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Keywords

elementary, engineering design, student engagement

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Abstract

Novel Engineering activities are premised on the integration of engineering and literacy: students identify and engineer solutions to problems that arise for fictional characters in stories they read for class. There are advantages to this integration, for both engineering and literacy goals of instruction: the stories provide "clients" to support students' engagement in engineering, and understanding clients' needs involves careful interpretation of text. Outcomes are encouraging, but mixed, in part owing to variation in how students frame the task. For instance, although students often pay close attention to the stories, interpreting and anticipating their fictional clients' needs, they sometimes focus more on the teacher and what they think she would like to see. This variation occurs both within and across groups of students, and it motivates studying the dynamics of student framing. Here, we examine a pair of students who share a central objective of designing an optimal solution for their fictional client, and who persist in achieving their objective. We argue that the students' stable framing of the activity involves their engagement in engineering design, and that the abilities they demonstrate in pursuit of a solution are evidence of their productive beginnings in engineering design.

Keywords: Elementary, engineering design, student engagement

Introduction

Consider a moment from a fourth grade classroom in a rural New England town. Two students, Stella and Alexi, are participating in Novel Engineering,[1] in which students design and construct engineering solutions to problems that arise in literature.

The class had read a story about a young boy, Marty, who finds a stray beagle he names Shiloh (Naylor, 1991). When Marty learns that Shiloh's real owner is abusive, he decides to keep the dog hidden, building a makeshift shelter and sneaking him food and water. The shelter, however, is not safe: Shiloh is attacked one night by another dog. The class identified that keeping Shiloh safe was a priority, and that, as engineers, they would design and build better shelters for him. Ms. C, the teacher, provided craft materials (e.g., cardboard, tape, glue, felt) and specified that their models should "fit on their desk." She also noted that their designs will be "tested" but did not say how.

On the first day of the project, Stella and Alexi are working on their dog pen sketch (Figure 1) when Ms. C asks them about their design decisions.

Ms. C: What kind of entrance is it?

[1] See www.novelengineering.org

http://dx.doi.org/10.7771/2157-9288.1123

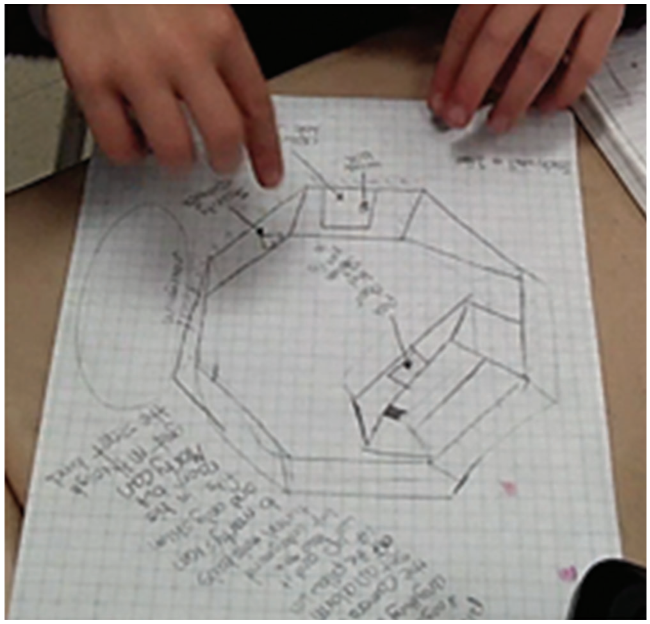

Figure 1. Stella and Alexi's design sketch.

Stella: It's…

Alexi: Just a little door, like the walls are two feet.

Ms. C: Two feet thick? Or two feet high?

Alexi: No, two feet high.

Ms. C: Two feet high, okay.

Alexi: I wrote it on this side somewhere (flipping paper), here it is. Oh yeah, oh, it's three feet.

Ms. C: Three feet! Wow. Why three feet? What made you decide three feet?

Alexi: Um, so it wouldn't be too short, like when Marty wants to go in, since it has, like, that glass that doesn't break on the top, he doesn't have to scrunch down (positioning her body to make scrunching gesture).

Ms. C: Ah, so Marty could go in as well?

Alexi: Yeah.

Ms. C: All right, very cool. Did the graph paper help you guys draw your diagram?

Alexi: Yeah.

Stella: Like, she did eight squares that way, and then six squares that way.

Ms. C: Oh, so you're using measurement as well, excellent work!

As Ms. C walks away, Stella and Alexi discuss the advantages and disadvantages of specific entrance locations, erasing, adjusting, and negotiating elements of their sketch.

Our first purpose in this paper is to argue that Stella's and Alexi's planning and reasoning show nascent abilities for engineering design. As they negotiate criteria (e.g., access, height, location) and constraints (e.g., abutting glass elements), they "prioritize the needs of their clients," ensuring that Marty will be able to access Shiloh and that he will do so easily and comfortably (Ropohl, 1997, p. 70). They generate multiple representations to analyze and evaluate features of their design and correlate their sketch and model to real-life dimensions, using graph paper to generate an appropriate scale.

The productive aspects of students' engagement are not common areas of focus in engineering education research. Many researchers instead highlight ways that students act as novices in contrast to experts (Crismond, 1997, 2001). For instance, scholars have argued that "beginning designers" (Crismond & Adams, 2012), may not fully grasp how complicated, fluid, and changeable design problem-solving landscapes can be (Dorst, 2003), or may be "unaware or unwary of the potential for cascading complexity" (Crismond & Adams, 2012, p. 747). Here, we focus on evidence of students' abilities.

Our second purpose is to suggest that students' demonstrations of those abilities depend on their sense of the activity. For Stella and Alexi, the task was about solving a problem for their fictional clients, and they developed and evaluated their design accordingly. We show they were stable in this, even when confronted with competing sets of expectations in the classroom evaluation. Other students, in contrast, shifted their attention away from the story of Marty and Shiloh, trying instead, for example, to showcase their knowledge of vocabulary terms (e.g. "stabilized" and "reinforced") or fantasizing alternative scenarios (e.g. imagining "laser beams" and "mini bodyguards").

We argue that students' understanding of the activity, that is their *framing* (Goffman, 1974; Tannen, 1993), affects the abilities they display. It is one thing to be able, for example, to scale a diagram; it is another thing to recognize a need to make use of that ability. Nobody had asked Stella and Alexi to scale their diagram to "real life"; they did that themselves as a natural part of depicting the dog pen on paper.

In the following sections, we review current literature in engineering education, highlighting the need for research on student engagement in design. We then discuss the construct of framing, in particular with respect to epistemic activity (Hammer, Elby, Scherr & Redish, 2005; Redish, 2004). Specifically, we discuss epistemological framing in classroom settings as applied to research on engineering design (Dym, Agogino, Eris, Frey, & Leifer, 2005; Schön, 1983; Vincenti, 1990).

We then return to Stella and Alexi, presenting data in three excerpts that show their productive abilities as well as their stability in framing. We then present a brief excerpt from another group of students who were less stable. In the discussion section, we propose that part of Stella's and Alexi's stability was their involvement in the story itself, including their empathy for the characters. We close the paper with further questions for research and possible implications for instruction.

Elementary students' engineering abilities

Much of the literature in engineering education documents students' lack of abilities. For example, researchers compare novices and experts to find that novices immediately try to solve the problem with little talk or forethought (Christian & Dorst, 1992, p. 132); make premature commitments to initial solutions (Cross, 2000); and treat design problems as well-defined textbook problems with clearly articulated initial states, identifiable collections of known variables, and set procedures for generating solutions (Atman & Bursic, 1996; Rowland, 1992). These findings have driven work on instructional strategies. In a recent, seminal paper, Crismond and Adams (2012) developed the "Informed Design Teaching and Learning Matrix," providing detailed descriptions of contrasting behavioral patterns between "beginning" and "informed" designers. The purpose of the tool was to help teachers address the "highly ineffective practices and habits of mind that beginners employ" (p. 741).

Meanwhile, there is significant research to show students have abilities for engineering design. They can navigate their own design processes, interacting with the social and material elements of the design situation (Roth, 1995, 1996), reason about uncertainty (Jordan & McDaniels, 2014), and scope complex problems (Watkins, Spencer, & Hammer, 2014). For example, Roth's (1995) study of fifth graders participating in a thirteen-week engineering design module illustrates how the students iteratively shaped and reformed their goals as they "construct, reconstruct, resolve, and abandon multiple interacting problems" (p. 366). Rather than being "stifled by open-endedness" or "unaware of the potential for cascading complexity" (Crismond & Adams, 2012, p. 747), the students attended to different aspects of problems, analyzing structural stability, function, and uses of specific materials.

In this article, we also show students' productive abilities, and we argue that students' sense of what they are doing – their framing (Goffman, 1974) – matters for the abilities that they enact. If students frame what they are doing as a traditional school activity, they are more likely to treat it as a well-defined problem with clearly articulated initial states, identifiable collections of known variables, and set procedures for generating solutions (Atman & Bursic, 1996; Jonassen, 1997; Rowland, 1992). On the other hand, if students frame the design activity as an opportunity to construct and evaluate their own designs, they may demonstrate "uncanny competence" (Roth, 1995, p. 372) for dealing with complex design situations. In our data, we see both. Here we present evidence of the latter: Stella and Alexi navigate their own design process in pursuit of an optimal solution for their clients. Our goals are to understand how they are framing the activity and how their framing involves their nascent abilities for engineering design.

Framing

In a given situation, people form a sense of what is taking place, whether playing soccer, learning science, or designing a bridge. Forming that sense, or "framing," involves structures of expectations formed from previous experiences, or "frames" (Goffman, 1974; Tannen, 1993). In these accounts, frames both shape and are shaped by experience, and framing is a dynamic interaction between expectations and perceptions. Frames are not static, rigid structures, but are active and responsive, perpetually evolving as they are informed, shaped, and tuned with new experiences; they are "schemas" (Bartlett, 1932) of activity. "One's structures of expectation make interpretation possible, but in the process, they also reflect back on the perception of the world to justify that interpretation" (Tannen, 1993, p. 20–21).

For Stella and Alexi, part of the challenge is to form a sense of their task, engineering for Marty and Shiloh, and that involves their tapping into patterns of their previous experiences of telling stories, doing projects in school, making things, and so on. Part of the challenge, too, is to understand the situation in the story. Their experiences similarly shape their comprehension of the novel, in structures of expectations about caring for dogs, ownership and protection, and so on. At the same time, their experiences in this task contribute to those patterns, perhaps helping them understand future experiences. Reading the story, for example, may be their first encounter with the idea of an abusive owner; designing the protective pen may be one of their first experiences of engineering.

Epistemological Framing in Classroom Settings

There are many aspects to framing, at multiple scales and with complex, nested relationships. An individual who is baking has an overall sense of what baking involves, but may cue finer-grained framings within subtasks of measuring, mixing, frosting, etc. In Stella's and Alexi's case, their framing of being students in a classroom may involve expectations for sitting at their desks, listening to their teacher or an adult in charge, and engaging in certain actions for specific time blocks. As part of being students, they may activate frames for "learning science" that involve experimenting and making sense of phenomena, and other frames for "learning spelling" that involve memorizing sequences of letters. Across and within different activities or classroom contexts, students activate and tune their expectations, including those with respect to knowledge and learning. Redish (2004) described this as "epistemological framing."

Research in science education has paid significant attention to students' expectations with respect to knowledge. A variety of studies have documented students experiencing science class as focused on the authority of the teacher or textbook (Hammer, 1994; Lemke, 1990; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Redish, Steinberg, & Saul, 1998), rather than on making tangible sense of natural phenomena. In these cases, students frame what they are doing as memorizing, storing, and reproducing known information, rather than, for example, producing and assessing knowledge. Recent accounts have built on this work by attending to the local dynamics of students' framing (Hammer, 2004; Louca, Elby, Hammer, & Kagey, 2004; Rosenberg, Hammer, & Phelan, 2006), showing sensitivity to features of context and social interactions. Researchers' findings indicate that for students to be actively learning science, they must not only frame what they are doing as sense-making about natural phenomena, they must do so with stability, and often with resilience against the familiar "classroom game" (Lemke, 1990) that focuses less on the natural world than on the authority of the teacher or text (Hutchinson & Hammer, 2010).

In engineering, too, students may frame what they are doing as a kind of classroom game, such as memorizing the engineering design process in order to pass a test, or finding the "right answers" (Hennessy & McCormick, 1994; Johnsey, 1995; Welch, 1999) to closed-form questions. On the other hand, students may frame what they are doing as solving a problem, helping a client, or designing functional solutions. Students framing what they are doing affects the abilities they invoke, for example, for planning (Portsmore, 2010). These variations motivate attention in engineering education beyond abilities to understand dynamics in student framing.

Productive Framing in Engineering

A view of framing sees engineers' understandings of design as involving patterns of familiar experiences, tuned to the particulars of situation. This is the heart of schema theory; a schema is "an active organization" of past experiences (Bartlett, 1932, p. 201), active to include local tuning. As Schön (1983) describes, engineers "are not confronted with problems that are independent to each other, but with dynamic situations that consist of complex systems of changing problems," (p. 16). In "making sense of a situation" (Schön, 1983, p. 40), an engineer maintains a heightened awareness of the overarching design task, while attending to the multiplicity of interacting subtasks (Dym et al., 2005). Accordingly, design tasks generally involve subtasks; understanding how to manage subtasks and coordinate design steps is part of framing in engineering.

For example, an engineer's framing of a bridge design project may involve meeting the client's needs while adhering to situational constraints. Within this overarching framing, the engineer is simultaneously recognizing subtasks, such as researching the environment, developing and analyzing computer models, and negotiating with contractors and community members. At each decision juncture, the engineer must reflect on the big picture, recognizing clients' needs and design constraints, and respond with appropriate modes of reasoning and action, such as analyzing, evaluating, constructing, etc. (Trevelyan, 2010).

Analogously, students' framing of a Novel Engineering activity may involve reflecting on the story and responding to characters' needs. Our early findings suggest that a story setting provides a sufficiently "messy" (Schön, 1983, p. 33) design context, in which story characters become clients with wants, needs, and potential dilemmas, and there are implicit physical, social, and economic constraints (McCormick & Hynes, 2012). Thus, in framing a complex design task as beginning engineers, students may recognize a need to reason, make decisions, and act as engineers: to develop an optimal solution for their client. We argue that engineering abilities, or "technical know-how" (Ropohl, 1997), should not be our sole end goal in engineering education. Fostering productive framing should be a central target for research and practice, such that students recognize a need to use their engineering abilities.

Methods

Research setting. This study is part of an NSF-funded project at Tufts University (Grant No. 1020243). The primary goal is to support elementary school teachers in using children's literature as contexts for engineering design. Participating teachers develop and implement Novel Engineering units using stories that are already part of their curricula. In preparation, teachers attend approximately 40 hours of professional development, working with project staff in developing lessons and implementation strategies.

This case study takes place in a fourth grade classroom in a rural town in Massachusetts, about forty miles from Boston. The teacher, Ms. C, had attended approximately 35 hours of professional development and was excited to try Novel Engineering using the book *Shiloh* (Naylor, 1991).

Data collection and analytic tools

The project collects video data *in situ,* in addition to students' written work and artifacts. As previous researchers have noted, videos provide a medium for analyzing naturally occurring phenomena (Derry et al., 2010). For our purposes here, it supports analyzing moments of student discourse and activity, including paralinguistic channels of communication, such as pauses, interruptions, and gestures (McDermott, Gospodinoff, & Aron, 1978; Jordan & Henderson, 1995). These often provide "meta-communicative messages" that signal one's framing (Bateson, 1972; Tannen, 1993).

For this study, two researchers, including the first author, were present during the classroom activities, providing materials, supporting teachers and students during building, as well as taking field notes and video recording. Researchers set up three cameras to capture group work and walked around with two additional cameras, recording student interactions and asking questions about students' designs. In our analysis, we draw on tools from discourse (Gee, 1998) and interactional analysis (Jordan & Henderson, 1995) with attention to both verbal and non-verbal aspects of the data (see also Scherr & Hammer, 2009).

Analysis

For this project, Ms. C gave the students two hours per day for three consecutive days[2]: Day One involved class read-aloud, discussing the major problems in the book, and starting individual plans; Day Two, working with a partner on design plans and building; and Day Three, finishing designs followed by group tests and presentations.

We show three further excerpts of Stella's and Alexi's work. In the first, earlier on day one than the excerpt in the introduction, Stella and Alexi explain their design decisions, focusing on their fictional clients' needs. In the second and third, they show resilience in this framing against competing expectations regarding testing and evaluating criteria. We then show brief snippets of data from other groups in the same classroom who were comparatively less stable in their framing.

Design considerations (Day One)

During the initial phase of their design, all of the students in class are working in pairs or groups of three to co-construct a sketch of a dog pen for Shiloh. When the materials for building (e.g., cardboard, paper, glue, etc.) become available, many students rush to grab them. Others, including Stella and Alexi, continue to work on the details of their design sketches. In the following, the first author asks the girls about their work.

Mary: That's a cool design. What is, so what do you have?

Alexi: It's like, in this [unclear], and there's a little lock, so Marty can just turn the lock, and there's a little door that Shiloh just fits in. And if the camera sees something that it doesn't recognize, like, if it's not Marty's family or something, or if it's something else, it'll, like, this door will go automatically open, and the pillow will come out, and there's underground tunnels, and there's, like, a little, um, there's kinda, like, a little box in here — I kinda drew dotted lines.

Mary: That's really cool!

Alexi: – and then there's tunnels leading to Marty's room, and an alarm will go off in Marty's room, so he can just crawl through the tunnels and get to Shiloh.

Mary: Oh, that's really cool! So you're thinking about how Marty can – is Marty the owner of the dog?

Alexi: Yeah.

Stella: Well, not necessarily the owner…

Alexi: But he wants to be the owner!

Mary: (laughing) He wants to be!

Alexi: So that's why he's trying to keep it very secret.

The girls focus on keeping Shiloh safe, comfortable, and accessible to Marty. They describe the functional issues of the tunnel connection, with attention to details from the story: the tunnel is accessed only through the pillow door, and provides a direct route for Shiloh to Marty's room. As they imagine Shiloh's escape route, they consider multiple perspectives: Alexi describes the path Shiloh will take to get to Marty's room, as well as a way for Marty to be alerted so he can quickly rescue Shiloh in the case of danger. They develop contingency plans to account for implicit "what if" circumstances, such as sizing the tunnel door so that "just Shiloh fits in," and not the big dog, while maintaining fidelity to "must haves" (i.e., a door to the pen) (Schön, 1983, p. 101). Although keeping Shiloh hidden or "secret" was never discussed as a classroom requirement, Stella and Alexi prioritize this criterion, realizing that if he is caught, he will likely be abused again.

As in the excerpt we presented at the opening of the paper, Stella and Alexi coordinate their overarching design

[2] The class spent a total of about 3 weeks on the book, included daily read-aloud time and discussions about the plot and characters.

goals of keeping Shiloh safe and secret with subtasks of developing and evaluating components. Their decisions are not driven by the classroom requirements of size and testability, but by the girls' interpretation of the physical and social setting of the story. These considerations, we argue, are evidence that they are framing the engineering design task as an opportunity to solve a problem for their fictional clients.

How Do You Test It? (Day Two)

At the start of Day Two, with the class assembled as a whole, Ms. C calls on Stella to summarize the requirements.

Ms. C: Stella, can you give a quick summary of what our requirements would be?

Stella: Oh, okay. Um, must fit on top of our desk and the test must be able to fit inside (referring to "inside" the dog pen).

Ms. C: Whatever we choose, however we choose to test, it (referring to testing object) must be able to fit inside (the dog pens) so we can see if Shiloh would be able to get out and if something would be able to get in. And there was one more on the bottom, it has to be some sort of...

Stella: Pen.

Ms. C: Pen, right? Some sort of enclosure.

The students' design task, as Stella remembers, is to construct a model of Shiloh's dog pen that is scaled to "fit on top of our desk," and the scaled model must be functional. Ms. C confirms and elaborates several criteria for the test: (1) the test object must fit inside the model; (2) the model must have boundaries that will prevent the object from leaving ("we can see if Shiloh would be able to get out"), and (3) the model must be protective in that it keeps outside objects from getting in. Shortly after, Ms. C specified that the test object would be a wind-up toy that moves by vibrating on four wire legs.

As the students in the class construct their pens, they all evaluate their projects as they are working in pairs, drawing from a wide range of criteria. For instance, whereas some evaluate based on how well it will work for Marty and Shiloh, others prioritize "classroom" expectations, anticipating how their projects will be assessed in comparison to their classmates'. In the following, Stella and Alexi are working on their project when another student, Owen, who has finished his dog pen, comes to look at their work.

Owen: Did you guys see ours?

Alexi: Yeah, yours is awesome. Did yours make it through the tests?

Owen: Not yet.

Mary: How are you guys testing it?

Stella: Um, over there. I don't know what she's going (pointing towards Ms. C).

Mary: How do you think you'd want to test it?

Alexi: I think she's gonna take, like, a little wind-up toy, and it's just gonna walk around and it can't, your thing can't fall over.

Stella: Well this is felt (referring to a soft cloth), so I don't even know if it would be able to walk. But the felt is good, cause then it's soft.

The interaction between Stella and Owen shows competing expectations for the design task. The classroom expectations involve passing the test with the wind-up toy; the client-focused expectations involve optimizing a design for Marty and Shiloh. When Alexi asks Owen if his dog pen "made it through the tests," she shows an awareness that their projects will be tested when they are done, that Ms. C is "doing" the test, and that it will be a basis for comparing their design other students'.

When the first author asks about the test, Stella reacts dismissively: she gestures to the other side of the classroom, but quickly resumes her focus on constructing, biting her lip as she figures out how to attach the roof. Alexi explains what the teacher will do; it is the teacher's test, not theirs. Stella notices a feature of their design that might perform badly in that test: the felt that they are using as a rug for Shiloh may prevent the wind-up toy from moving during the test. She wants to keep it anyway, asserting that it is "good" because it will be soft for Marty and Shiloh.

For Stella and Alexi, the test is disconnected from the story context and their goals. They describe as an action their teacher performs, refer to a "wind-up toy," instead of Shiloh and a "thing" instead of dog pen. They remain anchored in the story context, even though they recognize that many of their classmates are prioritizing the test. Stella's reasoning in the last line shows her explicit prioritization of Shiloh's and Marty's comfort over classroom testing criteria; she is aware of the competing sets of expectations but is committed to her own.

Evaluating for the Client (Day Three)

On Day Three, all of the students take turns presenting and testing their designs. Ms. C announces that the dog pen test is two parts: (1) a "small dog" test, which involves letting the wind-up toy scurry about inside the pen for thirty seconds without escaping, and (2) a "big dog" test, which involves winding up two bigger toy cars (to represent big dogs) and letting them crash into the sides of the pen.

During their presentation, Stella and Alexi highlight meaningful features of their design, elaborating on how the tunnel will function as an escape route in case the antagonists of the story come after Shiloh. When they are ready to test, Ms. C suggests that the first test should be for the small dog to slide down the secret tunnel part of the design. The students are gathered around Stella and Alexi's design to observe, hoping to see the small dog emerge from the bottom of the tunnel.

Students: He's at the bottom! ("He" refers to Shiloh and/or the toy).

Ms. C: Oh, he came out! All right, so the small dog was able to go through the tube (referring to the tunnel). Why might it be tricky to test going *up* the tube?

Alexi: He (Shiloh) doesn't go up the tube because Marty lives on the bottom of the hill and Shiloh's pen is on a hill. So he would just like (gestures down the tunnel), Marty would walk him up the hill.

Ms. C: Okay, so he's not expected to go back up the tube. He's expected to start at the top and go all the way down.

During the test, Ms. C raises the question of whether using the toy would be appropriate to find out whether the dog could go up the tunnel. For Alexi, though, the question is moot. She responds by describing how the design works in the story setting, insinuating that there is no reason to test the small dog going up the tube because that is not how the tunnel is designed to function. Rather than adapting their framing to incorporate the classroom expectations, Stella and Alexi persist in attending to their clients' needs and adhering to the constraints of the design context.

Stability and instability of framing

Stella's and Alexi's stable framing

Like engineers, Stella and Alexi were continually reflecting on and responding to their clients' needs within the context of the story, reasoning about and negotiating decision criteria, and iterating as needed to develop an optimal design. They maintained attention to their clients even when confronted with competing sets of expectations for what they should be doing in this task. The data give evidence of their stability: When Ms. C praises their use of "measurement," they acknowledge her comment, but continue working on their design. When testing parameters come up in conversation, the girls react dismissively and prioritize Shiloh's needs. When presenting, they do not adapt their design to accommodate their teacher's or classmates' comments; they argue for the evaluation criteria of the story setting.

Stella and Alexi were unusual in the stability of their framing. Other students' sense of the task shifted during their work. The following is a brief example.

Shifting from the story to the classroom

Jack's, Cooper's, and Thomas's early design discussions involved reasoning and making decisions based on "keeping Shiloh safe," and ensuring access to sunlight so Shiloh "doesn't feel trapped." Like Stella and Alexi, they were taking the perspective of their clients, articulating implicit criteria, and evaluating it based on meeting those criteria. When presenting, however, the boys highlight different aspects of their design thinking, information they expect their teacher values. In the following, Jack responds to Ms. C's prompt to reflect on what they would do differently next time.

Jack: Well, I think that we would probably make this (pointing to the door) more secure, and probably make this more like inside, so it like, more, what is called? Like, more stabilized.

Ms. C: Okay, using some really good vocabulary. I'm hearing *reinforce, stabilize, secure*.

Ms. C then gives the other students an opportunity to ask questions. One girl asks them why they thought to do "that kind of design." When Jack responds that he just thought of making a rectangle instead of a circle because it would be safer, Ms. C asks the boys about their choice of shape.

Ms. C: Why do you think rectangle versus a circle?

Jack: Because, um, well, a rectangle would keep him in.

Ms. C: You don't think a circle would?

Jack: It might, but, um, a circle we just thought of, and then (we) were like, a rectangle, what about that? And so, we all had circles and he (pointing to Thomas) had a rhombus.

Ms. C: I like the geometric terms we're using!

Thomas: I had a hexagon!

Jack initially reflects that their redesign would involve making it more "secure," and recalling a new word, more "stabilized." Ms. C then commends him for his use of "good vocabulary." Shortly after, when another student then asks the boys why they thought to do "that kind of design," Jack describes that the rectangle shape of the dog pen was a determining factor in making it "safer." When Ms. C asks them if they considered a circle, the boys shift into a slightly different sort of activity. In this, they showcase their knowledge of geometric terms,[3] including "rhombus," "square," and "hexagon," which they rightfully expected Ms. C would appreciate. For the moment, they seem less concerned about the Shiloh's safety and comfort than about classroom evaluation.

For Jack, Cooper, and Thomas, forming a sense of the task involved attending to what was socially valued in their immediate classroom context, i.e., knowledge of vocabulary. Their framing of the activity, in that moment, shifted to classroom expectations, influencing their choice of design features to highlight recognized words. The dynamics of student framing in engineering design align with other classroom-based accounts, in which students' ways of thinking are influenced by their interpretation of the task, may shift within a single conversation (Hutchison & Hammer, 2010), and continually interact with social, conceptual, and epistemological aspects of discourse (Scherr & Hammer, 2009).

Stable beginnings in engineering

Our initial motivation to study this case was to examine Stella's and Alexi's abilities to reason and act as engineers.

[3] The class had been recently discussing geometric shapes in mathematics lessons.

In early analyses, we examined how they spontaneously planned by considering multiple aspects of the design context and their clients' needs, and generated appropriate scales to ensure accuracy in a "real life" context. In accounting for social and physical dimensions, they seemed to tacitly recognize that "design does not take place for its own sake or in isolation, but rather is directed at a practical set of goals intended to serve human beings" (Vincenti, 1990, p. 6). Much like engineers, the girls demonstrated "design thinking," making informed assumptions about the problem situation (Adams & Atman, 2000), identifying and stating user needs (Bursic & Atman, 1997, p. 66), and considering outcomes of hypothetical situations (Dym et al., 2005).

As we continued to study Stella and Alexi, we became more interested in their framing of what they were doing, itself an aspect of their nascent engineering. Like engineers, Stella and Alexi were continually reflecting on and responding to their clients' needs within the context of the story. Stella's and Alexi's stability in engineering for their fictional clients allowed them to navigate a design process. To co-construct their design idea, for example, Stella and Alexi requested graph paper and used it draw a detailed plan view of the dog pen. To specify dimensions, they generated a scale based on their assumptions of the client's needs, and when evaluating their design, they prioritized criteria according to Marty's and Shiloh's safety and comfort. The girls did not "plan" because it was a step listed in their engineering design process; they planned because they were thinking about what might serve their clients. Similarly, they did not evaluate their design based on a test that did not make sense to them; they evaluated it based on how they meant it to function in the setting of the story.

In contrast to Stella and Alexi, other groups in the class were less stable in their framing, shifting in response to classroom cues. Jack, Cooper, and Thomas discussed their initial design decisions based on "keeping Shiloh safe," and ensuring access to sunlight so Shiloh "doesn't feel trapped," evidence of framing comparable to Stella's and Alexi's, but they shifted in moments later to focusing on using terminology they expected the teacher would appreciate.

In another instance, a pair of girls incorporated LEGO® figurines as "body guards" and pipe cleaners as "laser beams" to protect Shiloh. Because their initial design sketch did not include these imagined features, we suspect the girls' interest in craft materials triggered a shift in their framing away from the situation of the story. That is, they adjusted their framing of what they were doing, essentially shifting the genre of the story as written, to include elements of fantasy or science fiction.

To be sure, Stella's and Alexi's design had unrealistic elements. Their early conversation included a system equipped with cameras, facial recognition, and automatic doors, but these soon disappeared. Of course as well, their tunnel would have been quite difficult to dig, but that is not something we can expect they would know. Our claim is that their thinking remained close to the situation of the story, as they could envision it.

To summarize, many of the students' framings of the Novel Engineering task dynamically evolved as they responded to classroom prompts and interacted with other students in the classroom. Stella and Alexi, however, remained stable in their focus on designing for their fictional clients, even in potentially pivotal moments.

Empathy as stabilizing

Their stability piqued our interest and sparked a related research question: *What was it about their framing that enabled them to be stable*? We suggest that Stella's and Alexi's stability in this task came in part from their investment in the story, including their caring for the characters and their problem. We see evidence of the story holding their attention in their responses to questions about their activity, with references to details about the situation, such as Marty wanting to be Shiloh's owner. We also see evidence of their imagining aspects of the situation not explicitly in the story, such as how their system might need to let Marty's family in, that Marty might need to get in the tunnel himself, or that the real need for the tunnel would be to escape from the pen to Marty's room if endangered. In this, they demonstrate *design empathy* (Kouprie & Visser, 2009), an understanding of and concern for their clients, ensuring that Marty and Shiloh will have access to each other and that Shiloh's pen will provide safety, comfort, and security. By imaginatively projecting themselves into Marty's and Shiloh's situations (Koskinen & Battarbee, 2003), Stella and Alexi are able to deeply discern their clients' circumstances and perspectives (Battarbee & Koskinen, 2005), and to design a solution to best meet their needs.

Although the importance of empathy in design is well recognized (Batterbee & Koskinen, 2005; Brown, 2009), many researchers have noted that it is often lacking in the design process (Fulton Suri, 2003; Mattelmäki & Batterbee, 2002), and have developed a number of tools and techniques to enhance designers' empathy (Kouprie & Visser, 2009). In this case of children engaging engineering design, however, we see the opposite: Stella and Alexi's ability to empathize not only informs their design decisions, it supports and sustains their framing of the task as engineers.

Conclusion

In this study, we added to research demonstrating students' beginning abilities to reason and act as engineers, and we argued that students enact those abilities when their understanding of the experience calls for it.

For Stella and Alexi, developing an optimal solution for Marty and Shiloh was a central objective. Their actions of inferring design criteria and constraints, making informed assumptions and estimates, co-constructing scaled representations, and defining evaluation criteria served a purpose in helping them achieve this objective. The girls did not treat the task as well-defined or try to follow design steps in a linear order, as the literature claims "beginning" engineers do (Crismond & Adams, 2012). Instead, they explored the problem to understand their clients and iteratively navigated their own design process to meet their clients' needs. We argued that the girls' framing of the activity involved their engagement in engineering design, and that the abilities they demonstrated in pursuit of a solution were productive beginnings.

This case study is part of a larger project to understand students' framing in engineering (McCormick, 2015). The findings we present here suggest that when students' framings have them acting as constructors and evaluators of their design, they may purposefully navigate an engineering design process. From this and other observations and analyses, we suggest that student framing should be a central target in engineering education research and practice. By attending to student framing in research, we may illuminate not only students' engineering abilities, but also their reasons for enacting those abilities. Moreover, we may be better equipped to foster and cultivate productive framing during engineering activities in practice, providing students with opportunities to design for clients and to interact with multidimensional problem situations.

Implications

These complexities in framing dynamics spawn many questions for instruction and warrant further research to understand how students make sense of open-ended design activities. For instruction, we consider how teachers' lesson structures and responses to students' design ideas may play a pivotal role in their framing. Teachers must make choices regarding how open-ended to make the design activity, the nature of design constraints, available materials, whether students' designs will all be tested, and so on. These choices may largely influence how students take up the design task: in highly structured tasks, students may be more inclined to frame the design task as a "school" activity. However, in completely open-ended design tasks, students may deviate from the design situation to create representations of fantastical solutions (McCormick & Hammer, manuscript under review). We argue that these complexities warrant deeper research, particularly for recognizing students' engineering abilities and for understanding how instruction can be designed to tap into and nurture students' abilities.

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