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Learning Engineering and Teaching Engineering: Comparing the Engineering Epistemologies of Two Novice Teachers with Distinct Pedagogies of Design

Kristen Bethke Wendell, Tufts University

Kristen Wendell is Assistant Professor of Mechanical Engineering and Adjunct Assistant Professor at Tufts University, where she is also a Faculty Fellow at the Center for Engineering Education and Outreach.

Ms. Jessica E. S. Swenson, Tufts Center for Engineering Education and Outreach

Jessica Swenson is a graduate student at Tufts University. She is currently pursuing a Ph.D. in mechanical engineering with a research focus on engineering education. She received a M.S. from Tufts University in science, technology, engineering and math education and a B.S. from Northwestern University in mechanical engineering. Her current research involves examining different types of homework problems in mechanical engineering coursework and the design process of undergraduate students in project-based courses.

Dr. Tejaswini S. Dalvi, University of Massachusetts, Boston

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Abstract

This research paper describes the study of novice teachers' epistemological framing of engineering learning and teaching. The inclusion of engineering design at all grade levels in the Next Generation Science Standards calls for efforts to create learning opportunities for teachers to learn to teach engineering. In our research on the role of engineering in elementary teacher preparation, we ask, what learning goals do new elementary teachers take up when asked to do engineering design themselves, and what learning goals do they establish when setting up engineering design tasks for students?

We conducted an interpretive comparative case study with two purposefully selected cases, chosen to unpack contrasting epistemological framing of engineering. Ana and Ben participated in the same science teaching methods course and volunteered for a follow-up engineering professional development institute, which was the context for this study. Data sources included videos of the teachers solving design problems, teachers' written and oral reflections on engineering teaching experiences, and researcher field notes from the after-school week. We generated thick descriptions of the cases of Ana and Ben and used these to develop conjectures about their engineering epistemologies. Following microethnographic methodology and strategies from discourse analysis, we re-examined transcripts and other data artifacts for confirming and disconfirming evidence of these conjectures.

We found that Ana and Ben framed engineering learning as building knowledge versus delivering a product, respectively, and engineering teaching as building knowledge versus delivering knowledge. During her own engineering design, Ana took up the goal of not just meeting the needs of the client but ultimately of scientific sense-making about how something could function to meet those needs. When facilitating students' engineering, she prioritized their agency and sense-making about design success or failure. She also engaged frequently in her own sense-making about the success or failure of her teaching moves. By contrast, when Ben worked on his own engineering designs, he took up the goal of getting the job done. When facilitating students' engineering design, he provided particular materials and assigned prototyping tasks to deliver his knowledge about how the prototypes worked. His reflections on teaching emphasized classroom management and how to model design process steps.

Our findings have implications for incorporating engineering experiences into work with novice teachers. Teacher educators should consider supporting the framing of design as a knowledge building enterprise through explicit conversations about epistemology, apprenticeship in sense-making strategies, and tasks intentionally designed to encourage "figuring things out."

Introduction

The inclusion of engineering design at all grade levels in the *Next Generation Science Standards* necessitates efforts to create learning opportunities for teachers to learn to teach engineering [1]. The *NGSS* call for the "integration of engineering and technology into the structure of science education" at all grade levels, including elementary school (Volume 2, Appendix A, p. 3). This shift requires not only new thinking about elementary curriculum and pedagogy, but also a transformation in the preparation of new elementary teachers so that they develop the knowledge and skills necessary to include the discipline of engineering in their classrooms.

A number of science education researchers have documented strategies for improving novice elementary teachers' competence in inquiry-based science teaching [2, 3], but there is only limited research in the U.S. on how elementary teachers learn to teach engineering design [4, 5, 6]. There is a need for new strategies to prepare novice elementary teachers to teach engineering, and for new approaches to investigate how well those strategies are working. Important venues for this research include elementary teacher licensure programs. In our research on the role of engineering in elementary teacher preparation, we ask:

- What learning goals do new elementary teachers establish when setting up engineering design tasks for students?
- What learning goals do they take up when asked to do engineering design themselves?
- To what extent do these two sets of goals align?

In our research, we explore these questions through a comparative case study of two novice elementary teachers' engineering learning and teaching. The construct of epistemological framing provides a theoretical perspective for this work [7, 8].

Framework and Context

The Epistemological Framing of Learners, Teachers, and Engineers

In this work, we borrow from sociolinguists, anthropologists, and other social scientists the term *framing* to refer to individuals' underlying expectations for what they are experiencing [9, 10]. Research on framing in educational settings typically examines the ways in which learners use previous experiences to interpret what kind of activity they're engaged in [7, 11, 12]. The construct of *epistemological framing* is an emerging one, and it deals with how learners understand their activity with respect to knowledge, reasoning, and learning [8]. While early work assumed that learners adopt a stable epistemological framing, or fixed *stance* toward what it means to learn and develop knowledge [13], current work looks for the dynamics of epistemological framing [12]. We align with this view that it should not be taken as a given that teachers' and students' epistemological framing will exhibit stability. By stability, we mean an individual's or group's robustness to shifts in the focus of their attention and perceptions of their activity's goals [11]. If a group is stable in its framing of a task, its members will resist switching to play another kind of "game."

At any given moment, many contextual factors influence the way learners frame an activity, and the stability of that framing. For instance, teachers' prior experiences in teacher education courses (i.e., methods classes) on the teaching of math and reading may influence their expectations for what will take place in a science teaching methods course. Learners' framing of an activity is also influenced by the words, tone of voice, gestures, body language, and eye contact of fellow learners and instructors. All of these things convey a message about how someone is interpreting the activity, and this message influences others' senses of what it is that is taking place. Physical materials, texts, and technologies also contribute to framing. They interact with the messages conveyed by other people and with past experiences to help learners determine whether they are being asked to complete a required task [11]. For instance, if an instructor distributes a blank sheet of paper, asks students to put away their books, and writes a math problem on the blackboard, learners may expect that they are required to complete the problem on their papers in silence and that they will be evaluated on their work. The game learners would assume themselves to be playing is the "test" game. By contrast, if an instructor introduces a visitor from a nearby engineering firm and asks that visitor to present a dilemma faced by her organization, learners may assume a very different kind of game – one in which the goal is to solve a problem so that they can offer advice on how to overcome a real-life challenge.

When novice elementary teachers are asked to complete an engineering design task, we might expect stability in an "engineering game" frame only if the materials, texts, and actions and speech of other people are able to outweigh the powerful schemas [14] that teachers bring with them to a teacher preparation program. Teachers tend to walk into a teacher education classroom expecting to learn to teach something, and this typically involves playing and then unpacking the role of a student in a "classroom game."

Studies of epistemology in engineering education show promise to reveal unexplored influences on engineering learning outcomes. Danielak, Gupta, and Elby studied the personal epistemology of an electrical engineering student over three years, they found that the student's foregrounding of sense-making and intellectual curiosity conflicted with the traditional views of knowledge development valued in his upper level engineering courses [15]. Wendell studied contextual influences on pre-service teachers' engineering design practices, identifying features that helped stabilize their productive approaches [16]. In other work, she and colleagues identified interactions between teachers' attention to students' engineering learning behaviors and their framing of subsequent engineering learning situations [17].

In this study we apply this body of work on epistemological framing in an attempt to better understand new elementary teachers' approaches to learning and teaching engineering design.

The Novice Teacher Institute

The Community-Based Engineering (CBE) Institute was offered to new elementary teachers as a four-week professional development experience. This institute was a part of our research program on new elementary teacher development in engineering education [18]. The overall goal of the CBE Institute was to prepare these new urban teachers to incorporate student-centered engineering design experiences into their future elementary classrooms, and to do so in a way that reinforced science learning opportunities. All engineering learning experiences during the institute followed the community-based engineering approach [19], which involves finding and solving engineering problems in students' neighborhoods, community centers, or schools. A focus on the local community provides a common lens through which teachers and students can see the cultural and linguistic diversity of urban environments as a resource for inquiry and design, rather than as a challenge [20, 21]. The three authors of this paper were the co-facilitators of the CBE Institute.

The institute included the following phases:

- *Learn* - Week 1 (Three 2.5-hour sessions): During the learn "Learn" phase participating volunteers were engaged in learning through exploration of the engineering design process. They designed and tested prototype solutions to two engineering design problems posed by the institute instructors.
- *Plan* - Week 2 (Three 1- hour sessions): During the "Plan" phase the participants worked in pairs to plan an engineering module for elementary students. The problems had been previously suggested by elementary students in an urban community center's after-school program. The participants planned to facilitate the modules during the "Teach" phase (Week 3) of the institute. They were also asked to include in their module a plan for a science investigation that would inform the engineering design solution.
- *Teach* - Week 3 (Five 2.5-hour sessions): The "Teach" phase was carried out at an after-school program at a community center. The participants worked in pairs to facilitate their engineering modules, including the science investigation. Each teaching pair worked with a group of four to five elementary students for about two hours a day for five days.
- *Reflect* - Week 4 (Two 2-hour sessions): During this phase, the institute instructors led the teachers through several tasks (small-group and large-group discussions, writing tasks, instructional design for a future community-based engineering module) designed to support reflection on teaching engineering at the after-school program.

Ten novice teachers volunteered to participate in the first implementation of the CBE Institute. These teachers were just completing a master's level teacher licensure program; their graduation ceremony took place between the second and third weeks of the institute. All the teachers were completing student teaching experiences in urban elementary schools and going through the job search process.

Methods

Participants

We conducted an interpretive comparative case study with two purposefully selected cases chosen to unpack contrasting epistemological framing of engineering. Although we collected data on all ten teachers' participation in the CBE Institute, we chose Ana and Ben as the two case study subjects. They were students in the same fall semester science teaching methods course, and they both volunteered for the follow-up CBE Institute which took place in May and June.

Selection of Case Study Subjects

We selected Ana and Ben as the comparative cases because of the contrasting observations we made about their teaching during the Teach phase of the CBE Institute. During the Plan phase, both Ana and Ben had enthusiastically participated in planning engineering design projects for the elementary students. However, we noticed that Ana and Ben's facilitation of those projects during the Teach phase showed quite disparate pedagogies. Our initial impression of Ana's teaching (documented in our field notes) was that she positioned her student group as a design team and gave them the responsibility for debating each other, requesting materials, fabricating design features, and learning from tests of their prototype. We initially observed (and documented in our field notes) that while Ben encouraged his students to test and improve prototypes, they worked individually on separate artifacts, and Ben largely predetermined the materials the students would use and the structure their prototypes would have.

Hypothesis

Ana and Ben were chosen as comparative case study participants based on our observations of their substantially different engineering teaching approaches. We built on this difference as the base of our hypothesis. We hypothesized that their different teaching approaches may have been informed by different stances toward what it meant to learn engineering and/or different epistemological framing dynamics during engineering learning experiences. We set out to look for evidence - from the artifacts of Ana and Ben's own engineering learning, and from their teaching and reflecting on teaching - to support this conjecture or refute it.

Data Sources

Data sources included videos of the teachers solving design problems, teachers' written and oral reflections on engineering teaching experiences, researcher field notes from the after-school week, and engineering pedagogical content knowledge assessments completed by the teachers in paper-and-pencil format before and after the CBE Institute [22].

Data Analysis

Microethnography and Coding

To test our hypothesis we conducted three rounds of analysis. First, we generated thick descriptions [23] of the cases of Ana and Ben by gathering weekly as a research team to review data together and discuss the narratives we saw in the data. At these case analysis sessions, we reviewed video of Ana and Ben's engineering design work (roughly three hours of video for each team, from two different days of the Learn phase of the CBE Institute), read field notes about their engineering teaching, and read and reviewed video of their written and oral reflections on engineering teaching.

Second, we used these case descriptions collectively to develop conjectures about Ana and Ben's engineering epistemologies, both when positioned as an engineering "learner" and as engineering "teacher." Following microethnographic methodology [24] and strategies from discourse analysis[25], we re-examined transcripts and other data artifacts for confirming and disconfirming evidence of these conjectures.

Finally, our third step was to systematically examine evidence of Ana and Ben's moment-to-moment epistemological framing as engineering "learners," that is, as they worked on the small-group engineering design project assigned during the Learn phase of the CBE Institute. To analyze these framing dynamics, we developed a set of codes based on our notes from the first two rounds of analysis. Working with transcripts from Ana's and Ben's teams over two days of project work, we used methods from grounded theory and constant comparative analysis [26] to narrow the codes and achieve consensus on their definitions. Specifically, we were looking to label different kinds of bids made by group members to change the framing of the activity. We wanted to be able to characterize the duration and frequency of Ana's and Ben's (and their teammates') attempts to shift the epistemological framing (whether those attempts were taken up or not) of their design team. Table 1 below defines each of the codes and provides example data from each group for each kind of bid to shift framing.

Table 1. Codes for bids to shift epistemological framing during engineering design challenge

Framing Code	Definition	Example from Ben's Team	Example from Ana's Team
Building a product	A bid for making the team's activity about the construction of the product	Ben: Alright, so this could be the base. What, um, we could even double up on that if we think it needs more support. What do you think for the wings? What should we do for those, like a expanding?	Ana: You know what, guys? I actually like this idea and have the feeding tube coming out and then attach to it.
Satisfying a client	A bid for focusing the team on meeting the needs established by the client	Ben: Just imagine how Emily's - no sorry not Emily, ah, Jenn's roommate seeing that, right? Pipes coming from the sink!	Ana: Did she say what she's planting so we know? 'Cause-isn't it different for whatever you're -
Sense-making about a physical mechanism	A bid for sense-making about a mechanism, either related to a scientific phenomenon or a designed artifact	Ben: How does this material behave on it's own, like, soaking?	Ana: To be honest with you, before I even do this step I would want to like fill this up (the upside down plastic bottle) to see the flow of the water.
Meeting instructor's expectations for teacher PD institute	A bid for meeting an expectation set by the professional development (PD) institute instructor	Ben: I think for the purposes of the assignment, and like the limited time we have to prepare for it, I feel like that might be the easiest way to do.	Julio: Let's say then it only works for four seedlings at a time.
Small talk	A bid to talk about something not relevant to the project	Ben: You guys ever watch the show Thirty Rock?	Candace: Do your kids go to camp?

Units of Analysis

Our unit of analysis varied between the individual level and and the team level as we looked for evidence of epistemological stances and framings. When reviewing field notes and artifacts from the Teach phase, we focused on Ana and Ben as individuals. Although both Ana and Ben worked with teaching partners during the Teach phase, they each respectively took on the lead teacher role in their pair. (This leadership in making pedagogical decisions is part of the reason why Ana and Ben stood out to the research team.)

When coding the design activities in the Learn phase, we had to attend simultaneously to individual and team. We were coding discourse in which an *individual* made a bid to shift the team's framing of the activity; we coded for the framing to which they were attempting to shift, and we recorded the name of the individual who was making the bid. At the same time, we noted whether there was evidence that the *team* responded to the bid by shifting to the new frame. That evidence sometimes came from the talk of only one individual; sometimes it emerged from discourse among several team members. To represent and further analyze the results of coding, we tabulated bids to shift by Ana or Ben or their teammates (which we grouped together). When we graphed framing dynamics over time, we used special markers for bids by Ana and Ben, another kind of marker for bids by any of their individual teammates, and shading for stable framings by a team. Therefore, the representations of our data also attend to both individual and team.

Findings

We report our findings in two main sections: first, the epistemological stances of the two teachers as they taught engineering to elementary students for the first time, and second, the epistemological framing dynamics of the teachers and their teammates as they worked on a plant waterer design challenge during the first week of the CBE Institute. Although the "teaching" data were actually collected later in time than the "learning" data, we describe the findings about teaching first. This is because what we found in the teaching data is what motivated and informed the investigation of the learning data.

Results for RQ1: What learning goals do new elementary teachers establish when setting up engineering design tasks for students?

Ana

Ana and her teaching partner chose to have their elementary student team solve the community problem of lack of shelter for birds in the neighborhood (a list of potential problems had been suggested by the students prior to the Teach phase). They wrote their own design goal for the students: "Create a safe home from other animals for local species of birds and a bird feeder that will prevent other animals from stealing the birds' food." They also wrote 10 criteria (e.g., humans must be able to see inside shelter; golf ball must be able to fit through entrance to shelter) and 6 constraints (e.g., $50 materials budget; no toxic paint) on a design brief for the students.

They began the design project by sharing the design brief with their team of five students and discussing the list of criteria and constraints. Then they gave the students a large piece of paper and stood back as the students sketched their initial ideas and made a materials list. They asked the institute leaders to obtain all the materials on the materials list created by the students. The next day, Ana led a brief science inquiry lesson on the adaptations of birds. She asked the students how information about birds could help inform their design decisions. From that point on, Ana and her teaching partner primarily played the role of question asker. They allowed students to design and build largely on their own, except when sharp blades and hot glue guns were required.

In conversations with the institute leaders, Ana said that she wanted her students to shift from perfecting details of their prototype to testing it out, but she refrained from directly telling her students to make this shift. Instead she leveraged another student's advice to test. "If that's the question you're asking, "How does it work?", then what's the advice you should be giving? You should be telling them to test it!" Ana refrained from directly pointing out flaws in the students' design but instead guided them to the design goal: "What about the things we have to remember from our checklist?"

Table 2 provides more information about Ana's reflections on her students work and her post-workshop thinking about student engineering design practices.

Based on our analysis of multiple data sources about Ana's engineering teaching and reflection teaching, we find that the learning goal she established for her student team was to discover and figure out how something works, by working together on a design product and considering careful questions posed by the teacher.

Ben

For their student team in the after-school workshop, Ben and his teaching partner chose the community problem of a classroom that felt too hot in the afternoons. They wrote the following design goal for students: "Create a system or systems that create and/or retain cool air in their classroom." They also wrote 4 criteria (e.g., sturdy and durable, cool the entire classroom, function without constant human attention) and 3 constraints ($50 budget; ready to use by June 12) on the design brief they planned to give their students. However, after Ben and his partner created this design brief, the location for the workshop changed and the director of the new site asked if the "cool the room" design challenge could be narrowed to a challenge to create fans that work without an electrical outlet. Ben and partner agreed to pose the challenge as one of designing and building some kind of fan. They started the week by asking their students what they knew about fans and having them make individual sketches and materials list for what they might build. On Day 2, Ben facilitated a science lesson plan provided by institute instructors on transfers of energy. For the students to build their fans, he provided not the materials they'd listed on their plans but a more limited set: plastic laminate for the fan blades, clay for the rotors, and pencils for the support columns. (The institute leaders provided motors, wires, batteries, and solar panels.) Ben had his students work individually rather than as a design team, and he provided instructions for the basic assembly of fan parts. He gave his students smaller decision-making tasks such determining the shape and position of the plastic fan blades.

At the end of the workshop, Ben wrote that his biggest takeaway from the week was "The science concepts are easier for the kids to grasp when they are using materials (instead of textbooks and lectures)." He thought that the next time he taught engineering, he would do more to model design process steps and establish norms for teamwork.

The data from Ben's teaching case (Table 2) suggest that the learning goal he set for his students was to develop an understanding of a scientific explanation related to a designed artifact.

Table 2. Summaries of the engineering teaching cases of Ana and Ben

	Ana	Ben
Preparation for student engineering workshop	• Created design brief about bird shelter problem in neighborhood. • Created inquiry lesson on bird adaptations. • Grouped students as one single team.	• Created design brief about needing a cooling device for the community center classroom. • Had students work independently.
Key teacher moves during student engineering workshop	• Had students collaboratively make materials list, and asked Institute leaders to procure those materials. • Asked questions about how bird shelter would work and whether it met "checklist." • Helped student group only with cutting and hot-gluing.	• Provided a limited set of materials for fan blades, rotors, and support columns. • Gave students smaller decision-making tasks such determining the shape and position of blades. • Asked students to describe the performance of their fans.
Post-workshop reflections on student work	• Noticed that students asked each other for evidence to back up their design ideas. • Saw students reluctant to test their artifact as they focused on detailed fabrication of all its features. • Reflected: "The whole point for them is to discover it. It's so different than the other subjects. They come up with their own ways and they understand more."	• Said he thought students grasped "science concepts" easier "when they are using materials (instead of textbooks and lectures)."
Post-workshop reflections on teacher moves	• "Just me doing all the talking doesn't help…The less that I say, and the more questions I ask, it actually makes them think more." • Main role is asking the right questions to help the students "figure out." • Wanted to get better at asking "scientific questions." • To be ready to ask good questions, important for teacher to try the design challenge on his or her own.	• Wondered: "Where to draw the line on science explanations?" • Would have modeled the design process through videos of teenagers doing engineering design work. • Would have started each session with a list of teamwork norms to "minimize personality clashes, disagreements, and antisocial behavior."
Written assessment	• Noticed five student practices: "sketching	• Noticed three student practices:

(analysis of video case): Noticing of student engineering practices	design," "generating materials list," "asking questions," "re-designing," "combining" design ideas	"drawing models" to "determine a plan and express problems"
Written assessment (analysis of video case): Suggested teacher moves	• Suggested prompting students to elaborate on thinking to peers ("Can you show us evidence of why the magnets attract?"); having students generate lists of criteria, constraints, and materials; and having students cycle through building and testing	• Suggested facilitating "structured peer-to-peer feedback" and providing magnets for "more intimate magnet understanding."

To recap, Ana and Ben (and their respective teaching partners) both involved their elementary student teams in solving a community problem through designing, building, and testing a tangible artifact. However, they set up different expectations for what their students would learn via this engineering design experience. Ana's interactions with her students and reflections on teaching suggest that she wanted her students to build knowledge collaboratively about how things work with equal emphasis on engineering design and science reasoning through design tasks. Ben's management of his students' design process and his reflections on the workshop suggest that he wanted his students to acquire the scientific explanations that he shared with them about their hands-on work. His facilitation appeared to use engineering as a "hands-on" context to provide scientific explanations. These differing learning goals as distinct epistemological stances toward teaching engineering to elementary students in this after-school workshop environment. Ana and Ben had different sense of how knowledge would develop and what kind of learning would take place. This finding from our case studies of Ana and Ben's teaching were unexpected. Ana and Ben were graduating from the same teacher education program, had both been full-time interns in urban schools throughout the school year, had taken the same teaching methods course on doing science and engineering with children, and were participating in the same (name blinded) Institute on elementary engineering – where they received the same templates for planning an engineering module and saw the same modeling of pedagogical strategies. Yet when positioned as engineering teachers, they implemented engineering in quite different ways. This finding seemed to demand inquiry: since Ana and Ben had different epistemological stances toward teaching engineering, did they also have different epistemological stances toward *learning* engineering? Was there something about the way they framed their own engineering learning that might account for their framing of engineering teaching? If so, there might be implications for how teacher educators or professional development providers attend and respond to new teachers' framing of engineering learning.

In the next section we describe the results of our inquiry into Ana and Ben's epistemological framing as engineering design learners.

Results for RQ 2: What learning goals do new elementary teachers take up when asked to do engineering design themselves? To what extent do these goals for themselves align with the engineering learning goals they establish for students?

We transcribed three hours of video from each of Ana's team and Ben's team working on the automatic plant watering design challenge during Phase 1 of the NB Institute. We coded the transcripts for participants' bids to shift their team's framing – that is, their sense of what they were doing in the activity. We looked for bids to shift to five different framings: building a product, satisfying the client, sense-making about a physical mechanism, meeting the institute instructor's expectations, or small talk.

Ana's team designed, built, and tested a plant watering device made of PVC pipes and pipe fittings that supported flexible plastic tubing fed with water by a reservoir and valve. They honed in on the idea of using a flow system within the first few minutes of Day 1. Ben's team's plant watering solution consisted of a pot with a reservoir of water underneath it and a mesh liner for transplanting a plant to or from the pot.

Table 3 shows the tally of bids to shift initiated by Ana, Ben, or one of their teammates. For both teams, members most often made bids to frame their activity as building a product. This result makes sense in light of the explicit design task they were assigned. Besides building a product, Ana's team more often tried to interpret their activity as satisfying the client of the design challenge; during their three hours of work on the design project, Ana or her teammates made 16 bids to shift their team's framing towards client satisfaction. When watching the data and reading transcripts of Ana and her team, we noticed the frequency with which Ana in particular thought about and restated the wishes of the client. The number of times she initiated a conversation about the client, 12, affirms our original conjecture that she interpreted engineering design to have meeting the client's needs as one of its major goals.

Members of Ben's team more often interpreted their collective activity as meeting the requirements set by the instructor. Ben and his teammates made 17 bids to shift their framing to a "classroom game" of meeting the expectations of teacher professional development. Ben's team also more frequently played the "small talk game" as Ben or his teammates initiated shifts to talk about off-topic matters.

Table 3: Bids to shift the framing of collaborative activity initiated by Ana, Ben, or their teammates

Bid to shift to...	Ana	Ana's Teammates	Ana's Team Total	Ben	Ben's Teammates	Ben's Team Total
Building product	13	19	32	12	26	38
Client satisfaction	12	4	16	2	4	6
Sense-making	8	3	11	5	5	10
Teacher PD	1	5	6	4	13	17
Small Talk	1	3	4	4	7	11

Table 3 shows contrasts in the number of times members of the two teams attempt to shift the orientation of their team's activity. It does not show, however, whether those attempts were taken up by other team members such that the framing of the team actually changed. To enable a closer look at the dynamics over time of the teams' framings, we plotted both *bids to shift* framing and *actual framing* against time. Figures 1 and 2 show contrasts in what happened *after* team members made attempts to change their team's framing.

For example, while Table 3 shows the teams having a nearly equivalent number of attempts by team members to switch into the sense-making frame, Figures 1 and 2 reveal that Ana's team sustained that sense-making frame for longer most of the time that someone made a bid to shift to it. Further, Ana was the instigator of most of those locally stable sense-making moments, which occurred both on Day 1 and on Day 2. Ben, on the other hand, made bids to engage in sense-making only on Day 1, which was the session when his team was conceptual planning without any tangible materials. On Day 2, the building and testing day for Ben's team, Ben did not initiate shifts to the sense-making frame. In fact, only once during building and testing did a member of Ben's team shift the group into scientific sense-making about a physical mechanism.

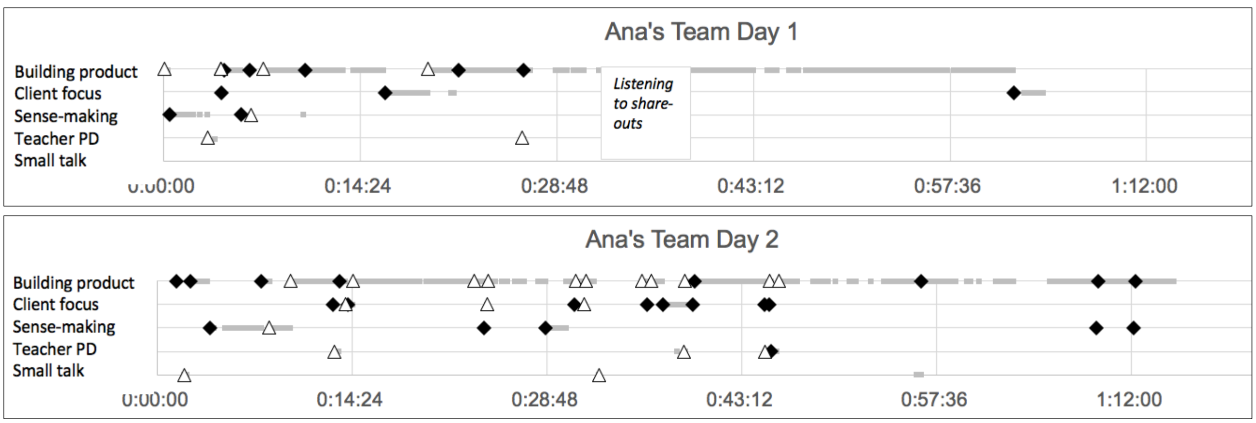

Figure 1. Epistemological framing tags for Ana's team as they worked on the engineering design of an automatic plant waterer. Black diamonds indicate shifts of framing initiated by Ana. White triangles are shifts of framing initiated by other team members. Gray indicates durations when team was stable in current framing.

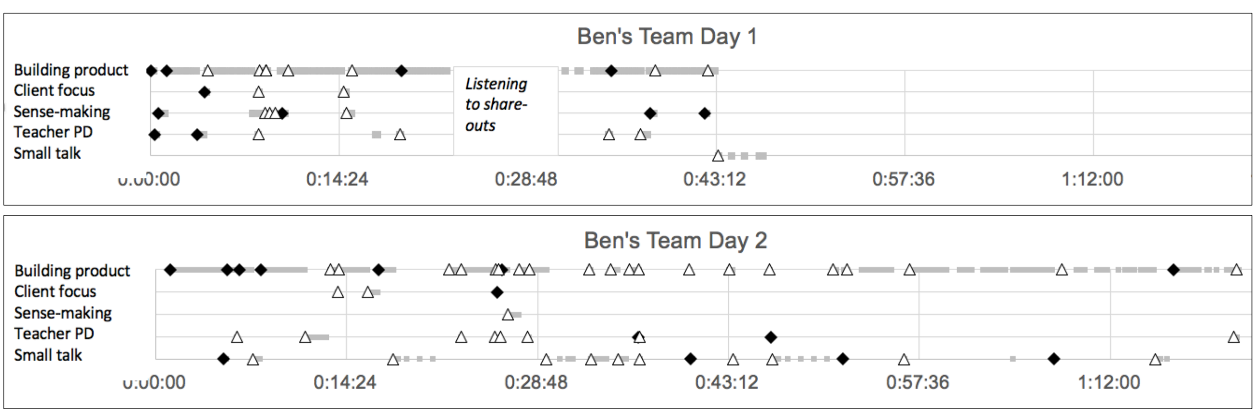

Figure 2. Epistemological framing tags for Ben's team as they worked on the engineering design of an automatic plant waterer. Black diamonds indicate shifts of framing initiated by Ben. White triangles are shifts of framing initiated by other team members. Gray indicates durations when team was stable in current framing.

Framing Dynamics of Ana and her Team

As shown in the upper plot of Figure 1, Ana and her teammates frequently made shifts to sense-making and client focus during first half of their design session on the first day of the plant waterer project. Then, after the share-out and feedback activity (when each of the three design teams presented their conceptual design and received feedback), they were stable in a sustained frame of building a product for nearly the entire second half. As everyone departed for the evening, Ana and her teammate Julio stayed behind for another few minutes to ask questions about the client scenario. They had shifted to the client satisfaction frame again.

Looking at Ana in particular on Day 1, we see that on her team, all of the bids or shifts to the client satisfaction and sense-making frame were initiated by Ana. To illustrate the nature of these shifts, we the following excerpt. It comes from the first minute of data on Day 1 and shows how a sustained sense-making framing was initiated by Ana. This is the first of many interactions where Ana's discourse indicates that she was interpreting their designing activity as being about understanding how physical mechanism work. To the left of each turn of talk we note the framing code we applied.

(Building)	Julio: If you had like (sketching a tube with a hole in it) really like a tiny, like the hole's gotta be like, really small. Like, imagine if you had (starting to sketch again)-
(Building)	Ana: Okay, the hole is going to be really small, but-
(Building)	Julio: So it'll, it'll steadily drip out. It will always be dripping. Like by the time she comes back, it's either still going or it's empty.
(Sense-making)	Ana: Right, but the thing is, that's what I'm trying to say. I know what you're saying, but when she pours the water on to this, what's the speed? What's going to control the speed of the water in order to drip?
(Sense-making)	Julio: Gravity.
(Sense-making)	Ana: How's it, how's that going to happen with gravity?
(Sense-making)	Julio: Cause it's, that, the water - if this like-
(Sense-making)	Ana: Because the pressure of the water will go-
(Sense-making)	Julio: So if you took off the cap it would just be shooting out water right? The cap is what controls the pressure.
(Sense-making)	Ana: Right.
(Sense-making)	Julio: Because only a little bit can come out at a time, so it's like a slow leak.
(Sense-making)	Ana: Okay.
(Sense-making)	Julio: So if you took the cap off, it would shoot water.
(Sense-making)	Ana: Right. But i'm saying here, though-
(Sense-making)	Julio: It's just full, it's full of water in the - what's happening is the gravity is pulling down-
(Sense-making)	Ana: So the gravity is going to be from here to like, this, this has to be something controlling here.

Ana not only drew her teammates into the opportunity that the design challenge provided to make sense of physical mechanisms, but she also tipped them to focus on design as client satisfaction. Here is an example, from minute 17 of Day 1, of a sustained client satisfaction framing that was initiated by Ana:

(Building)	Ana: Yeah, like cut, we would cut this part-
(Building)	Jeremey: Cut the top, yeah.
(Building)	Ana: And then just pour water.
(Building)	Julio: Right.
(Building)	Ana: Instead of her just doing this, or this, whatever, you know.
(Client focus)	Ana: The question is, like, how, like would this be enough water? That's the question.
(Client focus)	Julio: Well, we'd have to find out how much dripping-
(Client focus)	Candace: I wonder if [the instructor] knows.

(Client focus)	Ana: It will take-
(Client focus)	Candace: For each day.
(Client focus)	Ana: Like, how long every minute.
(Client focus)	Julio: Like seedlings ...we probably could look that up on the computer. Like, how, look up on the computer, how much you water seedlings, and it will tell you, like, daily how much water, and then we just have to do the math.
(Client focus)	Ana: But how would it stop? Because remember we need to use this for four days.

On Day 2, the overall pattern of framing and framing shifts for Ana's team was similar to Day 1. Mostly they treated their activity as building a product – a plant waterer device. But they also had sustained periods of seeing their work as scientific sense-making or satisfying a client. These periods of alternate productive framings were often initiated by Ana.

Framing Dynamics of Ben and his Team

For Ben's team, the plots of framing shifts versus time (Figure 2) reveals that their numerous bids to focus on expectations of the teacher professional development institute were not clustered together but occurred periodically throughout both days of the plant waterer project. However, there was only one time, about 10 minutes into Day 2, that the team sustained this "teacher workshop" game for longer than a few turns of talk, as indicated by the light gray bars on the plot. All other bids to shift to the teacher workshop game were either not taken up or short-lived. The same dynamics took place when Ben or his team made bids to shift to a frame of client satisfaction or sense-making about a mechanism. Most of these bids were not taken up by other team members, and the team went back to interpreting their activity primarily as building a product.

Another thing apparent on the framing versus time plot is that after the share-out discussions on Day 1, Ben's team was much less stable in its sense of its activity than was Ana's team. In the share-out discussion, each of the teams presented its plant waterer design, and the other teams gave positive feedback, questions, and suggestions for revisions. While Ana's team became very stable in the product building frame after the share-outs, in that same part of the session, Ben and his team members made bids to shift to sense-making, playing the "teacher PD game," and small talk. They looked over the feedback they received from their share-out, but none of the feedback convinced them to make major changes to their plan to build a container with reservoir and liner. They also determined that none of the prototyping materials in the room would be useful for building or testing their ideas. Not settling into any one frame for their collective activity, they decided to stop working earlier than Ana's team because they didn't think there was anything else they could do on the "assignment" until they collected some materials from home.

Looking at Ben's bids to shift frames in particular, we see that on Day 1 he initiated one of the bids to focus on client satisfaction and a few of the bids to do sense-making, but other team members also drove those shifts. Early on in Day 1, Ben was the person to try to shift the team's framing to meeting expectations of the teacher PD institute. The following excerpt is one of those shifts to play the teacher PD institute game. It comes from the first minute of Ben's team on Day 1. Ben answers a question by considering how "strict" the instructor might be about materials, and this tips the next several turns of talk to discussion about the existing solutions they might bring in from home to simply complete the project. Interestingly, Ben is the team member who shifts the group out of this frame and into a sense-making frame; he wants to think about the mechanism that allows one of those existing solutions – a hose timer – to function.

(Building)	Ben: There's like um ....if we can only use those materials, I'm assuming there's no like timer that will like do something, we could, you know, massage in releasing the water at a given time.
(Building)	Megan: Yeah, I was wondering that, how would we do like a timing?
(Building)	Paula: Yeah, or even like a hose timer that you could, you know put it on there.
(Teacher PD)	Ben: Well, I guess it depends how strict [the instructor] is with only the materials here cause if it's only-
(Teacher PD)	Paula: She said we could bring stuff in.
(Teacher PD)	Sarah: Probably depends on how-
(Teacher PD)	Megan: How about a hose timer? (Smiles.)
(Teacher PD)	Sarah: Just bring in an automatic waterer! (Laughs.)
(Sense-making)	Ben: What, um, do you know what when the timer goes off, like what physically happens? Like do they, is it open a valve, or-
(Sense-making)	Paula: I just asked my husband (via text message). He said he was going to get back to me.

Another interesting episode of "teacher PD game" framing took place thirty-eight minutes later on Day 1. Ben's team is focused on determining how they will contain the plant above the reservoir of water that they are designing. Ben suggests encasing the plant and its soil in a mesh liner. He realizes that this idea would require the client to move all of her plants out of their current containers, but he says that he doesn't see that as a problem. Picks up on this notion that they don't need to worry too much about inconveniencing the client, his teammate Paula makes a joke about the need for the design solution in the first place: maybe the client just shouldn't travel. The team members joke with each other in recognition of the fact that this design challenge is not real; it's an assignment in a teacher workshop, and they can "pretend" that elements of their solution are more appropriate than they really are.

(Building)	Ben: Yeah, like, I mean, I don't have a problem with like requiring that she [the client] transplant things. I don't- whatever.
(Teacher PD)	Paula: Maybe she [the client] won't go away next time [referring to the client's travel, the reason for the need for the plant waterer].
(Teacher PD)	Megan: Whatever. Beggars can't be choosers [saying this as a joke, laughing]!
(Teacher PD)	Ben: I, right, I mean, she-
(Teacher PD)	Sarah: It's her choice to leave [laughing]!
(Teacher PD)	Megan: Yeah, exactly, you don't leave for the weekend. I don't know. Okay, so we're going to do that instead of bigger or vice versa smaller.
(Teacher PD)	Ben: I think *for the purposes of the assignment* and like *the limited time we have to prepare for it,* I feel like that might be the easiet way to do [emphasis added].
(Teacher PD)	Megan: Okay.
(Teacher PD)	Paula: Well, we could pretend this is one-, that's not a seedling.
(Building)	Ben: Wait. (3 second pause, looking at sketch) If-
(Building)	Sarah: So these are like the medium pots
(Building)	Megan: So we have the soil, that's fine.
(Sense-making)	Ben: Here's a question, though. If um so this (pointing to sketch), this is all taped off. There's a sponge underneath. Will, like, if the soil touches the walls, which it will, that, would the water still evaporate? I mean I know-

Synopses of Epistemological Stances and Dynamics

Ben's teams more frequent shifts (compared to Ana's team) to frame their activity as completing a teacher PD task suggest that they were not as captivated by the design challenge as Ana and her teammates. Ana wanted to make the client happy and meet her needs. She also wanted to understand how water flows and how it would flow through their device. She commented that the work they were doing was "so hard" but also said "I love this!" She wanted to learn to do engineering and to learn something about how flow works. Ben's team wanted to complete the task of designing and building a plant waterer device, but for the purpose of meeting a teacher institute expectation rather than for the goal of learning how or learning why.

It is beyond the scope of this analysis to explore the reasons why Ana's team and Ben's team exhibited such different epistemological framing dynamics. We are not claiming that Ben's team was less capable than Ana's team, or that they were doing less than was asked of them by the institute leaders. We argue only that the goals they took up for themselves were different, and that Ana's teams goals aligned with the goals Ana later established for her students in the after-school engineering week, while Ben's team goals – primarily to deliver a finished product – were similar to the goals that Ben set up for his after-school students. Tables 4 and 5 summarize these aligned epistemologies.

Table 4: Ana's epistemologies as engineering teacher and learner

	When Positioned as Engineering Teacher	When Positioned as Engineering Learner
Learning Goals for an Engineering Design Experience	*Building Knowledge:* Goal for students is their **discovery of how things work.**	*Building Knowledge:* Goal for self is **making scientific sense** of the phenomena related to the design task while also truly satisfying the client with a working product.
Key Supporting Evidence	Reflective stance toward questions she posed to students and how to improve Noticing students reluctance to test how their product worked	Frequent bids to team members to shift the collective framing to sense-making and client satisfaction Lack of bids to shift framing to small talk or playing the teacher PD "game"

Table 5: Ben's epistemologies as engineering teacher and learner

	When Positioned as Engineering Teacher	When Positioned as Engineering Learner
Learning Goals for an Engineering Design Experience	*Hands-On Delivery of Knowledge:* Goal for students is their take-up of teacher **explanation of the science behind a hands-on artifact** built individually by students.	*Delivering a Finished Product:* Goal for self is **making a device** that efficiently meets the design requirements.
Key Supporting Evidence	Focus on what students "grasped" and teacher's own "explanation Control over student prototypes and processes	Bids to team members to consider teacher PD institute expectations Lack of sustained framing in sense-making stance

Discussion

In this study we examined the epistemological framing dynamics of two novice urban elementary teachers as they both learned and taught engineering design. We found that Ana and Ben framed engineering learning as *building knowledge* versus *delivering a product*, respectively, and engineering teaching as *building knowledge* versus *delivering knowledge*. During her own engineering design, Ana took up the goal of not just meeting the needs of the client but ultimately of scientific sense-making about how something could function to meet those needs. When facilitating students' engineering, she prioritized their agency and sense-making about design success or failure. She also engaged frequently in her own sense-making about the success or failure of her teaching moves. By contrast, when Ben worked on his own engineering designs, he took up the goal of getting the job done. When facilitating students' engineering design, he provided particular materials and assigned prototyping tasks to deliver his knowledge about how the prototypes worked. His reflections on teaching emphasized classroom management and how to model design process steps.

The data collected for this study do not support claims about causation of these framing dynamics. For example, we cannot say that Ana's framing of her own engineering design learning as *building knowledge* is what caused her to establish a knowledge building goal for her students. However, we see a strong association between the learning and teaching framings for both of of case study subjects. We put forward the possibility that a teacher's sense of what learning is taking place while she works on engineering design herself has an influence on her sense of what learning should take place when her students do engineering design. If further research bears out this relationship, then teacher educators should attend to novice teachers' framings as they participate in engineering design learning experiences.

Our data also do not support any claims about the abilities or capacities of Ben and his team members. Rather, we are describing the resources that were activated and the framing dynamics that took place in the particular contexts of the plant waterer challenge and the after-school workshop. These framing dynamics were influenced by a myriad of factors including Ana's and Ben's comfort with their team members, the communication styles of team members, the teachers' personal interest in the design challenge, the availability of physical materials that aligned with their design ideas, their level of fatigue from working full-time in an urban school, their science learning backgrounds, and so on. We argue not that some characteristic of Ben or his team was flawed and needed to be strengthened, but that we as instructors might have paid more attention to the epistemological framing dynamics that happened (for whatever reasons, and which are beyond the scope of this paper to figure out), so that Ben might have been tipped toward a different epistemological stance for the teaching of engineering to elementary students.

Another way to look at teachers as engineering learners is to analyze their design practices, processes, or products. The results of our study suggest that looking at teachers' epistemological framing contributes something additional to our understanding of teacher development in engineering. The framing lens can give us insights to the team's goals and focus, where coding for design practices tells us more about the actions on which the team spends it time and the strategies it uses to solve a design problem.

Looking at framing also enables us to conclude that success in *learning* engineering can be achieved quite distinctly from success in *doing* engineering. At the end of Phase 1 of the teacher institute, Ben's team had created an arguably "better" solution to the plant waterer challenge than Ana's team. The water reservoir and mesh plant container solution (Ben's team) was inexpensive, reliable, and functional (Paula took it home and tested it over the weekend). The pipe-and-tubing system was starting to work at the end of Day 2, and it was interesting, but it was probably more complicated and error-prone than it needed to be. Therefore one could conclude Ben's team did engineering better than Ana's team. But our data suggest that Ana's team may have *learned* engineering better. They were more engaged in the disciplinary pursuit of a design solution, and Ana and her teaching partner Julio carried into the after-school workshop a more nuanced perspective on the engineering practices they should be developing in their students. It is possible that Ana's more complex design (and the extra design steps required to manifest it) gave her more instances to reflect on as a teacher of engineering, whereas Ben's limited number of iterations, limited focus on the client's needs, and limited scientific sense-making episodes might have limited his conceptions about the disciplinary substance of engineering design.

Our findings have implications for incorporating engineering experiences into work with novice teachers. Teacher educators should consider supporting the framing of design as a knowledge building enterprise through explicit conversations about epistemology, apprenticeship in sense-making strategies, and tasks intentionally designed to encourage "figuring things out."

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