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Kristen Bethke Wendell

University of Massachusetts Boston, kristen.wendell@umb.edu

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Abstract

The incorporation of engineering practices and core ideas into the *Next Generation Science Standards* at the elementary school level provides exciting opportunities but also raises important questions about the preparation of new elementary teachers. Both the teacher education and engineering education communities have a limited literature base on the resources that novice elementary teachers bring to learning and teaching engineering. The purpose of this descriptive exploratory research study was to characterize the design practices used by preservice elementary teachers during an integrated engineering and literature experience. Using a modification of the Design Activity Coding Scheme (Atman et al., 2007), we examined the discourse of a team of preservice teachers as they worked on an engineering design challenge based on children's literature. The modified coding scheme included indicators for the teachers' design practices and conversational moves. We analyzed the coded data for patterns of design practices across group members and over time, and for evidence of the group's perceptions of the goals of their activity – their epistemological framing. The preservice teachers' utterances were almost evenly divided between design practices and conversational moves, and most design practices were distributed evenly across all members of the group. Conversational moves were concentrated within a subset of members. The teachers' discourse gave evidence of stable framing of their activity as a design task rather than as an exercise in satisfying the instructor's directions. However, within the design task framing, the teachers emphasized the design practices of generating possible solutions and feasibility analysis at the expense of information gathering, design solution modeling, and detailed evaluation of proposed solutions. The teachers' design practice profile differs substantially from that of both novice and expert professional engineers. The findings of this research suggest that novice elementary teachers may need opportunities to see the fruitfulness of problem definition and detailed analysis for engineering design success.

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Design Practices of Preservice Elementary Teachers in an Integrated Engineering and Literature Experience

Kristen Bethke Wendell

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Abstract

The incorporation of engineering practices and core ideas into the *Next Generation Science Standards* at the elementary school level provides exciting opportunities but also raises important questions about the preparation of new elementary teachers. Both the teacher education and engineering education communities have a limited literature base on the resources that novice elementary teachers bring to learning and teaching engineering. The purpose of this descriptive exploratory research study was to characterize the design practices used by preservice elementary teachers during an integrated engineering and literature experience. Using a modification of the Design Activity Coding Scheme (Atman et al., 2007), we examined the discourse of a team of preservice teachers as they worked on an engineering design challenge based on children's literature. The modified coding scheme included indicators for the teachers' design practices and conversational moves. We analyzed the coded data for patterns of design practices across group members and over time, and for evidence of the group's perceptions of the goals of their activity – their epistemological framing. The preservice teachers' utterances were almost evenly divided between design practices and conversational moves, and most design practices were distributed evenly across all members of the group. Conversational moves were concentrated within a subset of members. The teachers' discourse gave evidence of stable framing of their activity as a design task rather than as an exercise in satisfying the instructor's directions. However, within the design task framing, the teachers emphasized the design practices of generating possible solutions and feasibility analysis at the expense of information gathering, design solution modeling, and detailed evaluation of proposed solutions. The teachers' design practice profile differs substantially from that of both novice and expert professional engineers. The findings of this research suggest that novice elementary teachers may need opportunities to see the fruitfulness of problem definition and detailed analysis for engineering design success.

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Elementary teacher education programs have long faced the daunting task of preparing their teacher candidates to guide not only children's social and emotional development but also their learning across the academic disciplines of mathematics, the English language arts, social studies, and science (Hollins, 2011). This task has just been expanded by the *Next Generation Science Standards* (NGSS Lead States, 2013), which differ from previous national science education frameworks in several fundamental ways, including the elevation of engineering design "to the same level as scientific inquiry in science classroom instruction at all levels" (NGSS Lead States, 2013, p. 337). This prominence of engineering in the NGSS performance expectations for the elementary school grade bands raises new challenges and opportunities in preparing elementary teachers to teach engineering.

Correspondence concerning this article should be sent to Kristen Bethke Wendell at kristen.wendell@umb.edu.

The nature of these challenges and opportunities is dependent on the particular way the *NGSS* characterize the discipline of engineering. The *NGSS* focus on *design* as the key, unifying activity of the engineering enterprise. By design, the *NGSS* mean the iterative development of an object, process, or system to meet human needs and wants. The practices of engineering included in the *NGSS* – identifying problems and designing solutions – are design practices, and the three disciplinary core ideas of engineering included in the *NGSS* are ideas about design – defining and delimiting an engineering problem, developing possible solutions, and optimizing the design solution. A large body of research supports this design-focused characterization of engineering. Ethnographers and other scholars of the engineering enterprise have repeatedly shown design to be a central activity across all fields of engineering (Bucciarelli, 1994; Petroski, 1998; Vincenti, 1990), and research on engineering education has shown the practices and ideas of design to be important learning goals for all prospective engineers (Crismond & Adams, 2012).

This focus on design as engineering's key activity means that the new task for teacher educators is to prepare preservice teachers to teach the practices of and ideas about engineering design. While some policymakers and curriculum developers, including this author, have focused on engineering design problems as vehicles or contexts for science learning (Cunningham, 2009; Kolodner, 2006; Mehalik, Doppelt, & Schunn, 2008; National Research Council [NRC], 2009; Wendell & Rogers, 2013), this might overlook the facts that much more time in the typical elementary school schedule is devoted to the English language arts than to science, and that as generalist educators, elementary teachers are asked to make explicit connections across all academic subjects (Knipper & Duggan, 2006). Without extra time in the school day set aside for engineering, new elementary teachers will look for engineering experiences that are well aligned with the rest of the curriculum and that can accomplish objectives in other content areas as well. If teacher education programs can provide models for connecting engineering not only to science but also to reading and writing, elementary teachers may more easily try out identities as teachers of engineering and more readily embrace learning to teach engineering.

In most elementary teacher education programs, there will not be room for an additional course on engineering because these programs are already squeezed by state requirements for coursework on special education, English language learners, and child development, not to mention math, English language arts, science, and social studies content and methods (National Research Council [NRC], 2010). Learning to teach engineering design will need to fit into other content and methods courses, and therefore approaches that integrate engineering design with as many academic disciplines as possible will be attractive not only

to preservice teachers but also to teacher educators. The question for teacher educators is, how can we help preservice teachers develop the knowledge and understanding they need to integrate engineering into their elementary classrooms?

Currently the teacher education community has a limited knowledge base on how preservice teachers at the elementary level learn to facilitate engineering learning. We know that they typically enter teacher education programs having had minimal college-level coursework in science and none in engineering (Fulp, 2002). We also know that professional development on engineering design for in-service elementary teachers can increase their awareness of aspects of the engineering design process, especially the practices of testing and building and the substantial time required for a complete design cycle (Hsu & Cardella, 2013; Hsu, Cardella, & Purzer, 2010). We do not know if engineering design learning experiences for preservice teachers, who do not yet have classrooms of their own, can have a similar impact. More research is needed to inform new models for preparing preservice elementary teachers to teach engineering. The study presented here contributes to this emerging field by focusing on what resources for teaching engineering new teachers already exhibit and how they need to be further equipped to address the engineering dimensions of the *NGSS*.

This paper reports on a study within a larger project that is exploring one promising model for bringing engineering to the elementary classroom: integrating engineering with children's literature and literacy skills. In the integrated engineering and literacy approach, design challenges are drawn from children's literature. Students and teachers read narrative texts carefully, analyze the plot for problems faced by the characters, identify which problems might be addressed by engineering design, plan and test solutions to those problems, and then reflect in writing about the problems and solutions. The Integrating Engineering and Literacy project is exploring the potential of this approach for fostering the beginnings of engineering while also supporting literacy development in elementary students (McCormick & Hynes, 2012; Spencer, Watkins, & Hammer, 2013; Watkins, Spencer, & Hammer, 2014). But the project team is also interested the affordances and constraints of the approach for in-service and preservice elementary teachers. In particular, we are interested in *preservice* teachers' interactions with literature-based engineering experiences, with an eye toward identifying what further preparation or practice they might need to be effective at bringing engineering design to their future students. In order to design effective elementary teacher preparation approaches in engineering, teacher educators need to know more about preservice elementary teachers' starting points (NRC, 2009). What do they already know about engineering? What aspects of engineering practice are their strengths, and where are their weaknesses?

The purpose of the exploratory, descriptive research study described in this paper is to add to the research base on preservice teachers' starting point for learning to teach engineering design. Our intent is to contribute a case study of the engineering design practices used by preservice teachers as they participate in an integrated engineering and literacy learning experience. Because preservice elementary teachers tend to express confidence in reading narrative literature (Tschannen-Moran & Johnson, 2011), we expected the teachers in this study to feel comfortable tackling the literature-based engineering tasks. Our study was framed by the initial hypothesis that when solving engineering problems linked to fictional characters, teachers' identification with the characters might lead them to emphasize the practices of problem scoping (i.e., what does this character really need?) and idea generation (i.e., what would please this character?), while neglecting the practice of detailed development (i.e., what would be the actual structure and function of our product?).

Research Framework and Questions

In examining preservice teachers' engineering design practices, we take a situative, sociocultural perspective on the learning of engineering (Brown, Collins, & Duguid, 1989; Johri & Olds, 2011). According to this perspective, meaningful opportunities for the learning of engineering tend to be situated within social, collaborative work on real engineering tasks and in the context of practices consistent with engineering culture. Studies of engineers at work have shown that these practices include, for example, defining the engineering design problem to be solved, framing the problem from one's own and the client's experiences, determining requirements and constraints, evaluating tentative design ideas before implementing them, analyzing and testing potential and realized solutions, and creating representations of designed artifacts (Ahmed, Wallace, & Blessing, 2003; Bucciarelli, 1994; Cross, 2003; Dym, 1994; NRC, 2009; National Research Council [NRC], 2012; Tang & Leifer, 1991). The body of research shows that informed engineering designers carry out these practices in patterns that are distinct from those of beginning designers, and design expertise is characterized by these "informed design" strategies (Crismond & Adams, 2012).

We adopt a discourse analysis approach (Lemke, 1998) to investigating preservice teachers' participation in engineering practices. In particular, the framework we use to analyze the discourse of the teachers during their design process is the Design Activity coding scheme developed by Atman and colleagues (Atman, Adams, Mosborg, Cardella, Turns, & Saleem, 2007). Validated by the broad body of research on engineering design cognition and behavior (for a recent review, see Crismond & Adams, 2012), the Design Activity coding scheme includes codes for the phases

of problem scoping (problem definition and information gathering), alternative solution development (idea generation, modeling, feasibility analysis, and evaluation), and project realization (decision and communication). Originally developed through a synthesis of textbooks commonly used in first-year engineering classes (Moore et al., 1995), the Design Activity coding scheme was applied to verbal protocol analysis of the design processes of individual college freshmen and seniors (Atman & Bursic, 1998; Atman, Chinka, Bursic, & Nachtmann, 1999). Later Atman and colleagues applied the framework to compare college seniors and practicing engineers completing the same individual design task (Atman, Adams, Mosborg, Cardella, Turns, & Saleem, 2007) and to study changes in college students' design processes from their freshman to senior years (Cardella, Atman, Turns, & Adams, 2008). Yasar-Purzer and colleagues then showed the application of the coding scheme to data from teams of engineering undergraduates (Roberts, Yasar, Morrell, Henderson, Danielson, & Cooke, 2007; Yasar-Purzer, Henderson, McKay, Roberts, & de Pennington, 2008).

Recently colleagues on our research team (Watkins, Spencer, & Hammer 2014) called for a move beyond "simple codes and counts" toward a more "expansive methodology" for characterizing learners' engineering design practices. They were specifically studying children's problem scoping practices, and they expanded on previous work in two ways. They enlarged the definition of problem scoping to include not only naming the elements of a problem but also more features from expert accounts, including setting the problem context and reflecting on the constructed problem space. They also qualitatively analyzed long passages of children's discourse rather than parsing it into short excerpts to be coded. In this paper, we also attempt to move beyond "coding and counting," although we do *begin* our analysis by coding utterances and considering frequencies of problem scoping, solution development, and project realization behaviors. However, we expand on previous methodology by analyzing design discourse not only for these practices but also for certain conversational elements, and by considering not only short utterances but also long passages and the evidence within for epistemological framing. Our work uses a modified Design Activity coding scheme that takes into account conversational moves like re-voicing a teammate's idea and commenting on the instructor's directions for the task (Figure 1). We describe this coding scheme modification in greater detail in the Data Analysis section of the paper.

The use of the modified Design Activity coding scheme allows us not only to characterize preservice elementary teachers' design practices within an integrated engineering and literacy activity, but also to examine the stability of teachers' *framing*, or interpretation, of the literature-based engineering task. In this aspect of our study, we use the

Figure 1. Diagram outlining Atman et al.'s (2007) Design Activity coding scheme and the expansion made in the present study to analyze conversational moves within design teams.

term framing not to refer to the way engineers frame an engineering design problem (e.g., Cross & Clayburn Cross, 1998), but to the way preservice teachers perceive the purposes and goals of an academic activity. When we look at the teachers' framing of their activity, we are interested in what kind of "game" they perceive themselves to be playing. For example, is it a "classroom game," where the purpose is to complete a set of instructor-given exercises and the goal is to earn a good grade (Lemke, 1990)? Or an "engineering game" with the purpose of designing an artifact and the goal of convincing others that it functions well within constraints? The term framing is used in this way across sociolinguistics, anthropology, and other social science research fields to refer to individuals' underlying expectations for what they are experiencing (Tannen, 1993). Research on framing in educational settings typically examines the ways in which learners use previous experiences to set their expectations for current and future learning situations (Berland & Hammer, 2009; Hammer, Elby, Scherr, & Redish, 2005; Hutchinson & Hammer, 2010). Such research typically focuses on learners' *epistemological framing*, which refers to how learners understand their activity with respect to knowledge, reasoning, and learning (Scherr & Hammer, 2009). In this study we are interested in how the preservice teachers make sense of the activity of literature-based engineering design in a graduate-level teaching methods course. Does their discourse suggest that they understand themselves to be

playing a classroom game, an engineering game, a reading comprehension game, or some other kind of game? We are also interested in the *stability* of the preservice teachers' epistemological framing. 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 (Berland & Hammer, 2009). 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 dynamic nature of these factors influences the stability of that framing. First and foremost, learners' past experiences are organized into "schemas" about certain contexts or situations (Bartlett, 1932), and these schemas contribute to their sense of what is going on in a current activity. For example, preservice teachers' past experiences in methods courses 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 actions and speech of fellow learners and instructors. All aspects of communication, including words, tone of voice, gestures, body language, and eye contact, convey a message about how an individual is framing a task, and this message influences other individuals' sense 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 the

past experiences of the learner to help learners determine whether they are being asked to complete a required task (Berland & Hammer, 2012). 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 preservice 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 that teachers bring with them to a teacher preparation program. First and foremost, preservice teachers walk into the methods classroom expecting to learn to teach something, and this typically involves playing and then unpacking the role of a student in a “classroom game.”

With the perspectives of engineering as a cultural practice and epistemological framing in mind, we established three research questions to guide this study:

1. What engineering design practices do preservice teachers use when they participate in a collaborative engineering design task based on children’s literature?
2. Over the course of the design task, to what extent are the design practices distributed among preservice teachers collaborating in the same group?
3. Over the course of the design task, what patterns occur in how the preservice teachers move from one practice to another, and what do these patterns suggest about the teachers’ framing of the design task?

Study Design

The study participants were 26 graduate students enrolled in an elementary science teaching methods course at a large urban public university in the northeastern United States. On three different occasions, these preservice teachers worked in small groups on engineering design experiences that were based on problems faced by the main characters in works of children’s literature. In the first challenge, participants designed devices that would help a champion swimmer cross the English Channel (based on a biographical text about the swimmer Gertrude Ederle). After this experience, participants read a selection on science and engineering practices from the *Framework for K-12 Science Education* (NRC, 2012), and they viewed the ABC Frontline

Deep Dive video showcasing the design process at the product design firm IDEO. In the second literature-based engineering experience of the semester, participants designed “older sibling” furniture that would help an elementary-school-aged child cope with an energetic and intrusive toddler sibling (based on Judy Blume’s 1972 novel *Tales of a Fourth Grade Nothing*). In the third engineering experience, participants identified problems faced by the characters in the novel *From The Mixed Up Files of Mrs. Basil E. Frankweiler* (Konisburg, 1967) and developed related engineering tasks that elementary school students could tackle. The preservice teachers did not design solutions themselves during this third experience.

During all three literature-based engineering experiences, we collected data in several forms. We video-recorded all whole-class discussions as well as all small-group work by one team in each experience. Teams had four to six members, and there were five or six teams during each task. Although we have video data from only one small group per experience, the data from one group are rich enough for us to learn much about preservice elementary teachers’ engineering. We also took photos of all artifacts created by all groups during the champion swimmer and furniture design tasks, including three-dimensional models, sticky notes, chart paper posters, and sketches.

We selected the furniture design task as the focus of our analysis for two main reasons. First, we wanted to look at the preservice teachers’ engineering when they were at least modestly informed about the nature of engineering and when they felt comfortable working together in small groups. The champion swimmer design task was many teachers’ very first exposure to engineering, and it took place so early in the semester the teachers were still devoting much of their energy to managing social dynamics. Second, compared to the data from the champion swimmer task, the data from the furniture design task was more analogous in structure to that reported in previous applications of the Design Activity coding scheme, where Atman and colleagues studied the design processes of novice and expert engineers (Atman et al., 2007; Cardella et al., 2008). By focusing on the furniture design task, we would be able to compare the preservice teachers’ processes with those of practicing engineers in previous studies.

Figure 2 shows the furniture design task instructions presented to the preservice teachers. The design brief included three design requirements related to safety, older siblings’ privacy, and appeal to children and parents. It also stated two constraints: a materials budget of \$100 and adherence to the U.S. Consumer Product Safety Commission guidelines. The instructions handout also suggested four steps the design teams might take: brainstorming, deciding on a potential solution, determining tests to be conducted, and planning a pitch, which could optionally include demonstration of a physical prototype. The teachers worked

<h2 style="text-align: center;">A Better Bedroom for Peter</h2> <p><i>The Land of Nod</i> wants to offer a line for an “older sibs bedroom” for kids with toddler siblings. They’ve hired our engineering firm (our class) to design a suite of products.</p> <p>The Land of Nod is interested in furniture, protective equipment, safety devices, or any other technologies that will meet these requirements:</p> <ol style="list-style-type: none"> 1. Keep toddlers safe from older siblings’ things 2. Offer older siblings some protection of their belongings and some privacy 3. Be appealing to both kids and parents <p>They’ve stated two constraints:</p> <ol style="list-style-type: none"> 1. Cost of materials for any single product must be less than \$100 2. All products must meet safety guidelines of the U.S. Consumer Product Safety Commission 	<p>Keeping in mind Peter and his family as potential “end users,” work with your team to:</p> <ol style="list-style-type: none"> 1. Brainstorm (using the Post-It method) 2. Decide on potential solution(s) to pursue 3. Determine the tests you would have to conduct to make sure the solution(s) meets requirements and satisfies constraints 4. Plan a 60-second “pitch” to make the other teams in our engineering firm. <p>Your pitch:</p> <ol style="list-style-type: none"> 1. May include physical prototype(s), but does not need to 2. Should specify the tests that would have to be conducted 3. Describe why Land of Nod would want to offer your solution(s) to its customers
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Figure 2. Prompts specifying the furniture design task related to the children’s book *Tales of a Fourth Grade Nothing* (Blume, 1972). The prompts list the design requirements and constraints as well as a general procedure for the design teams to follow.

in randomly assigned small groups; they did not choose their teammates.

Data Analysis

We transcribed the video data from one small group’s collaboration on the furniture design task. The transcript was then divided into utterances. Each new speaker’s turn marked the beginning of a new utterance. To code the utterances for the preservice teachers’ design process, we used a systematic, iterative process of qualitative data analysis drawing from methods of discourse analysis (Lemke, 1998) and constant comparative analysis (Glaser & Strauss, 1967). This process involved applying the existing Design Activity coding scheme (Atman et al., 2007; Cardella et al., 2008) as well as defining emergent codes to describe the conversational moves among participants. We made room for emergent codes because unlike the data for which the original coding scheme was designed, our data involved a multi-person discussion rather than a single person’s think-aloud. We anticipated that there might be need for codes about conversational moves that could not be described strictly as engineering design practices. The coding process was conducted by two researchers: an elementary teacher educator who was previously a mechanical and aerospace engineer, and a doctoral student who had previously worked as a mechanical engineer.

The coding process proceeded along the following steps. First, the two researchers independently conducted line-by-line coding of the entire furniture design small-group episode using the original Design Activity coding scheme (Atman et al., 2007). With an inter-rater exact match of only 36%, it was clear that additional codes were needed to capture the utterances not clearly falling into one of the

Design Activity categories. The researchers iterated on category definitions and assignments until they reached consensus on a set of categories that described the preservice teachers’ engineering design practices as well as their conversational moves. The resulting set of categories included the full set of eight design activities from the Design Activity coding scheme (Atman et al., 2007) and five additional codes for conversational moves: re-voicing design ideas, agreeing with design ideas, disagreeing with design ideas, requesting clarification of design ideas, and debating the task instructions given by the professor. Inter-rater exact match when all utterances were coded with these 13 categories was 51%. The two coders discussed each discrepancy, and the final codes applied to all utterances were consensus codes assigned jointly by the two researchers. The nature of the discrepancies varied, but our most frequent initial disagreements dealt with whether the participants were simply revoicing an idea or generating or modeling a new one. During the consensus process, we carefully reviewed all previous utterances to determine whether indeed, the participants were re-stating an idea that had already been voiced, or whether they were putting a new design or detail on the table. Most of the time, we found prior evidence of the idea and came to consensus on assigning the revoicing code. We also found it problematic at first to agree on whether the participants were analyzing the feasibility of a proposed solution or simply requesting clarification of an idea. Here we used the consensus process to strictly apply the criteria that feasibility analysis required passing judgment on a design idea, and requesting clarification involved wanting to understand the idea under consideration but did not include making a judgment about whether it would work. Table 1 presents the modified Design Activity coding scheme used in this study.

Table 1

Modified design activity coding scheme for engineering discourse analysis (adapted from Atman et al., 2007).

Code	Examples from Pre-Service Teachers' Furniture Design
Design Activities (Atman et al., 2007)	
(PD) PROBLEM DEFINITION - Defining what the problem really is by re-stating the problem statement, identifying criteria and constraints, or re-framing the problem	"Was the requirement that the whole thing had to cost \$100?"
(GATH) GATHER INFORMATION - Stating the need for, searching for, asking for, or collecting additional information needed to solve the problem	N/A
(GEN) GENERATE IDEAS - Stating potential solutions (or parts of potential solutions) to the problem, and playing with and fleshing out those ideas	"Maybe the older kid can like put the ladder up when he's there, and take it away when he's not there."
(MOD) MODELING - Detailing how to build the tentative or final solution (or parts of the solution) to the problem. Involves making estimates, calculations, or fitting an element into the overall design	"I would say like [holds hands about 2 feet apart]."
(FEAS) FEASIBILITY ANALYSIS - Passing judgment on whether a possible or planned solution to the problem (or the parts of the problem) will function and meet the problem's criteria and constraints	"I'm worried about the height. I climbed stuff when I was a kid."
(EVAL) EVALUATION - Comparing and contrasting alternative solutions or solution elements, along a particular dimension such as strength or cost	"I think it would be better separate cuz those that already have a bed have the option of buying the chest separate."
(DEC) DECISION - Selecting one solution to the problem (or parts of the problem) from among those considered, or eliminating a design option, or explicitly changing one's mind about the solution	"This is, my product name is Chameleon Safe [puts sticky note that says "Chameleon Safe" on chart paper]."
(COM) COMMUNICATION - Communicating to external parties the elements of the decided-upon design, via sketches, diagrams, lists, or oral or written reports	"I'll give the pitch."
Design-Related Conversational Moves	
(REV) REVOICING - Restating one's own or other's idea related to the engineering task to affirm or check understanding	Speaker 1: "It would just look like a shoe box." Speaker 2: "A BIG shoe box."
(REQ) REQUEST - Requesting further clarification about an idea or a response from others about an idea; <i>not used for requests about instructor's intent</i>	"So what are we gonna do?"
(AGR) AGREEMENT - Without restating, acknowledging understanding of an idea or expressing favorable response; <i>if favorable response labels a particular dimension of the problem, should be coded EVAL</i>	"Mm-hm. That's a great idea."
(DIS) DISAGREEMENT - Expressing disagreement with other's statement or general unfavorable response to an idea, without feasibility analysis	"Well, no, but I'm, I'm thinking of, no, I'm thinking like it's more, it could be more like a chest."
(INT) INSTRUCTOR'S INTENT - Discussion of the instructional requirements rather than the engineering task; request for clarification about what the instructor has assigned	"Supposed to do 4 to 10 [sticky notes]. [Distributes more sticky notes]."
Other	
(OTH) OTHER - Conversation not relevant to the problem being solved; none of the other codes apply	"[Side conversation about electrical outlet near the desk]."

Findings

Overview of Focus Episode

Here we summarize the episode selected for analysis, which includes 17 minutes of small-group work in which six preservice teachers collaborate on the older sibling furniture design task (Table 2). As the episode begins, the group members are sitting down together and remarking that they all seem to be thinking similarly of a storage device for the older sibling. The conversation takes off in the direction of proposing features for an above-bed storage device. About two minutes in, after several options for storage access have been voiced, four out of the six group members notice the sticky notes distributed by Cathy and begin writing on them. The resulting notes say "Locker Safe," "built in chest w/keypad," "high cubby/door; sliding drawers," and "crawl space over bed w/removable ladder" (Figure 3). After discussion of the

"chest w/keypad" idea, Ben announces that the product should be called "Chameleon Safe" and adds another note to the chart. Flor reminds the group that they have to pitch a solution to the rest of the class, and they brainstorm options for the safe's locking mechanism. Deanna then questions whether the safe will be a stand-alone product or built into another piece of furniture, like a bed. This leads Cathy, at seven minutes in, to question whether the product can be built for \$100. The group discusses options for inexpensive fabrication until, at nine and a half minutes in, Deanna requests that they make a decision about the product's shape. In response, Ben, Flor, and Emilia construct the idea that the product's shape could be customizable – customers could request an animal or sports-themed shape, for example. Following this exchange, Ben again asserts his desire to pitch the Chameleon Safe. Cathy questions again whether the team has made a firm decision about what to pitch, and whether the Chameleon Safe will address the problems faced by

Table 2
Summary of small-group furniture design episode.

Time	Focus of Discussion
0 min	Brainstorm ideas for above-bed storage with several options for access (slider, drawer, cubby)
2 min	On sticky notes: "Locker Safe," "built in chest w/keypad," "high cubbys/door; sliding drawers," and "Crawl space over bed w/removable ladder"
3 min	Product name suggestion: "Chameleon Safe"
4 min	Brainstorm ideas for location and lock of Chameleon Safe
6 min	Brainstorm ideas for the appearance of the Chameleon Safe;
7 min	Brainstorm ideas for low-cost materials
9 min	Insistence that "the materials manufacturing are so cheap" and non problematic
10 min	Proposal for customizable appearance of Chameleon Safe
11 min	Affirmation of Chameleon Safe as design solution
12 min	Questions about size of the safe and configuration of drawers/doors/access
13 min	Questions about whether the safe addresses the problem faced by the book's main character
13 min	Discussion of product tests, including tests of the safe's lock
14 min	Brainstorm ideas for features of the lock mechanism
15 min	Renewed concern about whether the problem in the book has been solved
16 min	Renewed discussion of material composition
17 min	Summary of design solution: "It's like a secure toy box, basically"

the main character of the story. April and Ben review the instructor's handout and return the conversation to the tests that would have to be conducted before bringing the product to market. This move leads to renewed conversation and generation of ideas about the locking mechanism. At 15 minutes in, Cathy interjects with renewed concern about whether the problem in the book has been solved. Her teammates insist that the specified design problem has been solved, even if some problems in the book would remain. After a final conversation about the material

composition and dimensions of the Chameleon Safe, April summarizes their design solution "It's like a secure toy box, basically," and Ben affirms, "Exactly. It's really just a toy box." The team appears satisfied with their design decisions, as Flor tells the instructor they are ready to make their "pitch." They have planned for Ben to describe the Chameleon Safe with a simple speech. Unlike the other teams, this group has not created a diagram of their proposed solution or a poster to aide in their presentation. This team has also not taken advantage of the building

Figure 3. Chart paper with sticky notes posted by team members to represent their design ideas for furniture that would be appealing and safe for school-age children with toddler siblings.

Table 3
Purpose of utterances by pre-service teachers during furniture design task.

Code	Frequency	Percent
Design Activities		
PD (Defining the problem)	13	5%
GATH (Collecting needed information)	0	0%
GEN (Proposing design solutions)	49	19%
MOD (Specifying design details)	14	5%
FEAS (Passing judgment on possible design solutions)	31	12%
EVAL (Evaluating along particular dimension)	5	2%
DEC (Making design decision)	5	2%
COM (Communicating design to external parties)	1	0%
Conversational Moves		
REV (Restating design idea)	43	17%
REQ (Requesting clarification)	30	12%
AGR (Expressing agreement)	34	13%
DIS (Expressing disagreement)	4	2%
INT (Discussing instructor's intent)	15	6%
Other		
OTH (Conversation not relevant to design task)	14	5%
Total	258	100%

materials in the classroom to build any sort of model or prototype (but neither has any other team).

Findings for Research Question 1

What engineering design practices did preservice teachers use when participating in a collaborative engineering design task based on children's literature?

In the 17-minute episode, there were 258 audible utterances by the group of six preservice teachers. As they worked on the furniture design problem, the group engaged five or more times in six of the eight design practices of the coding framework (Table 3). The group's most frequent practices were generating potential solutions or parts of the solution (GEN: 49 utterances; 19% of total) and assessing or passing judgment on a possible solution or part of solution (FEAS: 31 utterances; 12% of total). Occurring less frequently were the practices of problem definition (PD: 13 utterances, 5% of total), modeling details of the solution (MOD: 14 utterances, 5% of total), evaluating solutions along a particular dimension (EVAL: 5 utterances, 2% of total), and deciding on one idea for the solution (DEC: 5 utterances, 2% of total). They did not exhibit the practice of explicitly gathering information needed to solve the problem, and they engaged in communicating design elements to external parties only one time.

About half of the group members' speech was devoted to design activity, and the other half was devoted to affirming or changing the emphasis of the oral conversation. Of the 258 utterances by the group members, 46% fit into design practice categories, 49% were conversational moves, and 5% did not fit into any category and were coded as "other." The most frequent conversational move was to restate one's

own or another person's idea related to the design task (REV: 43 utterances, 17% of total). Expressing agreement with another person's idea also occurred frequently (AGR: 34 utterances, 13% of total), as did requesting clarification about design ideas (REQ: 30 utterances, 12% of total). Less frequent conversational moves were to discuss the task directions given by the instructor (INT: 15 utterances, 6% of total) and to express disagreement with another person's idea related to the design task (DIS: 4 utterances, 2% of total).

Considering the group's design practices and conversational moves together, we see that the majority of their time was dedicated to brainstorming solution ideas, affirming or requesting details about those ideas, and assessing their feasibility. Although the group did make firm decisions to propose the "Chameleon Safe," they did not spend substantial time on detailed development, evaluation, or representation of design ideas before making those decisions. Disagreement among group members occurred very infrequently (only four instances in all). This lack of strong debate may have contributed to the group's coming to decisions without spending time modeling or evaluating design ideas.

For example, in the ninth minute of the episode, the group swiftly rejected the idea of a product connected to a bed; they decided the bed would easily exceed the \$100 budget. They also decided not to pursue a product to be hung on the wall because it would require them to create instructions for safe installation. With these ideas off the table, at nine minutes in, Deanna recycled Ben's Chameleon Safe proposal into a new idea for the group to consider: a plain old treasure chest. What happened next, as shared in the following excerpt, illustrates the group's typical emphasis on generating ideas, analyzing their feasibility, and revoicing and agreeing with each other.

Deanna	We could just do a plain old treasure chest.	GEN
Ben	It's dirt cheap to make plastic stuff. Honestly -	FEAS
April	Like here, you can buy like a [traces out a box shape] for like 50 bucks.	FEAS
Ben	Yeah, the materials, the materials manufacturing are so cheap.	FEAS
Flor	Yeah.	AGR
Ben	Well, why don't, I think we should sell the idea of that strat-, there's like a line, of like all the same things.	GEN
Flor	Yeah.	AGR
Deanna	Are we gonna build, are we gonna build this as something, or are we gonna do just like "chest"?	REQ
Flor	We could say that it is a treasure chest, but in the shape of [traces out a big sphere].	GEN
Ben	Well it would be a chest in the shape of something, you know what I mean, like a chest inside of like, she said, a big baseball, or something, I don't know, like a star or something.	GEN
Deanna	[Inaudible] baseball?	REQ
Ben	No, no, no, it would be, so it would be a chest <i>shaped</i> -	REV
Emilia	In the shape of a ball [puts hands out as if holding a baseball].	REV
Flor	Picture a white baseball [tracing out the shape of a big sphere].	REV
Deanna	Oh, that could open up!	GEN
Ben	Yeah. And like it just looks like it's kind of like a room prop, but it's really like a chest.	REV
Cathy	How are we gonna make it in a shape? That's a lot of work to shape it like that.	FEAS
Emilia	Oh, [waves her arm as if to say, "don't worry about it"], leave that for the engineers.	FEAS
Ben	Manufacturing [inaudible], it would be a [inaudible], it could even be, it could even be plastic. It could be plastic to save money.	REV
Flor	That's true. I mean, I was just, I'm just, it doesn't have to be a baseball, I'm just thinking off the top of my head.	AGR
Deanna	It could be an animal!	GEN
Flor	Yeah.	AGR

From an epistemological framing perspective, we find it particularly interesting that Emilia says, "Oh, leave that for the engineers," in response to Cathy's concern that shaping a plastic chest as a baseball is "a lot of work." Up to this point, the group members appear to be stable in framing their own activity as engineering design. They are engaged in an animated conversation about possible furniture

designs, and they exhibit agency in proposing pieces of furniture and making judgments about whether they will be safe, affordable, and appealing to potential users. So it is striking to hear Emilia suggest that they leave Cathy's question about how to shape the chest to "the engineers," as if they themselves are not participating in engineering. One possibility is that Emilia is indeed stable in her participation in design thinking (Razzouk & Shute, 2012), but she is making a distinction between the kind of hypothetical design task on which they are working and the real activities in which a professional engineering firm would participate. A professional design team – Emilia's "engineers" – would eventually have to tackle the problem of how to manufacture a newly proposed product. But in the classroom, Emilia may view herself and her teammates as having neither the material resources to do that kind of engineering work nor the necessity of doing so. They are not even required to build a prototype of their design, let alone develop a manufacturing process for it. Therefore, despite the evidence that Emilia and her teammate are stable, productive, and agentic in their participation in the furniture design task, they may not be fully framing their activity as the same kind of thing that "engineers" do.

Turning now to the second and third research questions of this study, we further explore the preservice teachers' design practices and epistemological framing by examining the distribution of practices across group members and their movement from practice to practice over time.

Findings for Research Questions 2 and 3

Over the course of the design task, to what extent were the design practices shared by preservice teachers collaborating in the same group, and what patterns and framing occurred in how the preservice teachers moved from one practice to another?

Analysis of utterance codes by speaker (Figure 4) revealed that some design practices and conversational moves were shared fairly evenly among group members, while others were the purview of just one or two members. In terms of design practices, all six group members generated multiple possible design solutions and participated in feasibility analysis at least twice. This is true even though some group members (Ben, Deanna, Flor) made three or four times as many utterances as others (April, Emilia). This means that even though April and Emilia talked less, it was not for lack of brainstorming or considering design ideas. The practice of evaluating two or more design ideas along a particular dimension was conducted only five times overall, but this was distributed among four group members (Ben, Cathy, Deanna, Emilia). Discussing the definition of the design problem and modeling the details of the design solution were practices shared by all but one group member (April). By contrast, the practice of making design decisions, which occurred

Figure 4. Design practices (solid shading) and conversational moves (stripes and dots) made by six preservice teachers collaborating on a furniture design task based on a piece of children's literature. Each group member is indicated by the first letter of his or her name (A is April, B is Ben, C is Cathy, D is Deanna, E is Emilia, and F is Flor).

just five times in all, was exhibited by only one group member (Ben).

Conversational moves were not shared as evenly across group members. The members who spoke the most (Ben, Deanna, Flor) were also the members who did the most restating of their own or others' design ideas, the most agreeing with others, and the most requesting of clarification. This result suggests that these group members talked more not because they engaged in more design practices but because they more often made moves to manage the conversation.

One conversational move was especially concentrated within a small subset of the group members: Cathy and Flor initiated almost all of the discussion of the instructor's directions or intent for the task (INT). The code for discussing instructor's intent was applied to 15 utterances, which occurred at about six points over the course of the episode. Here we examine these episodes for evidence of shifts in epistemological framing.

First, as the furniture design task begins, Cathy handed Flor a sticky note, a tool the instructor suggested using to record design ideas. Flor responded that she already had one, but Cathy insisted she should have more. Their dialogue, however, did not immediately influence the other group members. They remained focused on their verbal idea generation. As shown in the excerpt below, even Cathy and Flor themselves shifted quickly back to generating and clarifying ideas.

Cathy	Since it's a separate bedroom, what about just putting a childproof door there?	GEN
Flor	[Nods.] I was thinking something along those lines, childproof, or childproof -	REV
Cathy	[Hands Flor a sticky note.]	INT
Flor	No, I have one.	INT
Cathy	Supposed to do 4 to 10. [Continues holding out more sticky notes.]	INT

Flor	Per person?	INT
Cathy	Yeah. She said 4 to 10.	INT
Flor	I thought she said one. Okay.	INT
Deanna	Well we all have the same idea [laughs].	AGR
Flor	You know how kids love [inaudible], it's not exactly safe, like the [inaudible] desk [inaudible]. I'm just trying to think [gestures with arms up].	GEN
April	Like a bunk bed, like put something up high [gestures as if dusting a shelf], to put things up, like on top of the bed, or something [inaudible].	GEN
Cathy	So we would put drawers on the top?	REQ

Two minutes later, however, it was Flor who told another group member, Ben, to put his idea down on a sticky note and add it to the chart where all other group members had by now posted at least one note. Getting no response from Ben, Flor pestered him again a minute later, and this time he did post his "Chameleon Safe" note. Rather than prompt more discussion of the instructor's intent, the posting of this note seemed to be a decision point that moved the conversation to the appearance and location of the Chameleon Safe.

Flor	Ben, put your idea! [Ben does not.]	INT
April	[Adds sticky note to paper; it says "Crawl space over bed w/removable ladder"]	GEN
Cathy	[Asking about Deanna's note] "Chest with keypad," I don't know what that is.	REQ
Deanna	[Talking to Cathy] So, say it's on the side of the bed; you have a built-in, something that pulls out or slides, maybe just with two numbers, like they can flip through [gesturing as if pushing buttons or rotating dial on padlock].	REV

Ben So it's essentially like the locker safe. REV
 Deanna Basically. AGR
 Ben The way we talked about it was like, like GEN
 a disguised one, like something that
 blends in with the room, so it probably
 wouldn't be noticed, like wouldn't even
 want to touch it.
 Deanna Like if you had a cool treasure chest FEAS
 sitting in the room, the toddler wants
 to get in to it.
 Flor [To Ben; pointing to his sticky notes] Put INT
 something up there.
 Ben This is, my product name is Chameleon DEC
 Safe [puts sticky note that says
 "Chameleon Safe" on chart paper].
 Deanna Yeah, I'm gonna put that underneath REV
 [moves her sticky note which says "built
 in chest with keypad," underneath
 Chameleon Safe note].
 Cathy Oh, I get it, camouflage. MOD

Flor again brought up the instructor's directions around minute four of the episode. She reminded the group that they would have to make a pitch about their furniture proposal to their classmates. Only Ben responded. He quickly affirmed the Chameleon Safe idea as the best pitch. Meanwhile the other group members continued generating ideas for the safe's lock and alarm components. Flor participated in this conversation, but then one minute later turned her attention back to the instructor's handout. Reading aloud from the paper, she asked how they would test their design. Again, this request to organize their work according to the "classroom game" was not picked up by other members of the group. Instead, it was followed by Deanna's clarifying question about whether the Chameleon Safe was its own product or part of something else. Abandoning the handout, Flor immediately shifted her attention away from the classroom game (the steps outlined on the instructor's handout) and back to the design task. She was the first to respond to Deanna's question.

Flor Can I see the paper? INT
 Cathy Yeah. Sure. INT
 Flor So how would we test it? We have to INT
 follow this thing [takes paper, skims it].
 Decide on potential solution. Determine
 a test, to make sure it satisfies the
 requirements and constraints.
 Deanna Where, is this gonna be a separate, um, REQ
 is it gonna be separate or is it gonna
 be built into something?
 Flor It would be nice if it was in the wall, FEAS
 take less bedroom space.

Ben Well it depends on how we're gonna GEN
 [inaudible]. What I thought of was like,
 my son, the bottom, you can buy these
 humidifiers that are shaped like frogs
 and like random things.
 Ben So, like, if we're gonna do like a chest, GEN
 safe, type thing, we want it to blend it
 to the wall. Or if you wanna do like
 standard things that you see in a kid's
 room, that kind of thing needs to have
 like a fish tank look alike, like a fish
 tank that has something, and a shoe
 box, just random stuff.

Later, in the second half of the episode, there was really only one attempted shift to the activity of complying with the instructor's handout. At nine and thirteen minutes into the episode, Cathy and Ben asked to look at the handout, but they didn't say anything to the group about what they were reading. At minute twelve, April seemed to sense the group settling on a customizable, locking safe for children, and she pointed to the handout and asked the group how they would test it. This time all group members listened to April's question. Deanna then repeated it by reading from the handout, and several group members responded by suggesting feasibility requirements that the safe would need to pass. They picked up on April's shift in attention, but in a way that fit into their design frame rather than simply complying with the "classroom game."

Flor The main thing is that some siblings want PD
 privacy and respect for their things, what
 role we're showing [points to poster], and
 that's what we pitch.
 Cathy [Adds another note at very bottom left. It PD
 says "What it costs doesn't equal what
 they sell it for!"]
 April So how would you test it, isn't there INT
 something [points to paper that Deanna
 is holding], how would you test it?
 Deanna How would you test it, yeah. Should FEAS
 specify the tests that would have to
 be conducted. Making sure that
 they don't tip over, easily.
 Flor [Nods vigorously.] AGR
 Ben So safety. FEAS
 Emilia How much they could weigh, like, what FEAS
 they, it holds.
 Ben Yep. AGR

As the above excerpts demonstrate, Cathy and Flor made repeated moves early in the episode to shift the group's activity toward fulfilling aspects of the instructor's directions. The group as a whole, however, was stable in its idea generation and feasibility analysis, and barely responded to

these requests. When they did respond, such as by putting sticky notes on the chart paper, it was in a way that moved the engineering work forward rather than in a way that appeared disconnected from the engineering. It was not until April's move to consider tests in the second half of the episode that the group shifted wholly toward a specific direction on the instructor's handout. But here, even though they were attending to a "classroom game" requirement, their discourse continued to contain evidence that they framed their activity as design. At this point in their work, they found it productive to consider what tests their design might need to pass. They were responsive to April's request not because they respected her more than Cathy and Flor but because the timing of her request actually allowed them to use an instructor's suggestion to maintain their "design game" stability.

We have been considering the stability of the group's framing their activity as engineering design and their robustness to Cathy and Flor's requests to shift to a frame of simply complying with the instructor's directions. Now we consider how group members moved from one aspect of engineering design to another within that stable frame. Figure 5 maps the flow of the group's entire design process. It plots design practices and conversational moves, colored to indicate speaker, by time.

The bottom five lines of Figure 5 (from INT at the bottom, up to REV at the top) show the conversational moves that were added to the Design Activity coding scheme for this study of a collaborative design task. These lines reveal that restating and agreeing with design ideas were moves made frequently all throughout the design task, typically by the same two or three group members. These affirming utterances comprised a substantial portion of the discourse. Although these utterances might not contribute to the slate of alternative solutions or the detailed modeling of the chosen design solution, they may be important for preserving the group's framing of their activity as an engineering design task.

The top eight lines of Figure 5 (from PD at the top to COM near the middle) show the eight design practices of the coding framework. These lines show the group members' emphasis on generating design solutions in the first twelve minutes of the design task and their shift toward increased feasibility analysis and detailed modeling in the last five minutes. Figure 5 also depicts the lack of problem definition and information gathering at the beginning of the design work, and the sparse evaluation and communication of design solutions throughout the task.

Earlier we looked at an excerpt from the first half of the episode in which the group headed toward the Chameleon Safe decision without much attention to the detailed specifications of the product or to how they would evaluate it against other options. Here, to illustrate the shift toward more detailed modeling and feasibility analysis in the last part of the episode, we share an excerpt that begins around minute sixteen. Prior to this excerpt, the group had been discussing tests they would conduct on their Chameleon Safe design. Suddenly, Cathy

questioned whether the design fully solved the problem of the older sibling's need for privacy. Flor and Emilia convinced Cathy that they were meeting design requirements, even if not fully satisfying the character in the book. The excerpt begins at this point in the conversation, as Deanna reminds the group that they had been considering testing. Because they have reached consensus around the general Chameleon Safe idea, Denna's move at last leads them to propose more specific design details, including the safe's material composition, weight distribution, and dimensions.

Deanna	So, testing. We would have to test -	REQ
Ben	Testing, we would have to test durability, of like the whole thing itself.	FEAS
Deanna	Yeah, if he tries to like hit it with a [gestures as if hammering], it won't break.	FEAS
Cathy	Plas-, we're gonna make it out of plastic?	MOD
Deanna	Plastic?	REV
Ben	[Nods.] Uh-huh. But I think like thick plastic, like the thing that kids toys are made out of, plastic.	REV
Flor	[Inaudible.] Rolling, how do you balance plastic?	FEAS
Ben	Well cuz if like, if you think about a chest, right -	MOD
Deanna	It's gonna be weighted.	MOD
Ben	If you have like a flat bottom and then the base comes around, like a wide base.	MOD
Deanna	It's gonna have to be a heavy, heavy bottom.	REV
Flor	Yeah, because I'm imagining [gestures as if pushing against something].	FEAS
Ben	Even like a rubber bottom, almost, like a thick rubber bottom that would, and the [inaudible] comes out the top.	MOD
Cathy	For safety, can it have holes in it, so they can breathe, if they lock themselves in there?	MOD
Flor	No, they can't get in.	DIS
Deanna	This is just gonna be like, for like, little stickers, and trinkets, and tupples [?].	REV
Ben	I was thinking like [holds hand about 3 feet from ground] the biggest it would be is like that big. They're not gonna be able to get in there.	MOD
April	Yeah, it's like a secure toy box, basically.	GEN
Ben	Yeah, essentially, exactly. It's really just a toy box.	REV

The lines on Figure 5 connect each utterance code to the code for the next utterance in time. It is clear that many of the lines extending from generating possible design solutions (GEN) lead down toward the portion of the graph for conversational moves. This means that often, when group members proposed design ideas, other

Figure 5. Design activities and conversational moves over the course of 17 minutes of a furniture design task completed by a group of six preservice teachers. Shape and color indicate speaker; horizontal lines indicate codes for design activity or conversational move. Each group member is indicated by the first letter of his or her name (A is April, B is Ben, C is Cathy, D is Deanna, E is Emilia, and F is Flor).

group members carried out simple conversation moves like re-voicing (REV) and agreeing (AGR), rather than immediately assessing the feasibility (FEAS) of the design idea or suggesting a way to realize it (MOD). We analyzed the utterances occurring immediately after idea generation. Table 4 confirms that after a new design idea was stated, the next utterance was a restatement 16% of the time and an agreement 21% of the time. However,

26% of the time, it was another idea generation statement, and 12% of the time, it was feasibility analysis. Even though new design solution proposals often led to conversational moves, they also led to further new ideas and to idea critique. This result provides evidence of the stability of the preservice teachers' design task frame. Although they did often shift to managing the conversation after putting a design idea on the table, these were

Table 4
Design activities and conversational moves occurring immediately after Idea generation.

Code	Frequency	Percent
Design Activities		
PD (Defining the problem)	0	0%
GATH (Collecting needed information)	0	0%
GEN (Proposing design solutions)	11	26%
MOD (Specifying design details)	0	0%
FEAS (Passing judgment on possible design solutions)	5	12%
EVAL (Evaluating along particular dimension)	2	5%
DEC (Making design decision)	0	0%
COM (Communicating design to external parties)	0	0%
Conversational Moves		
REV (Restating design idea)	8	18%
REQ (Requesting clarification)	5	12%
AGR (Expressing agreement)	9	21%
DIS (Expressing disagreement)	1	2%
INT (Discussing instructor's intent)	1	2%
Other		
OTH (Conversation not relevant to design task)	1	2%
Total	43	100%

Note: Table includes only utterances that occurred immediately after utterances coded as GEN.

brief shifts that always led back to more design practices, and almost half (43%) of the time, idea generation led directly to more design practices without even a brief shift to managing the conversation.

For example, in the fourth minute of the episode, Flor conducted some feasibility analysis by judging the relative safety of a chest with a lock on it. She was worried about a toddler's access to the locking mechanism and was trying to think of how the chest could be kept out of reach. Cathy followed Flor's concern by generating a new idea: wall cubbies with folding doors. Often the statement of an idea like this was followed by revoicing and agreement, but in this instance, Ben proceeded immediately with more feasibility analysis. He was concerned about any product that is located high up from the floor.

Flor	I'm thinking things to keep it high, so they can't, they don't have access to lock it, that's -	FEAS
Cathy	Well you know, an idea is to have the wall things that fold out.	GEN
Ben	I'm worried about the height. I climbed stuff when I was a kid. My brother had [inaudible] and I -	FEAS
Flor	Yeah, that's true. You could have the kid in the cubby.	AGR
Ben	Like I feel like cubbies above a bunk bed, they're gonna want to crawl in. They're gonna hide [inaudible].	FEAS
Flor	I think the way I'm picturing it is, the bed doesn't have to be underneath. It could just be cubbies on the wall.	MOD
Ben	Oooh, I see, okay.	AGR
Flor	So the kid doesn't have, can't get on something, unless they put a chair underneath it, you know what I mean? Yeah, they always find a way, but [shrugs] it is what it is. I always found a way [laughs].	REV

Discussion

Our analysis of the preservice teachers' design process suggests that in an integrated engineering and literature experience, preservice teachers can show stable, productive attention to the engineering design task at hand, but within that stable frame they may focus on generating possible solutions and judging their potential feasibility at the expense of information gathering, design solution modeling, and detailed evaluation of proposed solutions. Here we compare these preservice teacher results to the design practices exhibited by novice and expert engineers. We also consider why the preservice teachers were so stable in their

framing of their task as engineering design, albeit a limited kind of engineering design. Finally, we discuss the instructional implications for preservice elementary teacher education in engineering.

Atman and colleagues (2007) conducted verbal protocol analysis of the design processes of college engineering seniors and expert practicing engineers as they independently completed a playground design task. Like the furniture design task, the playground design task did not involve design implementation (i.e., physical prototyping). Because the preservice teachers' initial design phase lasted for 17 minutes, we consider just the first 19-minute subset of the data presented in Atman et al.'s (2007) report of their study. The participants in Atman et al.'s study continued to work on the playground task for 80 to 90 additional minutes, and the preservice teachers worked in a whole-class setting on the furniture task for 40 additional minutes, but here we look at just the first phase of design from each data set.

In their first 19 minutes with the playground design problem, the expert engineers spent a substantial amount of time on generating ideas and analyzing their feasibility. They also transitioned often to the activity of information gathering, and spent as much time gathering facts and data as they did generating ideas or defining the problem. In fact, most of their instances of information gathering appear to have occurred just before or after problem definition efforts. The expert engineers' requests for information ran the gamut from material costs, to information about the surrounding area, to handicapped accessibility.

The senior engineering students (i.e., novice engineers) differed from the expert engineers in that they engaged in feasibility analysis only infrequently during the first phase of work on the playground design task. But they were similar in devoting much of their early time to both problem definition and information gathering. The average number of explicit information requests made by the senior engineering students was 15.8; for the expert engineers it was 25.2 (Atman et al., 2007). Both the novice and expert engineer groups also began to do at least some modeling of their possible design solutions within their first phase of work.

In contrast to the novice and expert engineers in Atman et al.'s study, the preservice teachers in this study did not make explicit requests for information about the design problem with which they were tasked. They did not ask what materials might be available to them, what the precise safety standards were (even though one design constraint specifically referred to federal safety guidelines), or what was known about the potential market for older siblings' furniture. Although many of the teachers had laptops and smart phones with them, they did not log on to the Internet to explore existing furniture designs. We interpret this absence of explicit information gathering not as evidence that the preservice teachers *were not able to* engage in problem scoping, but that they did not have a reason to do so explicitly and systematically. Instead, it could be that they made assumptions about

key information (safety, cost of materials) in the place of explicit requests or searches for information, and these assumptions served them well in completing the design task in what they perceived to be a satisfactory way.

We do acknowledge that Atman et al. (2007) include “stating an assumption or how s/he would go about getting the information” in their information gathering category. However, when the preservice teachers in our study stated assumptions, they typically did so in the service of passing judgment on an idea or persuading others to pursue their idea. For example, when advocating for his Chameleon Safe idea, Ben said, “It’s dirt cheap to make plastic stuff. Honestly.” Amy agreed, “You can buy like a [traces out a box shape] for like 50 bucks.” They were making cost assumptions to assert that a design proposal would fit within a budgetary constraint, and we coded such assertions as instances of feasibility analysis. In other cases the teachers made assumptions in the service of comparing two or more proposals for their costs, such as assuming that a treasure chest design including a bed would cost more than a stand-alone treasure chest. We coded these cases as instances of evaluation.

Relative to the novice and expert engineers (Atman et al., 2007), the preservice teachers as a group also did not engage at length in defining the criteria and constraints of the design problem. There were two early mentions of the budget by Cathy and Flor, and then later on – several times – Cathy questioned whether the problem was the need for space for the older sibling *himself* or just for his belongings. Thus Cathy did the most work to rehash and reframe the problem for which they were designing a solution; the other teachers did not spend time summarizing or elaborating this problem.

Some readers may wonder whether our category of attending to the “instructor’s intent” might have masked some data that would have been labeled “problem definition” with the original Design Activity coding scheme. Although we understand this concern, we do not believe there was overlap between the two categories. We constructed the instructor’s intent category to capture behaviors distinct from defining the design problem. We coded utterances as focused on instructor’s intent only when they involved talking about the required sticky notes, specifically asking to see the handout provided by the instructor, or reading aloud from the handout about what “she” wanted them to do, such as “carrying out a test” or “using sticky notes.” If the participants had read aloud the design problem statement itself, we would have applied the problem definition code. What they read aloud, however, were instructions about when to make sticky notes and what to do logistically to prepare for the “pitches” to be given at the end of the class meeting. Therefore we have confidence in our finding that among the teachers besides Cathy, there was a low frequency of problem definition.

These findings of limited problem definition and information gathering are interesting given the literature-based

context of the design task. We hypothesized that when solving engineering problems linked to fictional characters, elementary teachers’ identification with the characters might lead them to emphasize the practices of problem scoping (i.e., what does this character really need?) and idea generation (i.e., what would please this character?). Though we were correct about idea generation, our hypothesis regarding problem scoping was not supported by the data.

In summary, these preservice teachers engaged in a more limited set of engineering practices than did professional and undergraduate engineers in previous studies using a similarly hypothetical engineering design task. We do not intend for this finding to be interpreted as a negative assessment of the preservice teachers’ approach to the design task. In fact, their emphasis on idea generation may have been entirely reasonable given their perceptions of the goals of the activity and the resources available to them. Moreover, what is so encouraging about the preservice teachers’ engineering is that they were relatively stable – for their 17 minutes of small-group time – in framing their task as one of engineering design. In other words, they were playing the “engineering design game” that the instructor had set up for them. Although there were some key differences across group members, in general, most of the time they were not concerned with the “classroom game” of what the instructor wanted them to do, how they might get a good grade, or how their work compared to their classmates. They were focused, for the most part, on thinking and communicating about how to design an appealing piece of furniture for older siblings. Evidence of this stability was the group’s resistance each time one of the group members made a request to pay attention to the instructor’s intent for the task.

Implications and Conclusions

We find encouragement in the stability of the preservice teachers’ engagement in engineering design. However, the fact remains that their attention was stable on only particular aspects of engineering design, even though other aspects would have been productive in fully addressing the task at hand, in particular to satisfy safety and budget constraints and to convince their classmates that their pitch was best. The contrast between our preservice teachers’ narrow (though stable) engagement in engineering and Atman et al.’s engineers’ fuller engagement is something we point out because it raises an important question. *Why* did we not see the preservice teachers partake in design activities related to problem scoping? It is possible that because the problem was based on a literature text familiar to the teachers, they felt they understood the scope of an older sibling’s need for furniture and did not need to define the problem further. They may also have felt that the text gave all the necessary contextual details about the potential

furniture users, and there was no need for information gathering. One potential explanation is that integration of engineering design problems with children's literature creates less "demand" for information gathering. Perhaps the experience of reading the text is already an information gathering experience, so to speak. However, ongoing studies of children's approaches to literature-based engineering tasks (McCormick & Hynes, 2012; Spencer, Watkins, & Hammer, 2013; Watkins, Spencer, & Hammer, 2014) suggest that children do spend time refining and reframing the story-based problem that they are going to solve via engineering. Therefore teachers should be capable of this as well. Another possibility is that the preservice teachers – from their own life experiences – felt so comfortable with the general need of older siblings for privacy that they did not have any open questions about the criteria for design solution. However, the expert engineers working on the playground design task had likely visited playgrounds many times before, and felt comfortable with the need for playgrounds, and yet they found many areas where they needed to gather more information before making design decisions. We speculate, then, that one reason the preservice teachers did not engage in problem scoping may have been that they did not have awareness of or experience with its value in creating successful design proposals.

The instructional implication of this possible explanation is that preservice teachers need opportunities to see the value of problem definition and information gathering for engineering design success. One approach to helping preservice teachers make progress in problem scoping may be to assign more open-ended and longer-term engineering design problems – perhaps that preservice teachers work on gradually over the course of a semester (Bers, 2005) – that really cannot be solved successfully without narrowing the problem scope and collecting additional information. If this approach is successful, it might mean that for teachers to most effectively engage in (and teach) literature-based engineering problems, they should also experience real-world design problems where the necessary contextual information must be gathered from across many people and other resources, rather than concentrated into one piece of literature. Another approach to teacher learning about problem scoping may be to develop engineering case studies (Yadva, Shaver, & Mecki, 2010) – specifically for preservice teachers – that contrast the results of engineering teams who dedicate time to problem scoping to the results of teams who move full steam ahead to idea generation. These case studies might feature practicing engineers, other teachers learning about engineering, or even elementary school students working on the types of engineering problems that the preservice teachers might eventually pose. A third potential approach is to support preservice teachers' engineering design activities with scaffolds, such as the Design Compass (Crismond, Hynes, & Danahy, 2010), that prompt them to

consider spending time on each aspect of engineering design, including problem definition and information gathering. Future work is needed to confirm that preservice teachers struggle with problem scoping and if so, to develop and study the effectiveness of various approaches to increasing their engagement in it.

In conclusion, this study of preservice teachers' collaborative work on a literature-based engineering design problem showed that they can maintain a stable epistemological frame of their collective activity as a design task. It also showed that they can arrive at design decisions by focusing on idea generation and idea affirmation through the conversational moves of re-voicing and agreement. They can feel satisfied about their design decisions without having engaged in the design practices of gathering information or modeling design solution details. Because both novice and expert engineers place much more emphasis on problem definition and information gathering, these are potential focus areas for preservice teacher education in engineering.

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