanted the pipecleaners.
	Mitch	2 No we don't. Why do you want them?
	Jared	3 Do you mean for tying stuff together?
	Abe	4 Yeah
	Mitch	5 That won't work. (To Jared) Do you think those pipe cleaners will fit 6 through there?
39:50	Jared	7 You might be able to. I don't know. You'll have to see. Talk about it. 8 Think about it.

As Jared told them they should talk about it and think about it (lines 7 & 8), he was walking away, signaling that he did not feel like he should still be there helping them negotiate and that they should resolve this disagreement alone.

Table 8 - Jared addresses the idea of tradeoffs and mentions a strategy for maximizing your score after student have completed their designs

Time	Speaker	Word by word transcript
18:44	Jared	1 Some of those things were going to talk about tomorrow when wrap this 2 thing up. Were you meeting the needs of the community? And where do 3 you weight those things out? Like what if you designed one that didn't 4 fit inside the circle, but you're still catching all the plastic. You only lose
19:02		5 one point for that, so it might be worth giving up that one point. So 6 there's a give and take there, you know?

At the end of the second round of design, Jared addressed the class (Table 8). Interestingly, Jared suggests a strategy for maximizing the score by ignoring a criterion that is worth 1 point. He is suggesting that by taking that one-point deduction, it would make it easier to catch all the plastic and to increase your score. What is most interesting about this speech is that he waited until after everyone was done designing, testing, and improving their designs. This lends more evidence to the idea that he did not want to influence their designs.

Additional evidence contributes to our finding. During the teacher workshop, the teachers were asked to reflect on Lesson 6 and respond to two prompts: (1) How might you support students with these practices? (2) What questions or concerns do you have about this lesson? Teachers recorded their responses on our shared Google Slide file. Bea and Jeremy replied, "It will be important for the teacher to know their limits with helping vs. allowing students to experience the test on their own." This response suggests they feel that their role as teachers of young engineers is to let them design for themselves. In addition, after Bea and Jared completed their first design during the workshop and were waiting for the rest of the groups, Jared described to a student teacher an activity we did in the first session. He talked about not helping students with their designs. (Table 9) In it, he suggests that he is concerned that when teaching an engineering unit that he would become too involved with the designs and that he didn't want to "give them the answers" (line 2).

Table 9 – Jared reveals that he struggles with giving students answers too often

Time	Speaker	Word by word transcript
24:49 25:08	Jared	1 The only thing with all this is getting them to kind of think for 2 themselves and me not giving them answers and point like just and they 3 always want stuff just given to them making them kind of think. I'm 4 really bad at that.

Based on the feedback Bea and Jeremy gave during small group activities, their workshop reflection, and the aside given by Jeremy, we are confident that a major concern for these teachers was having too much influence on student design. This was unexpected to us because we suspected to see teaching aspects that were directly attributable to the workshop.

Conclusions

This pilot study took a unique approach at studying elementary teachers and their students learning engineering for the first time. Teachers attended a workshop in which they experienced engineering and the specific unit they taught from the perspective of both learner and teacher [8]. We are particularly interested in teachers engaging in the epistemic practices of engineering [4] because they are important to doing classroom engineering and appear in the most recent reforms of STEM education in the United States [1], [2]. Since most elementary teachers have no engineering experience, we took this opportunity to study them and then following them into their classes.

We recognize the limitations of a study that only looks at two teachers and their students, and therefore do not intend to overgeneralize. However, some things stood out that are important. First, all the teacher and student designs described in the study showed improvement. Improvement is a unique opportunity students to demonstrate learning regardless of the initial prototype [5] and an re-design phase should never be skipped. However, the improvements followed three paths. Some designs were expensive while others were not. Some initial prototypes were more effective in catching plastic than others. Thus, the improvements focused on either making it more effective, more efficient, or both.

Balancing tradeoffs, though, is unlike most schoolwork students have experienced. Most are used to having normative (correct) answers. Engineering is unique to them because there is rarely a “perfect” solution. However, the thinking about maximizing performance while minimizing cost requires complex strategies that learners are also not typically engaged with. But the evidence from this study suggests that even if balancing tradeoffs does not come naturally during the first iteration, the experience of testing, observing others’ designs, and the opportunity to redesign enables them to improve their designs through a better balancing of those tradeoffs. Teachers and those who design engineering activities for classrooms should also take note of how criteria and constraints (particularly cost) affects the design strategy and outcomes. For example, in this curriculum, the cost score came in bands (i.e. 1 point for designs from $4,001-$5,000). In this case, one would argue that a significant amount of discussion should surround how to decrease costs to get an additional point or to spend money on additional features up to the limit of that point band. Similarly, giving students a maximum budget would (should not) encourage a design much below that maximum budget. Meanwhile, if the constraint intend to minimize the cost, every dollar counts and that should be reflected in the design.

Last, the teachers in this study raise an important question for those in teaching and in teacher education. What is the role of teachers during the design process? Should they give advice? Should they engage groups in discussion about design decisions? We argue that it is important for teachers to be a strategic partner [6] with the students. Despite Jared's assertion that he might "give them the answer," there are few answers teachers can "give." But there are a lot of interesting discussions that can be helpful for students in engaging in the practices and habits of mind of engineers.

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