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Pre-Service Teachers' Engineering Design Practices in an Integrated Engineering and Literacy Experience

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The National Research Council's recent *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (Achieve, Inc., 2013) bring new urgency and importance to the task of exposing K-12 students to the practices and big ideas of engineering. At the elementary school level, this task requires not only the adjustment of curriculum and pedagogy, but also a transformation in the preparation of new elementary teachers. The teacher education community is limited in its understanding of how novice teachers of elementary students learn to teach engineering. Research is needed to inform a new model for preparing pre-service elementary teachers to teach engineering.

For elementary school teachers, preparation in engineering will most likely need to happen within existing teacher preparation courses because teacher education 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. In most programs there is not room for an additional course on engineering. However, it may be quite feasible to fit engineering teaching modules into science content and methods courses for pre-service elementary school teachers. Such modules would need to be sensitive to pre-service elementary teachers' academic backgrounds, which frequently lack science coursework and almost universally lack engineering coursework. Preparation in engineering also needs to be sensitive to the demand on elementary teachers to integrate across the curriculum, and the lack of time in the school day to do stand-alone engineering. Pre-service elementary teachers will be interested in ways to accomplish multiple objectives at once by integrating other subjects with engineering and vice versa.

There is a strong and growing base of evidence showing that with carefully designed support, pre-service elementary teachers can develop at least three key capacities important to high quality *science* instruction. First, when planning lessons, they can demonstrate understanding of the nature of scientific inquiry by adapting existing curriculum materials to better promote students' engagement in each of the National Research Council's (NRC, 1996) five essential features of inquiry (Forbes, 2011). Second, while teaching students, they can shift the focus of their attention from "correct answers" to the real substance of student thinking (Levin, Hammer, & Coffey, 2009). Third, they can analyze curriculum materials for whether they include clear and standards-aligned learning goals, elicit prior knowledge, establish a purpose for each lesson, and engage students in inquiry (Beyer & Davis, 2012). On the other hand, pre-service teachers have been found to struggle with other important components of high quality science instruction, including meaningfully assessing student learning and making science accessible for English language learners and students with special needs (Beyer & Davis, 2012).

There is currently a very limited research base on how pre-service teachers learn to provide *engineering* instruction. However, based on the findings reported above regarding *science* teaching, it is reasonable to expect that pre-service elementary teachers can develop capacities for high quality engineering instruction, but that they will need carefully designed support along the way.

One promising model for bringing engineering to the elementary classroom and to pre-service elementary teachers is to integrate engineering and literacy (e.g., McCormick & Hynes, 2012). In the integrated engineering and literacy approach, design challenges are drawn from children's literature. Students and teachers read texts closely, analyze the plot for problems faced by the characters, design and test solutions to the problems, and then reflect in writing about the problems and solutions. Although new engineering-and-literacy research studies are uncovering a great deal about elementary teachers' and students' engagement with literature-based engineering experiences, we have limited understanding of what *pre-service* teachers can know and do related to engineering design, and what they need to be effective at bringing engineering design to their future students. In order to design effective elementary teacher preparation approaches in engineering, we need to conduct research on pre-service 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 pre-service teachers' starting point for learning to teach engineering design. The study's broad research question is, *what are the engineering design practices that pre-service teachers use when they participate in an integrated engineering and literacy learning experience?*

We hypothesized 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 really be the structure and function of our product?).

Research Framework

In examining pre-service teachers' engineering design practices, we take a situative, sociocultural perspective on the learning of engineering (Brown, Collins, & Duguid, 1989; Johri & Olds, 2011). This means that we believe meaningful opportunities for the learning of engineering are situated within social, collaborative work on real engineering tasks and in the context of engineering "cultural" practices. We adopt a discourse analysis approach (Lemke, 1998) to assessing pre-service teachers' participation in these engineering practices. In particular, the framework we use to analyze the design process of the teachers is the Design Activity coding scheme developed by Atman, Adams, Mosborg, Cardella, Turns, and Saleem (2007), and confirmed by Cardella, Adams, Atman, and Turns (2008). This framework was developed for verbal protocol analysis of engineers solving design challenges, and it 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).

Three research questions guided our study:

1. What are the engineering design practices that pre-service 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 pre-service teachers collaborating in the same group?
3. Over the course of the design task, what patterns occur in how the pre-service teachers move from one design practice to another?

Study Design

The study participants were 26 graduate students enrolled in an elementary science teaching methods course. On three different occasions, these pre-service 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 *The Mixed Up Files of Mrs. Basil E. Frankweiler* (Konisburg, 1967) and developed related engineering tasks that elementary school students could tackle.

During all three literature-based engineering experiences, data were collected in several forms. We video-recorded all whole-class discussions as well as all small-group work by one team in each experience. We also took photos of all artifacts created during the design tasks, including post-it notes, chart paper posters, and sketches.

After all three engineering experiences took place with the pre-service teachers, the furniture design task was selected as the focus experience for this study. This selection was made because the furniture design task data set was the most analogous to the data reported in earlier applications of the Design Activity coding scheme to study the design processes of novice and expert engineers (Atman et al., 2007; Cardella et al., 2008). By focusing on the furniture design task, we could compare the pre-service teachers' processes with those of the practicing engineers in previous studies. Figure 1 shows the furniture design task instructions that were presented to the pre-service teachers.

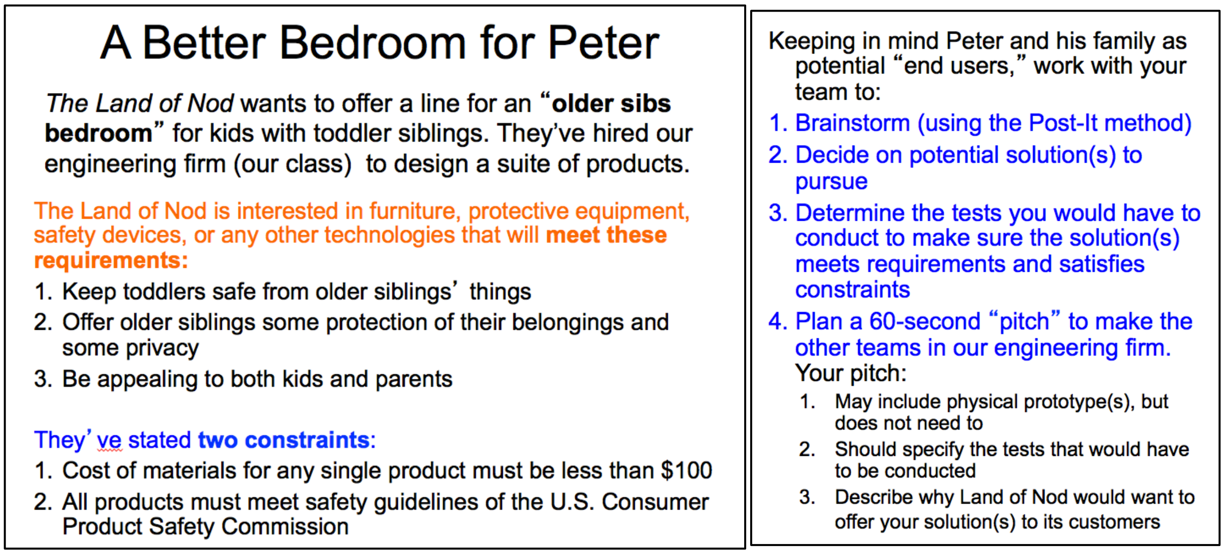

Figure 1. Prompts specifying the furniture design task related to the children's book *Tales of a Fourth Grade Nothing* (Blume, 1972). The prompts list the design requirements and constraints as well as a general procedure for the design teams to follow.

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, such that each new speaker's turn marked the beginning of a new utterance. To code the utterances for the pre-service 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 pre-service 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. Table 1 presents the adapted Design Activity coding scheme used in this study.

Table 1
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 post-it 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; *not used for requests about instructor's intent*	"So what are we gonna do?"

(AGR) AGREEMENT - Without restating, acknowledging understanding of an idea or expressing favorable response. *If favorable response labels a particular dimension of the problem, should be coded EVAL.*	"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 [post-it notes]. [Distributes more post-it 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: Table 2 summarizes the episode selected for analysis, which includes 17 minutes of small-group work in which six pre-service teachers (PSTs) collaborate on the older sibling furniture design task. 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. PST C immediately distributes post-it notes and reminds her teammates of the instructor's request to list several design ideas on individual notes. The group members do not do this immediately. Instead, 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, PST F notices the post-it notes and asks if they should write on them. Four out of the six group members do so at this point. The resulting post-it notes say "Locker Safe," "built in chest w/keypad," "high cubby/door; sliding drawers," and "crawl space over bed w/removable ladder." A discussion of the "chest w/ keypad" idea leads PST B to decide the product should be called "Chameleon Safe." After PST F reminds the group that a solution has to be pitched to the rest of the class, they brainstorm options for the safe's locking mechanism. PST F then reminds the group of the instructor's request to list the tests that would have to be performed on prototypes of the product. This leads PST D, at six minutes in, to question the size and configuration of the product, and PST C, 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, PST D requests that they make a decision about the product's shape. In response, PSTs B, F, and E construct the idea that the product's shape would be customizable – customers could request an animal or sports-themed shape. This discussion leads PST B to confirm the decision that the Chameleon Safe will be pitched. PST C 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 the main character of the story. PST B and PST A 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 leads to renewed conversation and generation of ideas about the locking mechanism. At 15 minutes in, PST C 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 of the Chameleon Safe, PST A summarizes their design solution "It's like a secure toy box, basically," and PST B affirms, "Exactly. It's really just a toy box." The team is satisfied with their design decisions. PST F tells the instructor they are ready to make their "pitch." They have planned that PST B will describe the Chameleon Safe orally; unlike the other teams, this group has not created diagram of their proposed solution or a poster to aide in their presentation of their solution. This team has also not taken advantage of the building materials in the classroom to build any sort of model or prototype (but neither has any other team).

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 post-its: "Locker Safe," "built in chest w/keypad," "high cubbys/door; sliding drawers," and "Crawl space over bed w/removable ladder"
3 min	Product name is "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"

Findings for Research Question 1: What are the engineering design practices that pre-service teachers use when they participate 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 pre-service teachers. As they worked on the furniture design problem, the group engaged five or more times in six out of the eight design practices included in the coding framework. They did not exhibit the practice of gathering information needed to solve the problem, and they engaged in communicating design elements to external parties only one time. As detailed in Table 3, of the six practices that occurred at least five times, the most frequent was generating potential solutions or parts of the solution (GEN: 49 utterances; 19% of total), and the second most frequent was assessing and 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).

Of the 258 utterances by the group members, 118 (46%) fit into design practice categories, 126 (49%) were conversational moves, and 14 (5%) did not fit into any category and were coded as "other." This means that 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. The most frequent conversational move was to restate one's own or another person's idea related to the design task (REV: 42 utterances, 16% of total). Expressing agreement with another person's idea related to the design 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 design task directions given by the instructor (INT: 16 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 design time was dedicated to brainstorming solution ideas (GEN), affirming or requesting details about those ideas (REV, AGR, REQ), and assessing their feasibility (FEAS). Although the group did make firm decisions to propose the "Chameleon Safe," they did not spend time on detailed development, evaluation, or representation of design ideas before making those decisions. We point out here that there was very infrequent disagreement among group members (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.

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)	42	16%
REQ (Requesting clarification)	30	12%
AGR (Expressing agreement)	34	13%
DIS (Expressing disagreement)	4	2%
INT (Discussing instructor's intent)	16	6%
Other		
OTH (Conversation not relevant to design task)	14	5%

Total		258	100%

Findings for Research Question 2: Over the course of the design task, to what extent were the design practices shared by pre-service teachers collaborating in the same group?

Analysis of utterance codes by speaker (Figure 2) 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 (B, D, F) made three or four times as many utterances as others (A, E). This means that even though PST A and PST E 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 (B, C, D, E). Discussing the definition of the design problem and modeling the details of the design solution were practices shared by all but one group member (A). By contrast, the practice of making design decisions, which occurred just five times in all, was exhibited by only one group member (B).

Conversational moves were not shared as evenly across group members. The members who spoke the most (B, D, F) were also the members who did the most re-stating of their own or others' design ideas, the most agreeing with others, and the most requesting of clarification. This suggests that these group members' additional utterances were more conversational moves than they were design activities. The move of discussing the task directions given by the instructor was also made predominantly by just a subset of the group members, PST C and PST F.

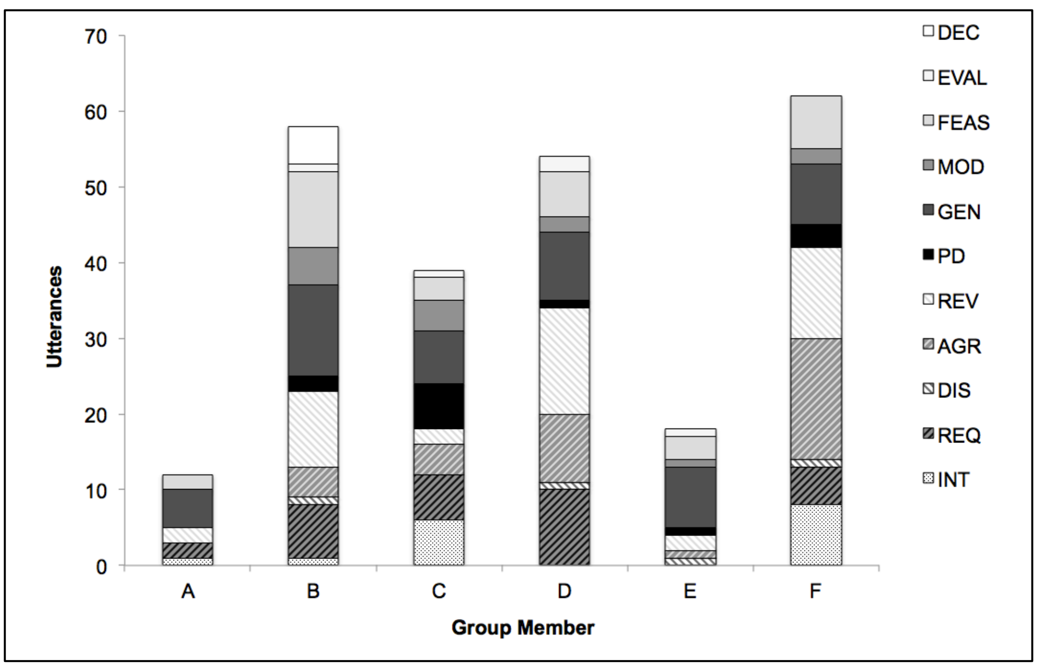

Figure 2. Design practices and conversational moves made by six pre-service teachers collaborating on a furniture design task based on a piece of children's literature.

Findings for Research Question 3: Over the course of the design task, what patterns occurred in how the pre-service teachers moved from one design practice to another?

Figure 3 maps the flow of the group's entire design process. It plots design practice and conversational moves, colored to indicate speaker, by time. The top eight lines (from COM at the top, down to PD near the middle of the graph) show the eight design practices of the coding framework. Focusing on these lines, we see the group members' emphasis on generating design solutions in the first twelve minutes of the design task and their shift toward increased feasibility analysis in the second half of the task. It also clearly 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 all throughout the task.

The bottom five lines (from INT at the bottom, up to REV at the top) of Figure 3 show the conversational moves that were added to the Design Activity coding scheme for this study of pre-service teachers *collaborating* on a design task. Previous studies using the original framework had included only individual participants completing design tasks independently. These lines of the figure 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. A good portion of the group talk was comprised of these affirming utterances, which are questionable in their value for improving the slate of alternative solutions or the success of the planned solution.

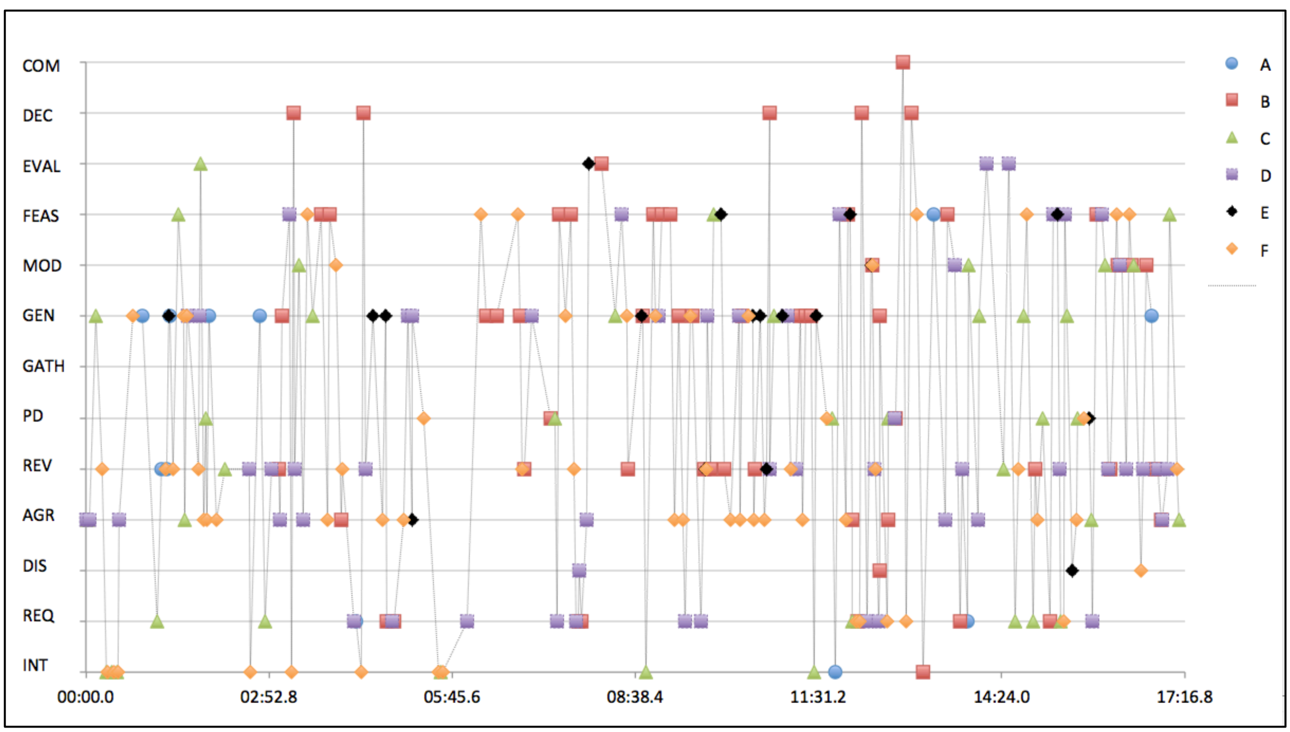

Figure 3. Design activities and conversational moves over the course of 17 minutes of a furniture design task completed by a group of six pre-service teachers. Shape and color indicates speaker; line indicates code for design activity or conversational move.

The lines on Figure 3 connect each utterance code to the code for the next utterance in time. It is clear that many of the lines extending from "GEN" utterances (generating possible design solutions) lead down toward the portion of the graph for conversational moves. This means that often, when group members proposed design ideas, other 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 GEN utterances. 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. This means that even though new design solution proposals often led to conversational niceties, they also led to further new ideas and to idea critique.

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)	7	16%
REQ (Requesting clarification)	5	12%
AGR (Expressing agreement)	9	21%
DIS (Expressing disagreement)	1	2%
INT (Discussing instructor's intent)	2	5%
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.

The connecting lines on Figure 3 also reveal that the practice of feasibility analysis was often preceded by a conversational move from the bottom of the figure. We analyzed the utterances that occurred immediately before feasibility analysis (FEAS) utterances, and Table 5 presents the results of that analysis. In Table 5 we see that group members' comments on the feasibility of design ideas were prompted both by the design activities of idea generation (GEN) and previous feasibility analysis, and by the conversational moves of restating, agreeing with, and requesting clarification about design ideas. However, there is not a single case of feasibility analysis being preceded by the modeling of a specific design detail or by a group member expressing disagreement with someone else's idea. This suggests that although the group members did pass judgment on the workability of their design ideas, they did so without great debate about the detailed elements and functioning of the proposed solution.

Table 5
Design Activities and Conversational Moves Occurring Immediately Before Feasibility Analysis

Code	Frequency	Percent
Design Activities		
PD (Defining the problem)	0	0%
GATH (Collecting needed information)	0	0%
GEN (Proposing design solutions)	5	18%
MOD (Specifying design details)	0	0%
FEAS (Passing judgment on possible design solutions)	6	21%
EVAL (Evaluating along particular dimension)	0	0%
DEC (Making design decision)	1	4%
COM (Communicating design to external parties)	0	0%
Conversational Moves		
REV (Restating design idea)	5	18%
REQ (Requesting clarification)	5	18%
AGR (Expressing agreement)	4	14%
DIS (Expressing disagreement)	0	0%
INT (Discussing instructor's intent)	2	7%
Other		
OTH (Conversation not relevant to design task)	0	0%
Total	28	100%

Note: Table includes only utterances that occurred immediately before utterances coded as FEAS.

Discussion

In summary, our analysis of the pre-service teachers' design process suggests that in an integrated engineering and literacy experience, pre-service teachers may focus on generating possible solutions and judging their potential feasibility, but neglect the activities of information gathering, design solution modeling, and detailed evaluation of proposed solutions. Here we compare these results to the design practices exhibited by novice and expert engineers. We also discuss the instructional implications for pre-service elementary teacher education in engineering.

It is illuminating to compare the pre-service teachers' design processes with those exhibited by novice and expert engineers in previous studies with the Design Activity coding scheme. 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). However, participants spent more than 100 minutes on the playground design task, much longer than the 17 minutes allotted to the pre-service teachers in the episode analyzed for this study. Therefore, here we consider just the first 19-minute subset of the data from Atman et al.'s (2007) study. 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 stem from or lead to 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. Both 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 pre-service teachers in this study gathered no additional 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 a design requirement was to meet federal safety standards), or what was known about the potential market for older siblings' furniture. None of the groups logged on to the Internet to explore existing furniture designs. Neither did the pre-service teachers engage deeply in problem definition. Although two group members, C and F, went back and forth several times about whether the problem was the need for space for the older sibling *himself*, or just for his belongings, this was the only meaningful attempt to frame the scope of the problem. This is especially interesting because we hypothesized 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?). Though we were correct about idea generation, our hypothesis regarding problem scoping was not supported by the data.

This contrast between pre-service teachers and engineers raises an important question. Why did the pre-service teachers neglect 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 as 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) 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 pre-service 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 the reason the pre-service teachers did not engage in problem scoping is that they did not have awareness of or experience with its value in creating successful design products.

The instructional implication of this possible explanation is that pre-service teachers need opportunities to see the value of problem definition and information gathering for engineering design success. One approach to helping pre-service teachers make progress in problem scoping may be to assign more open-ended and longer-term engineering design problems – perhaps that pre-service 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 before most teachers can effectively engage in (and teach) literature-based engineering problems, they need to engage in 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 pre-service 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 pre-service teachers might eventually pose. A third potential approach is to support pre-service teachers' engineering design activities with scaffolds, such as the Design Compass (Hynes, 2012), 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 pre-service 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 pre-service teachers' collaborative work on a literature-based engineering design problem 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 pre-service teacher education in engineering.

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