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RESEARCH ARTICLE

Epistemological framing and novice elementary teachers' approaches to learning and teaching engineering design

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Abstract

As engineering learning experiences increasingly begin in elementary school, elementary teacher preparation programs are an important site for the study of teacher development in engineering education. In this article, we argue that the stances that novice teachers adopt toward engineering learning and knowledge are consequential for the opportunities they create for students. We present a comparative case study examining the epistemological framing dynamics of two novice urban teachers, Ana and Ben, as they learned and taught engineering design during a four-week institute for new elementary teachers. Although the two teachers had very similar teacher preparation backgrounds, they interpreted the purposes of engineering design learning and teaching in meaningfully different ways. During her own engineering sessions, Ana took up the goal not only of meeting the needs of the client but also of making scientific sense of artifacts that might meet those needs. When facilitating students' engineering, she prioritized their building knowledge collaboratively about how things work. By contrast, when Ben worked on his own engineering, he took up the goal of delivering a product. When teaching engineering to students, he offered them constrained prototyping tasks to serve as hands-on contexts for reviewing scientific explanations. These findings call for teacher educators to support teachers' framing of engineering design as a knowledge building enterprise through explicit conversations about epistemology, apprenticeship in sense-making strategies, and tasks intentionally designed to encourage reasoning about design artifacts.

KEYWORDS
elementary school, engineering design, epistemology, teacher education, teacher framing

1 | INTRODUCTION

The inclusion of engineering design at all grade levels in the *Next Generation Science Standards* has prompted several large K-12 curriculum development efforts and studies of pre-college classroom engineering learning experiences (Moore, Tank, Glancy, & Kersten, 2015; NGSS Lead States, 2013). At the elementary level, numerous resources now exist for teaching stand-alone engineering units (e.g., Cunningham, 2009; Dalvi, Wendell, & Johnson, 2016; Smithsonian Science Education Center, 2018) as well as integrated science and engineering curricula (e.g., Delta Education, 2018; Eichinger, Doherty, Lehman, & Merwade, 2013; Ryan, Gale, & Usselman, 2017). Recent research literature provides windows into elementary students' engineering design practices (McCormick & Hammer, 2016; McFadden & Roehrig, 2018; Watkins, Spencer, & Hammer, 2014), navigation of social dynamics (Jordan & McDaniel, 2014), and science reasoning for design problem solving (King & English, 2016).

However, along with these resources for classroom instruction, the engineering education field also needs to develop and evaluate strategies to prepare elementary teachers to teach engineering design. Elementary teacher licensure and induction programs are key sites for this research (DiFrancesca, Lee, & McIntyre, 2014). While a large body of science education research has documented strategies for improving novice elementary teachers' competence in inquiry-based science teaching (e.g., Forbes, 2011; Windschitl, Thompson, & Braaten, 2011), the teacher education community is just beginning to learn how elementary teachers in the United States learn to teach engineering design (Capobianco, DeLisi, & Radloff, 2018; Rose, Carter, Brown, & Shumway, 2017).

Since the publishing of the *Framework for K-12 Science* Education (National Research Council, 2012), which foreshadowed the inclusion of engineering in the NGSS, our research group has been studying the integration of engineering learning and teaching in elementary teacher preparation. We have previously explored how pre-service teachers engage in engineering design practices themselves (Wendell, 2014) and how they learn to notice and respond to students' nascent engineering design efforts (Dalvi & Wendell, 2017). Other work on elementary teacher preparation in engineering has shown that methods courses can help pre-service teachers learn to support elementary students' engineering discourse (Mangiante & Moore, 2016), and that integrated STEM methods courses that include engineering design support engineering pedagogical development and lead to better STEM self-efficacy than traditional separate math and science methods courses (Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016). Collectively, these studies have generated resources for methods courses and tools for studying the development of pedagogical content knowledge. However, researchers have found substantial variation in enactment of engineering design in the classrooms of elementary teachers who have gone through identical preparation programs (Capobianco & Rupp, 2014).

We argue that a missing link is the study of *for what purpose* novice elementary teachers take up engineering design activities with students. In engineering education, there is a need for studies that mirror work done in science education revealing relationships between teacher epistemologies and their teaching decisions and actions (e.g., Lidar, Lundqvist, & Östman, 2006; Russ & Luna, 2013).

We conjecture that the epistemic understandings (e.g., Berland et al., 2016) that novice teachers have about engineering design learning and knowledge are consequential for what opportunities they create in their classrooms. The dynamics of engineering design experiences in elementary classrooms are influenced by the ideas that teachers have about what kind of knowledge is built during engineering activity. Therefore, teacher preparation programs need to attend not only to *what* new elementary teachers are doing with respect to engineering design—both their own practices and those they begin to implement with students—but also to *why* they are doing it.

To begin developing this argument, in this article we report on our comparative case study of the *epistemological framings* (Redish, 2004) of two novice elementary teachers during engineering learning and teaching. Simply stated, the goals of this study were (a) to uncover the learning goals that new elementary teachers take up when asked to do engineering design themselves and the learning goals they establish when facilitating engineering design tasks for students and (b) to explore the extent to which these two sets of goals—which could be considered "student hat" and "teacher hat" goals—were aligned with each other.

When we present our findings later in this article, we reverse the order of these two "hats." We report on the epistemological expectations the novice teachers brought to teaching engineering design before reporting on the expectations they brought to their own engineering learning activity. The reason for this order is to represent the arc of our research into their cases. We first studied the teachers' work with students, and we discovered that they operated under two surprisingly different sets of expectations about what kind of knowledge students should develop as they designed solutions to engineering design problems. This finding was unexpected because the two teachers 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 had been exposed to the same models for planning and carrying out engineering design pedagogy. Yet when positioned as engineering teachers, they operationalized engineering design in quite different ways.

This outcome demanded further inquiry: since these early-career teachers had different epistemological stances toward teaching engineering, had they employed different epistemic understandings when *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.

2 | THEORETICAL FRAMEWORK

2.1 | Personal epistemologies

Broadly, epistemology is the study of the nature of knowledge, including its sources and formation. In psychology and education, researchers have been concerned with *personal epistemology*, the particular beliefs or ideas that individuals have about how knowledge is structured and generated (Hofer & Pintrich, 2002). Initial work on personal epistemologies was domain-general and asked questions such as whether students viewed knowledge as certain or tentative (Hofer & Pintrich, 1997). In domain-specific epistemology research in science education, Sandoval (2005) called for a distinction between two kinds of personal scientific epistemologies: a *formal epistemology* of how knowledge is produced in professional science and a *practical epistemology* consisting of "ideas that students have about their own knowledge construction in school" (p. 636). These "epistemological beliefs" serve to "guide practice" (Sandoval, 2005, p. 648). Wickman (2004) used the term *practical* *epistemology* somewhat differently, to highlight that epistemologies are situated socioculturally in communities of practice and that a science learner's ideas and actions toward knowledge development are cued by the discourse, actions, and habits of others. Scholars of students' epistemic ideas in science have also argued that learners are often not self-aware of their epistemology (Hammer & Elby, 2003; Lising & Elby, 2005) and that science education researchers should care most about "epistemological ideas *in use*" (Berland et al., 2016, p. 1084). While early research in personal epistemologies assumed that learners travel through developmental stages of belief about what it means to learn and develop knowledge (Perry, 1970), current work expects that learners' epistemologies can be context-dependent (Berland et al., 2016; Scherr & Hammer, 2009) and subject to moment-to-moment dynamics (Hammer, Elby, Scherr, & Redish, 2005).

2.2 | Epistemological framing

The construct of *framing* has helped expand research on the context-dependent and dynamic nature of personal epistemologies. Framing generally refers to individuals' underlying expectations for what they are experiencing (Goffman, 1974; Tannen, 1993). Redish (2004) proposed the more specific term *epistemological framing* to deal with how learners understand their activity, or "what is going on," with respect to knowledge, reasoning, and learning. Hammer and collaborators have used epistemological framing to explore the ways in which science students interpret both current cues and previous experiences to make moment-to-moment, usually tacit decisions about how to approach classroom tasks (Berland & Hammer, 2012; Hutchison & Hammer, 2010; Scherr & Hammer, 2009). At any given moment, many contextual factors influence the way learners frame an activity and the stability of that framing. These factors include the words, tone of voice, and body language of fellow learners and instructors, as well as the arrangement of the physical space and its materials, texts, and technologies. Prior experiences in similar settings or scenarios also play a major role.

2.3 | Epistemological framing and teacher development

Research on the epistemological framings of science *teachers* has shown that they can be detected in situ, without interrupting for interview or survey, and that they are consequential for what transpires in pre-college classrooms. For example, from classroom video data, Russ and Luna (2013) detected distinct patterns in what a teacher noticed about student reasoning and used these patterns to infer different epistemological frames held by the teacher. Their findings confirm that teachers can shift between multiple different frames during a single classroom episode and show how teacher framing influences the choices teachers make about student learning. Likewise, Levin and colleagues analyzed video of novice science teachers facilitating classroom discussion and found that not only are novice science teachers capable of framing classroom activity as focused on student reasoning (as opposed to being focused, for example, on "covering" material or teaching terminology), but when they do frame classroom activity in this way, they attend to the disciplinary substance of student thinking and help students construct deep understanding of scientific concepts (Levin, Hammer, & Coffey, 2009).

We take a situative, sociocultural perspective on the learning of engineering (Brown, Collins, & Duguid, 1989; Johri & Olds, 2011). According to this perspective, to learn engineering design is to become a more legitimate participant in its disciplinary practices (Lave & Wenger, 1991), and meaningful learning opportunities tend to occur within social, collaborative work on real engineering design tasks. However, drawing from epistemology research in science education (Lising & Elby, 2005), we recognize that learning outcomes likely also depend on whether engineering learners sense that they are supposed to be engaging in disciplinary knowledge-building practices, and on what they consider those practices to be.

Therefore, as we study novice elementary teachers' first encounters with engineering curriculum and instruction, we combine the sociocultural perspective on learning with the body of work on personal epistemologies and epistemological framing. We propose a new theoretical framework for exploring novice elementary teachers' entrance into engineering education: epistemological framings for engineering learning and teaching. This theoretical framework sets our case study apart from studies of researcher-elicited explicit representations of teachers' personal epistemologies (e.g., Kang, 2008). Instead, we look for evidence of the mostly implicit epistemic ideas underlying the decisions novice teachers make about (a) how to participate in engineering design learning activities and (b) how to construct engineering experiences for students. Our focus on epistemological framings of activity is akin to observing epistemologies-in-practice (Berland et al., 2016) and to attending to *enacted* epistemologies rather than *professed* epistemologies (Louca, Elby, Hammer, & Kagey, 2004). Our framework also builds on prior studies of students' engineering design practices and of epistemology in engineering education, as discussed in the following sections.

3 | LITERATURE REVIEW

3.1 | Disciplinary practices for engineering design

Studies of students' engineering design abilities, behaviors, or practices comprise a major subfield of research in engineering education. Launching from research on professional engineering design cognition and behavior (e.g., Bucciarelli, 1994; Cross, 2003), education researchers set out to identify how student approaches to engineering design differed from those of experienced professionals (Atman et al., 2007). One goal was to characterize student progress from first to final year of college (Cardella, Atman, Turns, & Adams, 2008); another goal was to provide heuristics for evaluating the quality of learning experiences (Crismond & Adams, 2012). For example, if a design challenge failed to prompt any students to engage in feasibility analysis, then curriculum developers could conclude that it was not providing opportunities to learn the full range of engineering design practice.

Although they have generated useful tools for characterizing engineering design learning experiences, in situ studies of design activity have not been coordinated with similarly moment-to-moment attention to epistemological framing for engineering design. We argue that we may be able to better explain engineering design learning outcomes by pairing observation of disciplinary practices with attention to the purposes learners assign to those practices.

3.2 | Personal epistemologies and epistemological framing for engineering design

In undergraduate engineering education, research related to personal epistemologies confirms the variability of student views on what counts as engineering knowledge and learning (Danielak, Gupta, & Elby, 2014; McNeill, Douglas, Koro-Ljungberg, Therriault, & Krause, 2016; Swenson, 2018). In many contexts, including both interviews and in situ coursework activity, engineering students have appeared to treat engineering knowledge as mainly a collection of mathematical procedures (Lee, McNeill, Douglas, Koro-Ljungberg, & Therriault, 2013) or information about designed technologies and their underlying science (Kittleson & Southerland, 2004). But other studies have shown students approaching engineering as a site for constructing knowledge while also constructing technological systems, particularly when they are encouraged to dialogue with peers (Swenson & Wendell, 2017) or work on carefully designed "engineering world" tasks (Koretsky, Gilbuena, Nolen, Tierney, & Volet, 2014).

In pre-college engineering education, studies have also revealed the wide range and context dependence of epistemologies for engineering learning. Within a single classroom, Hegedus and Carlone found a number of different elementary student conceptions of "a smart engineering student" (Hegedus, Carlone, & Carter, 2014), and Wright and colleagues revealed that within a broader cultural context of school accountability and behavior management, some students from historically marginalized communities came to see engineering learning as just another site for "doing school," which largely meant compliance with expectations for polite, cooperative behavior (Wright, Wendell, & Paugh, 2018).

Moving from context-dependent epistemologies to moment-to-moment epistemological framings, McCormick identified the shifting framings of third-grade students who were designing a device for characters from a work of literature (2016). Within single class sessions, the students moved back and forth between treating engineering design as the activity of attending to the characters' needs, fulfilling teacher expectations, and constructing physical prototypes.

While these previous studies have explored students' epistemological framings, others have examined teacher framing of engineering. Cunningham and Kelly characterized the discourse moves used by Jean, a highly skilled elementary engineering teacher, to intentionally frame aerospace engineering as "a field that is dedicated to design and redesign through principled uses of data" (Cunningham & Kelly, 2017a, p. 299). Jean modeled data collection and analysis strategies, posed questions that directed attention to a subset of relevant design variables, and re-voiced student responses about data patterns. Jean's framing of engineering and her skill in teaching it was honed over 6 years of close collaboration with engineering curriculum developers, which included the piloting of 11 different engineering units with her students. Most novice teachers will unfortunately not have such extensive opportunities to learn to teach engineering.

3.3 | Epistemological framing for engineering in the teacher education context

As teacher educators and engineering education researchers, we conclude from previous research that when we ask novice elementary teachers to complete an engineering design task, we cannot assume that their epistemological framing will be productive. Their framing will depend on the interplay between the materials, texts, actions, and speech of other people in the methods course and the powerful expectations that they bring with them to a teacher preparation program. Many pre-service teachers walk into our teaching methods courses expecting to learn to "deliver" a lesson, and this typically involves playing and then unpacking the role of student in the classroom game or in "doing the lesson" (Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000). However, if we disrupt their expectations, for instance by inviting a visitor from a nearby engineering firm to present a dilemma faced by her organization, the pre-service teachers may assume a very different kind of game—where the goal is to solve a problem so that they can offer advice on how to overcome a real-life challenge. Contextual influences can cue them to interpret a methods course activity as engineering design rather than simply a "classroom game" (Lemke, 1990) required for a grade. As teacher educators, our reasoning is that if we cue novice teachers to take up epistemological framings that are productive for solving actual engineering design problems when they are positioned *as learners*, they may be more likely to apply those epistemological framings when they are positioned *as teachers.*

In this article, we test out that reasoning by addressing two guiding research questions:

1. What epistemological framings do new elementary teachers employ when teaching engineering design?

2. What epistemological framings appear when new elementary teachers are asked to work as engineering design learners, and what is the relationship between their epistemologies as engineering learners and teachers?

The research questions may seem out of order. However, we intentionally report on our findings in this order to mirror the order of our inquiry. Our findings about teachers' epistemologies for engineering during teaching episodes spurred our investigation of their epistemological framing during learning episodes.

4 | METHODOLOGY

In this qualitative research study, we adopted the methodological approach of comparative case study. We purposefully selected to cases to unpack contrasting epistemologies for engineering design. A comparative case study is an empirical inquiry that relies on multiple sources of evidence to investigate and compare at least two instances of a contemporary phenomenon within its real-life context (Yin, 2009). Case study designs feature in-depth descriptions of a bounded system or unit of study. In this research, our units of study were two novice elementary teachers as they participated in a professional development institute. We bounded these cases by limiting our study to the learning and teaching activities that the teachers conducted during the in-person sessions and homework assignments of the institute.

Case study designs can be descriptive, interpretive, or evaluative in nature (Merriam, 1998). In this article, we present an *interpretive* comparative case study because we seek to go beyond basic description, toward conceptualizing a typology of individual teachers' epistemologies for engineering and a possible relationship between their epistemologies for engineering learning and their epistemologies for engineering teaching. Furthermore, interpretive case study is used to support, illustrate, or challenge existing theory (Merriam, 1998). Our investigation of teacher epistemologies for *engineering* is framed by prior work in *science* education that suggests teachers' epistemologies for science inform their teaching decisions and the kinds of scientific activity they make available for their students (Berland et al., 2016; Miller, Manz, Russ, Stroupe, & Berland, 2018; Russ & Luna, 2013). A key feature of case study methodology is its utility for explaining why human situations play out as they do (Merriam, 1998). In this article, we capitalize on this heuristic power of case study research to explore why two novice elementary teachers with very similar preparation for teaching engineering turned out to enact engineering instruction so differently.

Within case study designs, various analytical methods can be used to interrogate different data sources. As described in more detail below, we adopted a discourse analysis approach (Lemke, 1998) to look for evidence of epistemological framing in verbal data of learning interactions. When we did not have direct verbal data of interactions, we adopted a cross-case matrix analysis approach (Miles & Huberman, 1994) to look for evidence of epistemological framing in participant-generated artifacts and researcher-generated field notes.

5 | METHODS

5.1 | Study context

The Community-Based Engineering Institute was offered to new elementary teachers as a four-week professional development experience, to be followed by quarterly call-back sessions for two subsequent years. Its overall goal was to prepare 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 a community-based engineering approach, 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 (Barton, 2003). The three authors of this article were the co-facilitators of the institute, which included four phases in sequence: Learn, Plan, Teach, and Reflect (Table 1).

Ten novice teachers volunteered to participate in the first implementation of the 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.

5.2 | Selection of participants

Although we collected data on all 10 teachers, 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 institute which took place in May and June. 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 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 and positioning of students (van Langenhove & Harré, 1999). Our initial impression of Ana's teaching was that she intentionally 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 that while Ben encouraged his students to test and

TABLE 1 Phases and activities of the novice teacher institute on elementary engineering education

Week	Phase	Duration	Activities	Collected data
1	Learn	Three 2.5-hr sessions	With a team, design and test prototype solutions to engineering design problems posed by institute instructors, including an automatic plant watering device to keep a large balcony garden watered while the owner was away.	• Video recordings • Design sketches and constructions
2	Plan	Three 1-hr sessions	With a partner, plan an engineering design module for elementary students in an urban community center's after-school program. Incorporate design problems previously suggested by elementary students and a science investigation that informs the design solution.	• Instructional planning artifacts produced by teaching pair
3	Teach	Five 2.5-hr sessions	With partner, facilitate the engineering design module for a group of four to five elementary students.	• Field notes • Teaching artifacts • Student design sketches and constructions
4	Reflect	Two 2-hr sessions	Reflect on teaching engineering at the after-school program, via small-group and large-group discussions, writing tasks, and instructional design for a future community-based engineering module.	• Video recordings • Written reflections • Written analysis of student video case

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.

5.3 | Initial data-based conjecture

Our observations of Ana and Ben's different teaching approaches served as the basis for our initial conjecture that their different teaching approaches may have been informed by different personal epistemologies about what it means to learn engineering. We expected these differing epistemologies might be observable in the dynamics of their epistemological framings during their own engineering learning experiences. To look for evidence to support or revise this conjecture, we conducted separate analyses of their epistemological framing during engineering teaching and engineering learning and then compared results from the two analyses.

5.4 | Data sources

Data sources for the *teaching* analysis were researcher field notes, student work, and teacher artifacts from the after-school groups taught by Ana and Ben during Week 3 of the institute, Ana and Ben's written and oral reflections on their Week 3 engineering teaching experiences, and written analyses of a student video case completed by Ana and Ben after Week 4. This video case analysis was part of an engineering pedagogical content knowledge assessment on which we have previously reported (Dalvi & Wendell, 2017). Due to limited consent from parents of the elementary students, it was not possible to video record Ana and Ben while they taught engineering at the after-school program.

Data sources for the *learning* analysis were researcher field notes, design sketches and artifacts, and video records of Ana and Ben's team engineering design sessions during Week 1 of the PD institute. All video records were transcribed, and transcripts included speech as well as gestures and interactions with materials.

5.5 | Data analysis

5.5.1 | Analysis of teaching phase

To begin characterizing Ana and Ben's approaches engineering teaching, we first worked to develop case stories of Ana and Ben (Stake, 1995). At this stage, we did not exclusively focus on epistemological framing but rather aimed to understand the full arc of Ana and Ben's preparation for, implementation of, and reflection on the engineering teaching they carried out during the institute. We gathered weekly as a research team in the months following the institute to review data together and discuss the narratives we saw in the data. We read and discussed Ana and Ben's lesson plans and instructional scaffolds, our field notes about their engineering teaching, the artifacts their students constructed, and their written and oral reflections on engineering teaching. We also reviewed the written analyses of a student video case that they had completed as a post assessment after the institute and which we had scored for a previous study. These data review sessions resulted in written memos about the approaches that Ana and Ben appeared to have developed for teaching engineering design.

Next, we conducted cross-case matrix analysis (Miles & Huberman, 1994) detailing what each of the data sources revealed about the epistemological expectations Ana or Ben conveyed for students' engineering learning. In the cross-case matrix, we listed each data source with the epistemic ideas it conveyed related to engineering design. This two-step process of case story development and matrix analysis allowed us to characterize how Ana and Ben epistemologically framed students' engineering design work in four different contexts: preparation for teaching, instructional moves during students' engineering activity, post-teaching reflections on student work, and post-teaching reflections on instructional moves. We present this characterization in Section 6.

5.5.2 | Analysis of learning phase

Next, we analyzed data from Ana and Ben's participation during the Learn phase of the institute. We first reviewed field notes, artifacts, and portions of the video record in weekly research team gatherings. Because we had a full video record (unlike the “Teach” phase, which we did not have sufficient permission to record) we conducted interaction analysis as we reviewed video episodes (Jordan & Henderson, 1995). During this process, we used memo writing to characterize the differing framings that Ana and Ben team seemed to be adopting with their design teams to solve the plant-waterer challenge (Table 1).

Second, following the methods of Hammer and collaborators in their various examinations of epistemological framing in physics classrooms (Hutchison & Hammer, 2010; Scherr & Hammer, 2009), we used more focused discourse analysis (Lemke, 1998) to systematically examine evidence of Ana and Ben's moment-to-moment epistemological framing as they worked on the engineering design challenge. Our aims were to identify and label different kinds of bids made by Ana and Ben to change the framing of the engineering design activity, to document whether those bids were taken up as new framings by their design teams, and to determine the duration of those framings. Based on our notes from the initial review of data from the Learn phase, we identified the range of epistemological framings evident in the teachers' talk and behavior during the design challenge. We then used constant comparative analysis (Glaser & Strauss, 1967) to narrow to five main framing codes and achieve consensus on their definitions (Table 2). We then coded the transcripts of both Ana's team and Ben's team working on the plant waterer design challenge. Both teams worked on the challenge for about 150 min spread over two sessions. We labeled each turn of talk for the apparent framing of the team at that moment. We paid attention to gestures, interactions with physical materials, pauses, and interruptions, since these paralinguistic channels can provide “meta-communicative messages” signaling framing (Tannen, 1993). When we could not determine the team's framing from the transcript alone, we reviewed the video footage again to look for indicators from intonation or gaze. If the turn of talk included a bid to shift framing, we noted the bid and the speaker who made it.

Finally, we conducted a round of analysis to ensure that a learner's epistemological framing during engineering is a distinct phenomenon from a learner's engineering design practices. In this phase, we worked with the same two sessions of engineering design challenge data, but we coded for Ana and Ben's design practices. Our goal was to confirm that coding for a team's framing dynamics during engineering reveals different patterns than coding for the team's design practices. To code for engineering design practices, we applied the Informed Designer categories established by Crismond and Adams in their synthesis of research on beginner and informed designers' engineering design practices (2012). They identify nine practices of design: understanding the challenge, building knowledge, generating ideas, representing ideas, weighing options and making decisions, conducting experiments, troubleshooting, revising and iterating, and reflecting on process. In our analysis, we used the “informed” description from Crismond and Adam's matrix as the starting definition for each design practice code, and we extended that definition to make it more applicable to our data context (see Supporting Information).

5.5.3 | Attending to individuals and teams

As we looked for evidence of epistemological framings during teaching and learning, we shifted between coding individual actions and decisions and coding collective team actions and decisions.

TABLE 2 Codes for epistemological framings during engineering design challenge for teachers

		Example bid to shift team into framing	
Framing code	**Definition**	**From Ben's team**	**From Ana's team**
Building a product	Making the team's activity about the construction of a tangible device	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	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-is not it different for whatever you are -
Sense-making about a physical mechanism	Sense-making about a mechanism, related either to a scientific phenomenon or to a designed artifact	Ben: How does this material behave on its 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.
Doing the lesson	Meeting a requirement 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[a]: Let us say then it only works for four seedlings at a time.
Small talk	Chatting about something not relevant to the project	Ben: You guys ever watch the show Thirty Rock?	Candace[a]: Do your kids go to camp?

[a] Julio and Candace, Ana's design teammates, are quoted for these two codes because there were no examples of Ana making this kind of bid to shift framing.

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 (other institute participants) 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 noted 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. When we graphed framing dynamics over time, we used distinct 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.

6 | FINDINGS

We report our findings in two main sections: first, the epistemological framings of the two teachers as they taught engineering to elementary students for the first time, and second, the epistemological framing and design practice dynamics of the teachers and their teammates as they worked on a plant waterer design challenge during the first week of the institute. The findings from the teaching data motivated and informed the investigation of the learning data. Therefore, we describe the findings about teaching first.

6.1 | Results for RQ1: What epistemological framings do new elementary teachers employ when setting up engineering design tasks for students?

6.1.1 | Ana

The analysis of data from Ana's engineering teaching indicate that the kind of knowledge activity she desired 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. Her epistemological framing for engineering design teaching treated engineering design as collectively building knowledge about how technological artifacts work.

Preparation for teaching

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 elementary students prior to the Teach phase). They did research with life science curriculum materials to plan an inquiry activity on bird adaptations. 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.

Instructional moves during teaching

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 positioned the students as one single team. They gave them 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 then 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 fretted about how to help her students shift from perfecting details of their prototype to testing it out. She wanted them to test early and often. However, she refrained from directly telling her students to make this shift. Instead, she waited until another student critiqued the team's design process during an informal peer review, and then she re-voiced that student's advice. “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?”

Reflections on student work

When asked to reflect after the workshop on the strengths her students' engineering design work, Ana focused on how they provided and asked each other for evidence to back up their design ideas. Ana's post-workshop analysis of the student video case also honed in on the students' use of evidence to try to convince each other of their ideas for solving the design challenge. When reflecting on her own students' weaknesses, she returned to their reluctance to test their artifact as they focused on detailed fabrication of all its features. She explained that she wanted them to do more testing because, “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.”

Reflections on instructional moves

In her post-workshop reflections on her engineering teaching, Ana revealed that she saw her main role as asking the right questions to help the students “figure out” their engineering design. She said she wanted to get better at asking “scientific questions” because “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.” Similarly, her proposed response to the student video case focused on asking students to elaborate on their thinking in their discourse with peers; she also suggested that the students should cycle through multiple rounds of building and testing. Her reflections also revealed that she saw a link between teachers engagement in engineering learning activities and their engineering teaching: she said that to be ready to ask good questions, it was very important for the teacher to try the design challenge on his or her own.

Summary

In her engineering teaching, Ana enacted decisions to give students agency as a design team, attend to their practices of presenting evidence for design ideas, and focus her role on asking questions for student discovery and “figuring out.” In these decisions, we see evidence of a stable epistemological framing for engineering teaching that treated students' engineering design as collectively constructing knowledge about how technological artifacts work.

6.1.2 | Ben

The data from Ben's teaching case suggest that the kind of knowledge construction activity he desired for his students was to *acquire an understanding of a scientific explanation related to a designed artifact.* His epistemological framing for engineering design teaching treated engineering as an act of delivering science knowledge through hands-on fabrication.

Preparation for teaching

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 four criteria (e.g., sturdy and durable, cool the entire classroom, function without constant human attention) and three constraints ($50 budget; ready to use by June 12) on the design brief they planned to give their students. After Ben and his partner created this design brief, the location for the workshop changed. 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 his partner agreed to pose the challenge as one of designing and building some kind of fan.

Instructional moves during teaching

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 energy transfer. For the students to build their fans, he did not provide the materials they listed on their plans, but rather gave them a 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 provided direct instructions for the assembly of fan parts, which included the basic circuit. He gave his students smaller decision-making tasks such as determining the shape and position of the plastic fan blades.

Reflections on student work

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)." When prompted to think about weaknesses of his students' design work, he shifted from science concepts to focusing on the challenges they faced in interacting with each other socially. In his analysis of the student video case, he shifted back to conceptual understanding, suggesting that the students in the video would benefit from a deeper scientific understanding of magnets, which were a central component of their design solution.

Reflections on instructional moves

In post-workshop reflection on his engineering teaching, Ben's most pressing question was, "Where to draw the line on science explanations?", meaning that he wondered about how much detail and technical terminology to use when presenting students with a mechanistic description of how something works. He also thought seriously about how to support students' social interactions during engineering design, both in his reflections his own teaching and in his analysis of the student video case. He suggested modeling the design process by showing videos of teenagers doing engineering design work. If given the chance to do it over again, he would have started each session with a list of teamwork norms to "minimize personality clashes, disagreements, and antisocial behavior" and he would have facilitated more "structured peer-to-peer feedback."

Summary

In his engineering teaching, Ben enacted decisions to provide clear structure and limited materials for an engineering design task, position students as individual makers, and present a canonical science explanation (of energy transfer) related to that design task. Yet he also reflected on ways to facilitate higher quality interactions between students. In these decisions and reflections, we see evidence of an epistemological framing for engineering teaching that treats students' engineering design as a hands-on context for acquiring science concepts. However, we also see interest in engineering design as a site for productive social interactions.

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 epistemological frames for what their students would learn via this engineering design experience. This outcome inspired the question, had they also taken up different epistemological framings for their *own* engineering learning? In the next section, we describe the results of our inquiry into Ana and Ben's epistemological framing as engineering design learners.

6.2 | Results for RQ 2: What epistemological framings do new elementary teachers take up when asked to do engineering design themselves?

We transcribed 150 min of video from each of Ana's team and Ben's team working on the automatic plant watering design challenge during the Learn Phase of the 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, doing the lesson (completing instructor requirements), 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 framing 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 two and a half hours of work on the design project, Ana or her teammates made 16 bids to shift their team's framing toward 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 client needs as one of its major goals.

Members of Ben's team more often interpreted their collective activity as doing the lesson—that is, simply meeting the requirements set by the institute instructor. Ben and his teammates made 17 bids to shift their framing to this classroom game of completing the assignments 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 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. Figure 1 shows contrasts in what happened *after* team members made attempts to change their team's framing.

While Table 3 shows the teams having a nearly equivalent number of attempts by team members to switch into the sense-making frame, Figure 1 reveals 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 conceptually 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.

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
Doing the lesson	1	5	6	4	13	17
Small talk	1	3	4	4	7	11

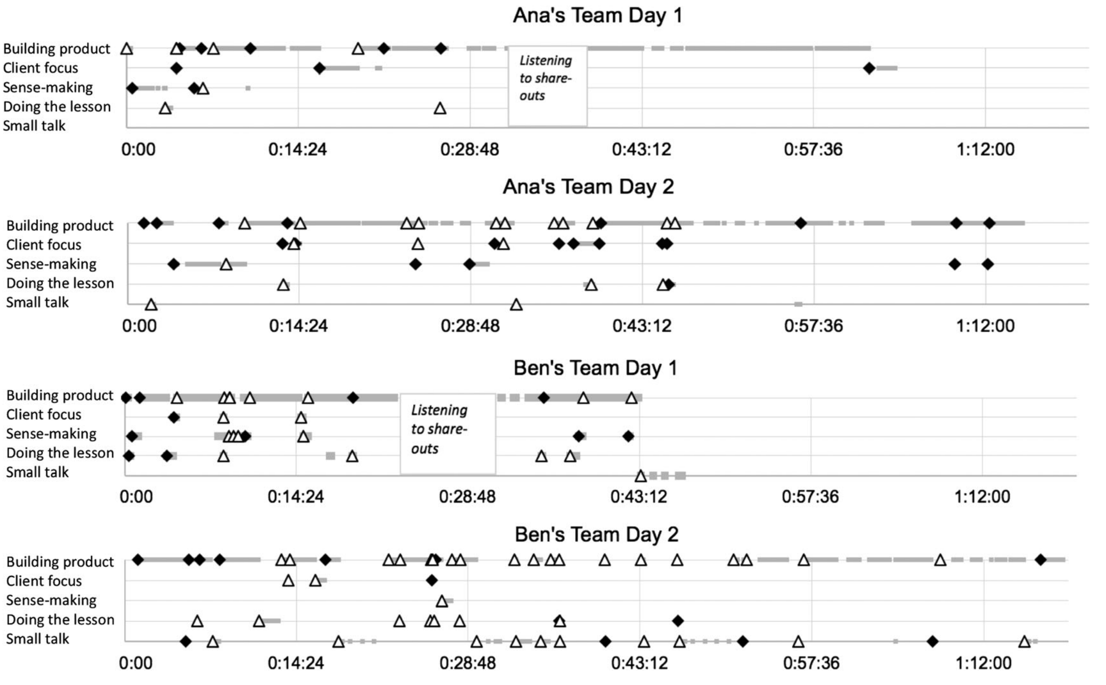

FIGURE 1 Epistemological framing tags for Ana's team and Ben's team as they worked on the engineering design of an automatic plant waterer. Black diamonds indicate shifts of framing initiated by Ana (top two plots) and Ben (bottom two plots). White triangles are shifts of framing initiated by other team members. Gray bars indicate durations when team was stable in current framing

6.3 | 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 the 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, she was the one to initiate all of the bids or shifts to the client satisfaction and sense-making frames. To illustrate the nature of these shifts, we share 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 was the first of many interactions where Ana's discourse indicated that she was interpreting their designing activity as being about understanding how physical mechanisms work. To the left of each turn of talk we note the framing code we applied.

(Building a product)	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 a product)	Ana: Okay, the hole is going to be really small, but-
(Building a product)	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 a product)	Ana: Yeah, like cut, we would cut this part-
(Building a product)	Julio: Cut the top, yeah.
(Building a product)	Ana: And then just pour water.
(Building a product)	Julio: Right.
(Building a product)	Ana: Instead of her [the client] 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 4 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.

6.4 | Framing dynamics of Ben and his team

For Ben's team, the plots of framing shifts versus time (Figure 1, bottom) reveals that their numerous bids to focus on doing the lesson set by the institute instructor were not clustered together but occurred periodically throughout both days of the plant waterer project. However, there was only one time, about 10 min into Day 2, that the team sustained this game of appeasing the instructor 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 doing-the-lesson 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.

The framing versus time plot also shows 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, doing the lesson, 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, which was to build a container with reservoir and liner. They also concluded 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 did not 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 “doing the lesson.” The following excerpt is one of those shifts to play this type of classroom 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 a product)	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 a product)	Megan: Yeah, I was wondering that, how would we do like a timing?
(Building a product)	Paula: Yeah, or even like a hose timer that you could, you know put it on there.
(Doing the lesson)	Ben: Well, I guess it depends how strict [the instructor] is with only the materials here cause if it's only-
(Doing the lesson)	Paula: She said we could bring stuff in.

(Doing the lesson)	Sarah: Probably depends on how-
(Doing the lesson)	Megan: How about a hose timer? (Smiles.)
(Doing the lesson)	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 doing-the-lesson framing took place 38 min 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 does not see that as a problem. Picking up on this notion that they do not 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 should not 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 a product)	Ben: Yeah, like, I mean, I don't have a problem with like requiring that she [the client] transplant things. I don't- whatever.
(Doing the lesson)	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].
(Doing the lesson)	Megan: Whatever. Beggars can't be choosers [saying this as a joke, laughing]!
(Doing the lesson)	Ben: I, right, I mean, she-
(Doing the lesson)	Sarah: It's her choice to leave [laughing]!
(Doing the lesson)	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.
(Doing the lesson)	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. [Emphasis added.]
(Doing the lesson)	Megan: Okay.
(Doing the lesson)	Paula: Well, we could pretend this is one-, that's not a seedling.
(Building a product)	Ben: Wait. (3 second pause, looking at sketch) If-
(Building a product)	Sarah: So these are like the medium pots -
(Building a product)	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-

In summary, Ben's teams more frequent shifts to frame their activity as doing the lesson, or completing an instructor-posed 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 their 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 more for the purpose of checking off a requirement of professional development rather than for the goal of learning how or learning why.

6.5 | Design practices analysis

Part of our argument is that attending to learners' epistemological framings during engineering design experiences is distinct from attending to learners' design practices. To confirm this distinction empirically, we conducted a separate design practice analysis whereby we coded the same data sets—for Ben's team and Ana's team—for the practices of informed designers (Crismond & Adams, 2012).

First of all, we found that during the plant waterer challenge, Ana's team spent more time than Ben's engaged in activity that could be classified as one of the nine design practices in the informed designer framework (Figure 2). However, by the end of the challenge, both teams engaged meaningfully (for 1 min or longer) in the same seven practices: understanding the challenge, building knowledge about the problem, generating ideas, representing ideas, weighing options, conducting experiments, and troubleshooting. Revising/iterating and reflecting on process were the two practices in which neither team engaged for more than 1 min.

However, we found that across the two teams, there were differences in how the design practices clustered within epistemological framings, particularly the sense-making and client satisfaction framings. When Ana's team framed their work as a sense-making activity, they were carrying out the

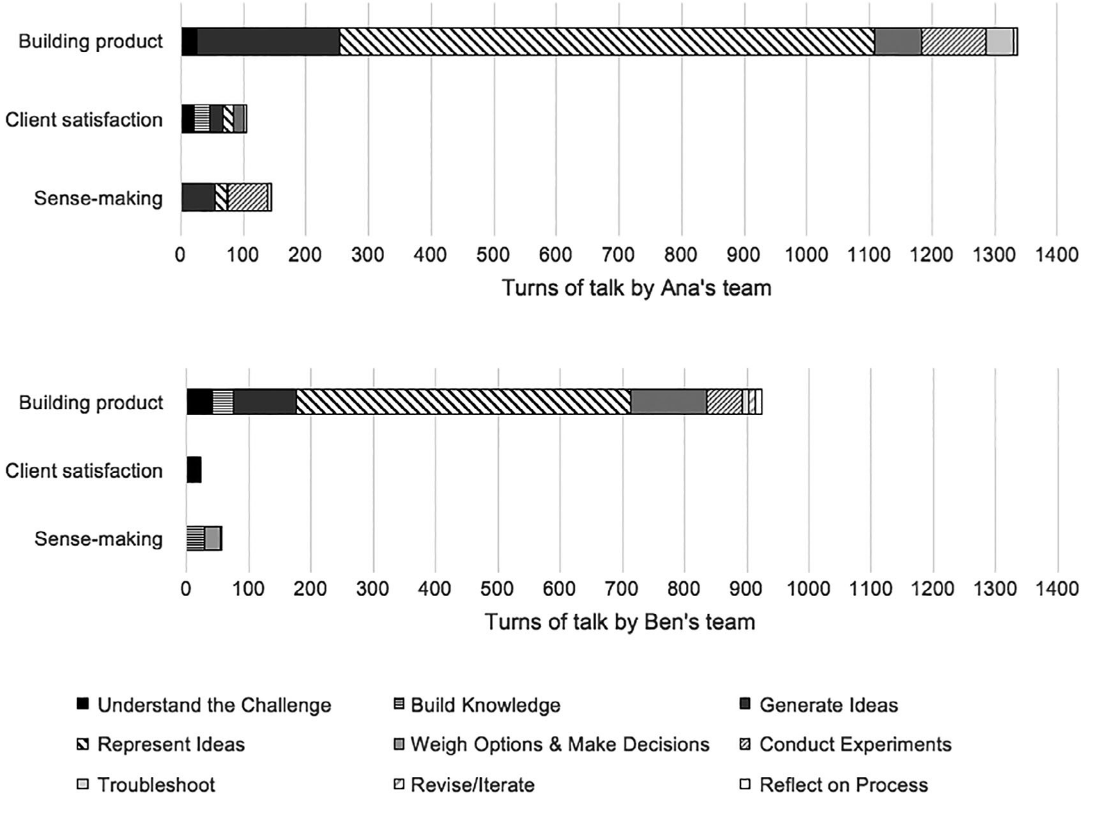

FIGURE 2 Frequency of engagement in engineering design practices during three different epistemological frames

design practices of generating ideas to solve the problem, representing those ideas, conducting physical experiments, and troubleshooting an assembled prototype. Ben's team, on the other hand, framed the design challenge as a sense-making activity only when they were building knowledge about the design problem and weighing options toward making a design decision. A similar difference occurred for framing the design challenge as a client satisfaction task. Ana's team engaged in six different design practices while being oriented toward satisfying the client: understanding the challenge, building knowledge, generating ideas, representing ideas, weighing options, and reflecting on process. By contrast, understanding the challenge was the only design practice in which Ben's team meaningfully engaged while oriented toward a goal of client satisfaction.

These results mean that particular design practices do not necessarily imply particular epistemological framings, and that attending to framing is different than noticing design practices. Learners employing the same sets of design practices might be framing the goal and purpose of their activity quite differently. Instructors may miss important aspects of learners' progress if they check off design behaviors only. If we had coded only for design practices, we would have counted both teams as working to build knowledge about the design problem, and we would have seen both teams conducting experiments with physical materials and collaboratively weighing options before making design decisions. We may have concluded their design process approaches were roughly similar, and similarly productive. Yet coding for epistemological framing enabled us to see the reasons *why* each team carried out particular design practices—that is, toward what epistemic goal they were applying a particular practice. For example, Ana's team conducted experiments to make sense of mechanisms and to build a product, whereas Ben's team conducted experiments only to build a product.

6.6 | Comparison of epistemological framings for teaching and learning engineering

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 frequently wondered about and looked for evidence of the success or failure of her teaching moves. Ana's interactions with her students and reflections on teaching suggest that she wanted her students to build knowledge collaboratively about how designed things work, with equal emphasis on engineering design and science reasoning through design tasks.

By contrast, when Ben worked on his own engineering designs, he took up the goal of getting the job done; he wanted to deliver a functioning product that would meet the engineering design criteria set out by the facilitators of the professional development institute. When facilitating students' engineering design, he provided particular materials and assigned prototyping tasks that would provide context for him to deliver scientific explanations about how the prototypes worked. His reflections on teaching emphasized classroom management and how to model design process steps. Ben's management of his students' design process and his reflections on the after-school workshop suggest that he wanted his students to acquire the scientific explanations that he shared with them about their hands-on work. He appeared to use engineering as a hands-on context to equip students with ready-made scientific explanations.

7 | 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 also identified their engineering design practices during a design task. Considering only observable disciplinary practices, we found that Ana and Ben participated in the same range of engineering design activities. However, when also considering epistemological framing dynamics, we found that they operated under different sets of expectations for the meaning of engineering learning and teaching. While Ana framed both engineering learning and engineering teaching as acts of *building knowledge*, Ben framed engineering learning as an act of *delivering a product* and engineering teaching as an act of *delivering knowledge.* It is beyond the scope of this analysis to explore the reasons why Ana and Ben exhibited such different epistemological framing dynamics. We argue only that the goals they took up for themselves were different, and that Ana's goals as both learner and teacher foregrounded building knowledge for oneself, while Ben's goals as both learner and teacher focused on delivering something—either tangible product or conceptual knowledge—to someone else.

Readers may question why this result matters. At face value, the work done by both Ana and Ben's students in the after-school program seemed consistent with what many would consider good engineering design practice for elementary students: they all built and tested physical artifacts to solve real problems (Moore et al., 2014). However, at a deeper level, the two groups of students were experiencing different perspectives on what it means to do engineering. This outcome is reminiscent of Carlone, Haun-Frank, and Webb's (2011) comparative ethnography of two elementary classrooms both deemed at the surface level to be sites of reform-based science teaching. Through the investigations that they selected for students, the two elementary teachers in Carlone et al.'s study appeared to provide similar opportunities for students to engage in science practices. Yet, they established different social and cultural norms for science discourse and thus sent different epistemological messages to their students about what *doing science* means (Berland et al., 2016; Russ & Luna, 2013). One teacher positioned science as individual turn-taking to try out ideas while the other positioned science as collective problem solving and investigation.

This difference in epistemological messaging had important consequences for the students' learning trajectories: all of the students in the collective problem solving-classroom ended up identifying themselves as similar to smart science students, while only half of the students in the turn-taking classroom (and none of its students of color) did (Carlone et al., 2011). Moreover, the students in the collective problem-solving classroom tended to describe doing science as observing, thinking, and being a good team member. The students in the other classroom tended to associate doing science with answering teachers' questions correctly. We could not collect student-level video data in our study, but applying the findings from Carlone et al.' work, we might reasonably expect Ana's students and Ben's students to have drawn different conclusions about what counts as doing engineering.

As noted earlier, the data collected for this study do not support claims about causation of the observed 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 an association between the learning and teaching framings for both 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.

Another way to look at teachers as engineering learners is to analyze their design practices, processes, or products (Crismond & Adams, 2012; Shah, Smith, & Vargas-Hernandez, 2003). 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 provided insights to the team's goals and focus, whereas coding for design practices told us more about the actions on which the team spends it time and the strategies it uses to solve a design problem.

Our data also do not support any claims about the abilities or capacities of Ben and his team members. Rather, we are describing the epistemological resources that were activated (Louca et al., 2004) and the framing dynamics (Scherr & Hammer, 2009) 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, etc. We are not claiming that some characteristic of Ben or his team was flawed and needed to be strengthened. Instead, we argue that we, as instructors, might have paid more attention to the epistemological framing dynamics that happened, so that Ben might have been tipped toward a different epistemological stance for the teaching of engineering to elementary students.

Looking at framing also reminds us that success in *learning* engineering design can be achieved quite distinctly from success in *doing* engineering design. This distinction between what is productive for professional doing and what is productive for learning a discipline has recently received attention in science education (Berland et al., 2016; Elby & Hammer, 2001; Russ, 2014), and we consider it a powerful idea for engineering education as well. Russ points out that there has long been a limited "tacit model of epistemology and learning" which holds that "professional scientists do X and think like Y; therefore learners of science should also do X and think like Y" (2014, p. 389). She calls for science educators to pivot "toward thinking about learners as adopting epistemologies *for* science" such that "the motivation for and value of particular learner epistemologies is the productivity of those epistemologies for constructing knowledge of the natural world" (p. 391).

In engineering education, what might happen if we similarly began to measure epistemologies not for their "fidelity to professional epistemologies" but according to their productivity for constructing knowledge of the designed world (and abilities to re-design it)? Learning to participate in engineering design is not the same thing as professional designing (Danielak et al., 2014; Harel & Papert, 1991; Roth, 1996). 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 by Ben's team was inexpensive, reliable, and functional. Paula actually took it home and tested it over the weekend. The pipe-and-tubing system by Ana's team 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. However, our data suggest that Ana's team may have *learned* engineering better.

Put another way, one could argue that Ben's epistemological framings—which more often treated engineering design as building a product—were closer to professional engineers' epistemologies *of* engineering. However, they may have been more limited than Ana's epistemological framings—which more often treated engineering design as a chance to make scientific sense of the way technological artifacts were working—as epistemologies *for* engineering. Ana's adoption of more productive epistemologies *for* engineering may explain why she was more engaged in the disciplinary pursuit of a design solution, and why 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 opportunities to problematize and thus more intellectually engaging moments (Chin & Chia, 2004) on which she could reflect 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 opportunities to develop epistemic understandings about the disciplinary substance of engineering design (Coffey, Hammer, Levin, & Grant, 2011) .

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 out" (Schwarz, Passmore, & Reiser, 2017). Engineering design is a rich sociocultural activity and collaborative intellectual endeavor (Cunningham & Kelly, 2017b). Teacher preparation programs can play a role in preventing it from being reduced only to a simple design process algorithm or a physical building activity. Preservice methods courses and teacher induction programs can expose novice teachers to a range of windows into engineering design in action, engage them in interesting engineering design problem-solving that supports their own knowledge construction about the designed world, and help them reflect on what it means to learn engineering.

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