122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12630

From Pretending to Engineering: An examination of students' dynamic engagements in Novel Engineering design activities (Fundamental)

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Pretending and Engineering: An examination of students' dynamic engagements in Novel Engineering design activities

(Strand: Fundamental)

Introduction

Recent reports, frameworks, and assessment criteria[1-3] have called for a shift in the focus of student learning in engineering design from specific content knowledge[4] to disciplinary core ideas and practices[2]. This shift requires that educators, curriculum writers, and researchers develop student learning experiences that share central aspects of professional engineering situations – i.e., problems that are open-ended, ill-defined, and occur within rich, socio-material contexts[5]. To develop informed approaches, the community needs a deeper understanding of the phenomenological aspects of student learning and engagement that unfold in rich, multilayered learning situations[6-8]. In this work, we examine how students learn to manage "messy" design situations[9], in which they must make assumptions, accommodate conflicting goals, and recognize the importance of multiple and diverse solutions methods[10].

This paper builds on and is motivated by previous research in which we conducted in-depth case study analyses of students engaging in Novel Engineering design activities[11-13]. In Novel Engineering activities, students identify problems that occur in children's literature and engineer solutions to help the story characters. Across and within participating classrooms, we have identified variations in how students engage in the task: while some attend to the characters and the story setting as their fictional clients and design contexts, others prioritize the expectations of their immediate classroom, and many shift between and combine aspects of both the story and the classroom. Our analyses of student engagement suggest that students' tacit understandings of the activity – what they think is going on – influence their engagement in engineering design[12,13].

In this study, we invoke a *framing* lens to examine how students make sense of Novel Engineering design activities on a moment-by-moment basis. We conduct an in depth study of one group of students to (1) explore how the students' framings dynamically shift and evolve over the course of their design experience, and (2) examine how their framings interact with their engagement in disciplinary practices. We present our development of a coding scheme that is grounded in data to capture framing transitions and stabilities over the course of students' design trajectories. To deepen our understandings of how students' form, negotiate, and maintain their framings, we draw from discourse analysis to explore students' moment by moment interactions. This effort is the first step in a larger study that will explore the dynamics of student framing across multiple groups of students participating in different Novel Engineering activities.

Qualitative accounts of elementary students engaging in engineering design indicate that students have nascent abilities for reasoning and acting as beginning engineers: they navigate their own design processes by interacting with the social and material elements of the design situation[14,15], reason about uncertainty[16], and scope complex problems[17]. Roth's (1995/1996) study of fifth graders engaging in engineering illustrates how the students iteratively shape and reform their goals as they "construct, reconstruct, resolve, and abandon multiple interacting problems" (p. 366). Instead of following a sequence of design process steps, the students attend to different aspects of problems, analyzing structural stability, function, and uses of specific materials and aesthetics, and consider trade-offs in their pursuit of optimal solutions. Similarly, in their analysis of student discourse, Jordan et al. (2014) show how students collaboratively manage multiple aspects of uncertainty in engineering design by enacting strategies to cooperatively manage, negotiate, and clarify vague or ambiguous dimensions of the design situation.

These accounts and others[17,18] show that students enact sophisticated ways of reasoning in engineering design as they are solving ill-structured and open-ended problems. However, researchers have also indicated this is not always the case; in other instances, students with little formal design experience may not fully grasp how complicated, fluid, and changeable design problem-solving landscapes can be [19] and may immediately try to solve the problem without planning[20,21]. In a synthesizing study, Crismond and Adams (2012) summarize that students are more likely to attempt to solve a problem with little talk or forethought; skip research instead of generating solutions immediately; start their design with few or only one idea; and enact design as a sequence of steps in their search for a solution. Our review of the literature indicates a wide range in students' abilities to engage in engineering: in some instances, students demonstrate an "uncanny competence" to resolve ambiguities and "exploit the open-ended situations in a productive way," (Roth, 1995, p. 378), while at others, they "can be unaware or unwary of the potential for cascading complexity" (Crismond & Adams, 2012, p. 747).

Our research on the Novel Engineering project reflects similar contrasts in student engagement[11, 23]. For example, we have found that some students may consider multiple dimensions of the design situation and develop optimal solutions for their clients[17], while others disregard criteria of functionality or feasibility, opting instead to repurpose craft materials in imaginary ways (e.g., "laser beams") or focus on using the "right" vocabulary terms (e.g. "hexagon" and "rhombus")[23]. We have noticed these differences emerge within and across groups and change dynamically as students interact in their local environment: in one moment, students may evaluate their solution for clients' needs, and in another, they may fill out a planning worksheet with little research or forethought, instead focusing on how they will be evaluated. The variations in students' abilities in the literature and within our project have raised many research questions for us, mainly in understanding the dynamics of student engagement and what has them engaging in these ways. Based on our data, we argue that the differences in student engagement are not accurate descriptors of their varying abilities, but are likely entangled with students' sense of the activity, including their local goals, purposes, and perceived constraints or rules of the activity. For research, we argue that assessments of students' abilities in engineering need to account for what students think the activity is about.

A *framing* perspective – students' tacit understandings of "What it is that's going on" [24] offers explanatory insight to students' varying interpretations: in framing the activity, students draw from previous experiences they perceive to be similar and adapt their expectations to reflect their current situation. In this view, students' novice-like behaviors may be explained by their previous experiences in school settings: when framing a design activity as a "classroom game"[25] or "doing school"[26], students may treat design problems as well-defined textbook problems with clearly articulated initial states, identifiable collections of known variables, and set procedures for generating solutions[27, 28, 29]. Students may also draw from their other experiences (e.g., imaginative play, storytelling, problem solving) as they are making sense of an engineering design activity. In these instances, incorporating fantastical technologies might be justifiable; while in others, navigating complex problem contexts, reasoning about uncertainty, and considering clients' needs might be logical things for students to do.

Research in science and mathematics education provides numerous accounts of how students' moment-by-moment framings interact with social, epistemological, and conceptual dimensions of their experiences. These accounts highlight the dynamic and contextually sensitive nature of framing and the implications for student learning in classroom settings (e.g. [30, 31, 32]). For instance, Hutchinson and Hammer's (2010) work illustrates that participation in science may involve choosing equations and plugging in values to produce a numeric answer in one moment, and may shift to involve making conceptual connections and reasoning about phenomena in another. In their analyses of classroom episodes, the authors show the sensitivity with which students' framings of a discussion shift between treating science as the production of answers and as an opportunity for making sense of the natural world[30].

Scherr (2009) and Scherr and Hammer (2009) illustrate similar shifts in students' framings at a group level: when working together, students may arrive at locally coherent, shared framings by tacitly sending and receiving *metamessages*[33] (e.g., gestures, tones of voice). By examining students' interactions and subtle changes in behavior, the authors show that students are more likely to be discussing the substance of each other's ideas when gesturing and talking loudly to each other than when they are focused on worksheets with eyes downward and whispering. Their analysis illustrates the interrelatedness of students' behavior, framings, and the conceptual substance of their reasoning.

While much of the literature highlights a dichotomy between "doing school" and disciplinary engagement[30,34], others suggest that students' framings in learning activities can be more diverse and overlapping. For example, students may adapt their classroom practices to include practice of scientific argumentation, allowing them to engage in the scientific practice without drastically transforming the ways in which they typically interact in the classroom[35,36,37]. Hogan and Corey (2001) argue that introducing new scientific practices into a classroom results in a "composite culture," which entails aspects from both the extant classroom practices and the practices of the scientific community. Similarly, Berland (2013) shows how students' existing classroom practices influence their practices in disciplinary scientific argumentation. Berland's study points to alignments and overlaps in goal structures that allow student to adapt and evolve integrated forms of scientific and classroom practices.

In design studies, the complexity of student framing may be augmented by the additional design context; when designing for a client in a unique design situation, students may draw from experiences that involve imagining, perspective taking, representing, authoring, etc. Jurow's (2005) work illustrates how students account for multiple dimensions when engaging in a project-based mathematics curriculum premised on the objective of designing a research station in Antarctica. In the study, Jurow documents how students shift between, combine, and layer multiple "figured worlds," including the world of the immediate classroom, the disciplinary world of mathematics, and the world of the design setting (Antarctica). Jurow's findings indicate that students did not see the different contexts of the design setting, classroom, and disciplinary mathematics as being mutually exclusive; instead, she found that students participated in multiple "embedded and interpenetrating figured worlds," (p. 68). Jurow (2005) concluded that the multiplicity of contexts supported students in identifying emergent goals and using mathematics to solve meaningful problems. From a framing perspective, we conjecture that as the students were shifting in their attention to multiple worlds, they were also adapting, negotiating, and co-constructing shared framings of their activity, which allowed them to use mathematics purposefully in pursuit of design solutions.

Our review of the literature indicates that that attention to student framing is critical in understanding and assessing students' abilities for engineering design. As research in science education has shown, the dynamics of student framing may be very complex; students may, in one moment, frame a discussion a sense-making, and in another, as "doing school." In design-based studies, researchers have pointed out that students' patterns of engagement may include multiple other experiences, which students may layer or blend when forming a sense of the activity. We argue that these complexities warrant deeper research into the nuanced dynamics of student framing in open-ended, ill-structured design activities.

Here, we explore how students make sense of Novel Engineering design situations by coordinating, negotiating, and managing aspects of the story and their immediate setting, including the materials that are available, how the task is structured, who their clients are, etc. Our theoretical intent in this work is to understand the dynamics and nature of student framing in a Novel Engineering design activity over the course of their design process as it relates to disciplinary engineering. To do so, we explore the following research questions:

1. How are students framing their activity in a Novel Engineering task over the course of their design experience?

2. How do their framings interact with and reflect their engagement in engineering reasoning and actions?

Theory and Conceptualization

In this study, we adopt a *framing* lens to way to understand how students make sense of design situations. Various uses of framing and related terms fall into two categories: (1) frames of interpretation, which characterize the work of anthropologists and sociologists[24,39] and (2) knowledge structures, which we refer to as *schemas*, but which have been labels in work in artificial intelligence[39], linguistic semantics[40,41], and cognitive psychology[42]. To frame an event, utterance, or situation in a particular ways is to interpret it based on previous experience: to bring to bear schemas, or knowledge structures constituted by patterns of activity[43], and the corresponding knowledge, expectations, and assumptions that are a part of that activity[44]. Framing is useful in this work because it provides an analytical lens and language for interpreting how students understand the activity, particularly with respect to their conceptual understandings of the task, including their objectives and the constraints in the task.

Our use of *framing* is related to, but distinct from, *problem framing* in engineering education literature[45-49]. The former relates to a construct that originates in anthropology and linguistics to describe how an individual or group forms a sense of "What is it that's going on here?" [22,23,58]; the latter typically describes an engineer's process of scoping the particularities of a problem, gathering information, identifying criteria, constraints, and requirements[45]. In this view, problem framing may occur within engineering framings: in framing a bridge design project, an engineer may recognize the need to identify design criteria and constraints, consult with clients, stakeholders, or community members, and research the environmental landscape.

Our focus here is on students' framings of their Novel Engineering design activity, including their sense of purpose and understandings of the objectives and constraints of their design. We focus on the ways in which students organize themselves in terms of logic of conversation and information in the situation; more specifically, we attend to how students foreground specific information and prioritize aspects of their designs to meet classroom expectations and those they recognize as being relevant to the fictional design setting.

Methods

Research Context

This study is part of a larger research project entitled Novel Engineering that is funded by the National Science Foundation (DRK-12 grant 1020243). We are currently working with fifteen elementary teachers (Grades 3 – 5) in nine schools of varying demographics. Our work with teachers involves facilitating professional development experiences during the summer and the school year, co-developing classroom lessons and activities, and supporting teachers in classrooms during implementation.

The analysis we present in this study builds on previous research[11,12,], which examined how students are framing Novel Engineering activities, and how their framings involve and are evidence of their engagement in engineering. In this work, we conduct an in-depth analysis of one group of students over their entire design experience to more closely examine the dynamics of their framing, and develop a coding scheme to capture these dynamics over their entire design trajectory. The focal group in this study involves four students (one girl, three boys) in the third grade in a rural New England school. The students had participated in two prior Novel Engineering design experiences earlier in the school year. For the project that is the focus of this study, the students were engineering solutions to problems based on the book *From the Mixed Up Files of Mrs. Basil E. Frankweiler*, by E.L. Konigsberg. The project extended over four days, for approximately 45 – 60 minutes per day.

Analytic Tools

In our analysis, we focus on the moment-by-moment shifts in meanings that occur as students are learning in socially and materially rich settings. To account for subtle shifts and coherences in the flow of activity, we collect *in situ* video data during all engineering activities. As previous researchers have noted[50,51], videos provide a medium for analyzing naturally occurring phenomena. During classroom activities, our research team sets up small, tripod-based cameras on randomly selected student groups, often with additional microphone units to capture sound adequately. Our primary data sources include direct observations and videotapes of design-related activity, field notes, and students' engineering artifacts. Our selection of data for this study is based on the availability of video data on the group, their explicit articulation of their objectives for the task, and their changes we noticed in their design solution over the course of their project.

In analyzing the video data, we draw from interactional analyses of observational data[51] and discourse analysis[52], which are based on the notion that knowledge and action are fundamentally social in origin, organization, and use, and are situated in social and material ecologies. We seek evidence of framing in the substance of students' speech and in linguistic markers associated with speech acts, such as register and tone[1], as well as nonverbal actions, such as gestures, body positioning, and interactions with materials[23, 65]. We draw on the notions of footing[53] and positioning[54] to examine how students align themselves in relation to others activities and ideas or with respect to context-specific frames.

In previous work, we conducted in-depth case study analyses, which focused on students' framing stabilities and on the dynamics of their instabilities[23]. Here, we expand on previous work by forming a coding scheme to capture the dynamics and patterns of student framing over the course of the design trajectory. As described below, we examine local (group) coherences and stabilities in student framing, as evidenced in clustering of codes, to look at the transitions in their framings over the course of the design activity. We then examine the substance of student reasoning, acting, and decision making within and across framing stabilities to identify productive engagement in engineering.

Coding

We developed a coding scheme to track patterns of student framing, specifically for how they were framing the task with respect to specific design contexts – here, layers and co-occurrences of story and classroom framings. These codes were developed as a tool to capture patterns that have emerged in classroom experiences during Novel Engineering activities over the last three years and that we have begun to characterize through in-depth video analysis. We draw on coding tools from grounded theory approaches (e.g [55,56]), starting with line-by-line coding and then chunking data based on coherence and

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[1] Patterns in vocal register include *joking* (when students are talking with silliness), *telling* (when

stability. We iteratively developed our coding scheme[2] using a single case, narrowing it down to five possible codes (Table 1): *classroom-oriented, story-oriented, blended,* and *making*. We also coded for when students were *off-task*, such as when they were talking about recess or going to lunch, but have not included examples in this paper. These codes are not mutually exclusive; our analysis reveals that students are often attending to, combining, and blending aspects of both classroom and story framings. That is, when students are "on task," they are usually layering classroom and story frames, embedding one in the other, and are sometimes blending frames, fluidly attending to both contexts.

Coding process

We coded student talk, gestures, and behaviors by watching video and coding each utterance based on evidence of students' framing – their sense of purpose, their reasoning about design objectives, uses of and assumptions about materials and artifacts, and their understandings of the design constraints. Our codes reflect variations and interactions in student framing, mainly in combinations of story and classroom orientations (see also Table 1).

Table 1: Code descriptions

Codes		*Description*	*Examples*
Story	**Class**		
Classroom-oriented			
Background	**Foreground**	Focus is on how they are evaluated in the classroom	Wait, we need three solutions at least.
		Rituals or classroom norms	So, should someone shop for ideas?
		Focus on physical functioning	On the other side. Since the expo marker is heaavier than the money in the bundle, Um once they, it'll make the money go up, up.
Story-oriented			
Foreground	Background	Discussing ideas, constraints in the story context. Focus on characters' activities, needs, personalities	And the Egyptian Wing, they could wrap themselves in like...and put tape and stuff or Toilet Paper so they could pretend to be like the mummies and then they could hide in the coffin. They're only hiding at night. Outside, during the day, they're normally outside doing stuff, remember?
Blended			
Foreground	**Foreground**	Evaluating how design works in story based on how their physical design works in classroom	There's a heavy thing weighing up so the coin will be weighed up- up here (gesturing to show the location in museum setting). Then we'll cut off the heavy- the heavy weight or- or object. So, we cut off that (showing where they cut it), and then the night guard will bend down, pick up the penny, and while he's bending down, Claudia and Jamie will run past him.
Making			
Background	Background	Building, making- not directly related to book or classroom	So why are we using the pipe cleaners for? Or I'll can make a basket out of pipecleaners. Guys, I found easier to cut string! No, this is easier. It's thinner. Wait, we need to tie it... We need a little more so it doesn't come undone.

Analysis/Findings

This study is based on a group of four third grade students participating in a Novel Engineering activity based on the book, *From the Mixed Up Files of Mrs. Basil E.*

[2] A detailed account of iterations is available upon request.

Frankweiler, by E.L. Konigsberg. In the story, a brother and sister pair (Jamie and Claudia) run away from home and hide out in the Metropolitan Museum of Art in New York City (museum). While they are there, they encounter all sorts of problems (e.g., running out of food and money, finding a place to sleep at night), and eventually have to solve a mystery.

In this classroom, the teacher, Ms. M., had read over half of the story aloud to the class before stopping to do an engineering activity. As Ms. M. read the story in the weeks prior, she had her students reflect on the problems the main characters were facing and collectively list the problems on a large piece of chart paper in the front of the classroom. She then had students write down the problems they wanted to solve as engineers for the characters, and grouped the students based on their matching problem choices. The four students in this study, Colin, Allie, Ben, and Chico, all wanted to help the characters find a way for the characters to be inconspicuous in the museum.

We have organized these the following three episodes to show the nuanced dynamics in student framing and have selected clips that evidence complexities and show emergent clusters of local framing stabilities. In what follows, we illustrate the recurrent framing patterns that emerge in our coding scheme, while drawing out the epistemic, conceptual, and social aspects of student framing in the data.

I. Problem scoping

The following excerpt occurred during their initial planning stages. In this excerpt, the four students are sitting in a circle, some with pencils and paper, and taking turns looking at a map they had printed out of the Metropolitan Museum of Art. In the following, they are brainstorming possible places for Jamie and Claudia (the story characters) to hide.

Excerpt 1: Students' problem scoping discussion. Refer to Table 1 for coding scheme.

Story	Class		
		Colin:	I've got an idea on where they– there's one near the Egyptian Wing.
		Colin:	They could hide in the tomb, or hide in a coffin, dressed as a mummy and scare tourists potentially. *[laughing, makes mummy gesture*]
		Allie:	Where are the bathrooms?
		Ben:	We can act that out. I can be a mummy. (*rising intonation*)
		Chico:	I found the [bathrooms!
		Ben:	[Guys,
		Colin:	I know; there are multiple ones.
		Chico	Hey, it's BOYS NEXT TO GIRLS!
		Ben:	Ok, I have an idea!
		Chico:	Coff…[in.
		Allie:	[Guys, I have a plan already. See? [Wing. Egyptian Wing.
		Colin:	[Hide in a - Hey, there's a restroom near the [Egypt Wing!
		Chico:	[Hide in cof:::fin.
		Colin:	So, where should they hide? In the Egypt?
		Chico:	Hide in *Sar:KOHF::ahh::gus*. It's called a *Sarcophagus*.
		Colin:	I don't CARE what it's called!

The students, in this moment, are imagining locations in the museum and considering where the characters (Jamie and Claudia, "they") will hide. The students come up with possible hiding locations based on what the infer from the story, such as characters' proximity to those places and what the characters will need for safe hiding. Colin suggests that if they are near the "Egyptian Wing," they will have hiding options, such as in the coffin and tomb.

Colin's brainstorming is evidence of story-oriented framing: he announces he has an idea for where "they," referring to the story characters, can hide, and without pausing, describes that they can hide near the Egyptian Wing, in a tomb, or in a coffin, and "scare tourists potentially." As he describes the part about scaring tourists, his voice rises and a big smile stretches across his face. Colin then acts out his idea by lying on the floor with his hands by his side and popping up (to show how they would scare people). The rise in his voice marks a change in register from *serious/task-oriented* work to *silly/joking pretending* with classmates. He animates the story characters to show his idea and to elicit laughter. Colin's change in register and animated behavior evidence a shift in his footing[53, 57]; in communicating to his classmates, he manages the reception of his idea by ensconcing meaning in pretend and silly behavior. From Goffman's view (1981), his embedded footing may be evidence of layered frames, which involves pretending to demonstrate a scene in the book.

Allie and Ben then respond, almost simultaneously, in different ways. Allie, disregarding the silliness, gestures to the map to ask about the location of the bathrooms. She asks about the location of the bathrooms, but does not direct her question to anyone in particular. Her question about the bathrooms is evidence of her attention to the story context. In the book, the two main characters, Jamie and Claudia, hide in the bathrooms. By not responding to Colin's silly behavior and setting the tone with a more serious question, Allie may also be trying to keep the group on task.

Ben, latching onto Colin's joking register, adds that they can "act that out" and he can "be the mummy." Ben is implicitly layering a criterion of something they can enact or a solution they can represent in the story setting, while affirming that the Egyptian Wing is a feasible option. In this moment, he aligns himself with Colin's framing of the design task; their shared sense of "what it is that's going on" involves generating ideas that would solve the characters' problems in the story, and demonstrating their ideas by pretending with props. Importantly, in these moments, the students are also tacitly constructing a shared sense of "what counts" as a design solution. Here, they count a solution as viable based on whether it makes sense in the story and if they can recreate the scene in the classroom.

Allie, who does not have the map in front of her and is not as loud as her group members, has to establish her social position with the group in different ways; in this excerpt, she holds the notecard that the teacher had given the students to write their ideas, and reminds her group members that she has an "idea already," referring to the Egypt Wing idea. In this moment, she assumes a footing that aligns with expectations for their classroom projects (i.e., filling out the notecard), and positions herself to meet those expectations (*classroom-oriented*). Chico makes similar moves. When Colin is describing how Jamie and Claudia will hide in the Egypt Wing, Chico corrects his description of the coffin and "sarcophagus." Colin's reaction ("I don't care what it's called") is evidence of a tension in the students' framings of the task: Chico makes a move to position himself with respect to correct knowledge of the story setting (*classroom-oriented*), while Colin makes it clear that his priority in the project is the quality of their design ideas (*story-oriented*).

Although there are transient fluctuations and tensions in their sense of what they are doing in this moment, the group has an overarching local stability in a story-oriented framing; in their collective brainstorming, they tacitly negotiate what the task is about and begin to bound the space of possible solutions. The data indicate that they are establishing coherence as they converge on ideas that meet solution criteria in the story context, focusing on solutions that would help Jamie and Claudia stay hidden (i.e. the proximity to bathrooms, availability of materials to help them build a hiding device). This episode also shows instances in which the students shift in register and tone, ensconcing ideas in joking manners or establishing social positions through acts of telling. This, we believe, is to be expected: frames, such as ideating in design, may envelop coordination of multiple registers[44]. We argue that the changes in register and tone coupled with the group's persistence in brainstorming story-based solutions are evidence of stability within their *story-oriented* frame.

In this early stage in their design, students are negotiating not only their purpose in the design task, but also their social positions within the group. These two aspects are mutually constitutive: they negotiate authorship of ideas, making tacit assumptions about the activity purpose, constraints, and design context, while managing their and others' positions within the group. The dynamics of their framing are evident in the complex and multilayered discourse; students continually position themselves and others with respect to social, conceptual, and epistemological dimensions of the situation. As they align their views with respect to the purpose of the task, they begin to narrow the problem space while scoping possible solutions.

II. Design iterations

In the thirty minutes following the previous excerpt, the group continued to discuss the potential solutions with each other, other students, and Ms. M. Through these discussions, they clarified and narrowed their initial problem, "hiding," to include the central problem having to do with hiding: Jamie's and Claudia's inability to travel through the museum at night without being seen by the night guard. The data suggests that their problem evolved as they identified and were held accountable to the criteria and constraints in both the classroom and story contexts (i.e., they had to develop a solution that "has to work" in the story as well as the classroom context).

To solve this problem, the group designed a mechanism that Jamie and Claudia could build and use to distract the night guard: they would hang a small box with money on a hook from the ceiling, and hold the other end of the hanging string from a specific hiding place. As the students conceptualized, Jamie and Claudia would let go of the string when the night guard was near, the guard would be distracted and pick up the money, and the kids would be able to run to their safe hiding place.

In the following, the students are working on a scaled, testable model to determine how to optimize the amount of time Jamie and Claudia would have to run past the guard. As they are testing, they iterate by varying string lengths, hook height, holding positions. Colin and Ben are working on a scaled model (a cardboard box that represents the museum wall), while Allie and Chico are making representational figures of Jamie and Claudia. Their need to construct corresponding scaled figures emerged from their need to communicate how the design would work to their classmates and teacher. In this excerpt, Colin proposes a revision to their idea. To communicate his revision to Ben, Colin uses a marker and a nearby piece of cardboard to sketch the improved mechanism.

Excerpt 2: Students discussing different ideas. Refer to Table 1 for coding scheme.

Story Class

Colin:	I've got an idea on how they– it's rea[:::son– oh, sorry.
Ben:	[Oh NO!
Colin:	Sorry. It's reasonably simple and I think, and it would erase the, the, all the tracks. It would erase the ability of the, the – °well, it'd make it harder for the night clerk to know what they were doing.
Ben:	How.
Colin:	[telling register] Want me to show you *how?*
Ben:	Ok.
Colin:	So, there would be a hook on top of the string with the coin. And there'd be a latch here, [*pointing to a part of the sketch he has drawn on a piece of cardboard to show the position*], and they could pull the string. Well, they're holding the string there with one hand – Jamie and Claudia – when the penny is up. When they let **GO**, though, the penny would fall, the hook would fall off this hook and then the penny would go to the ground without a trace of, without him being able to trace it back to where Jamie and Claudia are.
Ben:	Hm. [*looking at their model*] But, but wouldn't they have an easier chance of being caught if they were to let go ri:::ght here [*holds string at a point at the corner of their model]*?
Colin:	Hm, [*Looking up*]
Ben:	I have an idea! [*Holding one finger up in the air*] We can do it– ***both*** ideas. We can do both ideas.
Colin:	Ok?
Ben:	Do you know ***HOW***? See, we have [this box,
Colin:	[Oh, they-
Ben:	And we can do one idea on this side [*pointing to side of box*], and one idea on this side [*pointing to other side of box*].
Mary:	Oh, and think about what works best?
Colin:	Yeah.
Ben:	Or we could just do both for the *presentation*.

As Colin is describing he uses two forms of representation – a detailed sketch he has drawn on with a marker on a loose piece of cardboard, and their small-scale model of the design idea. As he is communicating his idea, he enmeshes classroom and story frames (*blended* framing): his verbal narrative of how the design will work is based on the characters' action, as indicated in his uses of pronouns and descriptors ("they," "here," "there"); as he describes, he gestures to places on both forms of representation (i.e., the sketch and the physical model). We see other evidence of Colin's framing in both his falling intonation and body gestures as he is describing his idea. In describing a primary advantage of his idea ("it would erase the ability of the night guard"), his voice lowers to a whisper, and he crouches his body down close to Ben. We suspect that, in this moment, Colin is juggling frames[44]; he describes his idea both in terms of it working for them in the classroom and as the characters, possibly embodying Jamie and his need to be stealthy. Tannen and Wallat (1993) describe that juggling frames may occur when the cognitive load of shifting between both causes them to intersect, often leading to slipping of vocal register.

In trying to understand Colin's idea, Ben aligns his framing[76], suggesting that there is a greater likelihood of the characters being caught if they were to let go from a specific place. To interact with Colin's idea, he exploits their shared understanding of the representation (as a referent to a specific location in the museum) to reason about positioning-time relationships with respect to the characters' needs. In this moment, there is local coherence in their shared uses of the representations and stability in their co-constructing an optimal solution for the story context. Their simultaneous habitation in both story and classroom frames (*blended* framing) allows them to utilize physical aspects of their immediate environment to interact with and evaluate alterations to a design idea.

As Colin is considering Ben's idea, Ben suddenly holds one finger (in a "Eureka!" gesture) and announces in a rising intonation and louder volume that he has an idea. His new idea – to show both ideas– however, is with respect to a different framing: instead of engaging in the conceptual substance of the design mechanism, Ben proposes that they present both ideas by using two sides of the box instead of one (*classroom-oriented* framing). In doing so, Ben positions himself with respect to the classroom expectation– how they will be evaluated during their presentation. The boys' interaction evidences a mismatch in their framings, specifically with respect to task objectives: Colin prioritizes adapting the design for a solution that will be optimal within the context of the museum, while Ben focuses on ensuring that both of their ideas are heard during their presentation to the class.

III. Final Presentation

Shortly after the previous excerpt, Ms. M. approached the group to ask how their design works. After they finish explaining it, she suggested making a "life size" prototype, or functional model. The four students, very excited by this suggestion, collected materials and began to fabricate the life-size prototype. They attached a hook to the ceiling, and then looped a rope through the hook. They tied a small box with coins inside to one end of the rope, and connected the other end to a latch they made on a shelf.

Much of their designing, in these moments, are coded as *making*. Their discourse reflects considerations of materials, specifically how to connect components, cut string, use money as a prop, and attach hook to ceiling. Their brief exchanges and interactions are coded as *making* because they do not reflect immediate or explicit framing with respect to either the classroom or the story; however, the students are still working towards a solution that draws from both frames – they use classroom materials to construct a solution for a problem in the story. Within local *making* stabilities, they enact frames that are more directed at meeting criteria in their immediate classroom (physical evaluations), and others that are more closely oriented to meeting story criteria (story-based evaluations). For example, as they are constructing the life size prototype, they fluidly evaluate their design, testing it for functionality ("It's time to test – test time!"), but also considering how it will work in the setting of the story ("This (referring to the release mechanism) would have to be back then they would have to run from here.").

On the third and final day of the project, each group presents their designs to the class. In the following episode, Colin, Ben, and Chico are presenting their design. Allie was absent during this time. In the front of the room, the group uses the box to show their design concept to the class. They then move to the side of the room, where they have fabricated their life-size prototype, to show how it will work. In the following, they present their idea to the class.

Excerpt 3: Students evaluating and presenting design. Refer to Table 1 for coding scheme.

Story	Class		
		Colin:	Okay, this is what would happen. [*To Chico*] Cut it.
		Ben:	There.
		Colin:	Finally!
		Ben:	That - The money and the night guard.
		Colin:	He'd see the money, and he'd also like the box [turns to class] 'cause who wouldn't want a box to keep their money in?
		Ben:	And then Jamie and Claudia would-
		Colin:	And then they could run. [*Begins to run*]
		Ben:	Then Jamie and Claudia [*Runs with Colin*]
		Ben:	And he (the guard) would pick up their money...[*gestures to show guard picking up money*]
		Chico:	Run into the room they're supposed to.
		Colin:	And then run into the Balcony Lounge.
		Ben:	And (the guard) would keep walking. [*Enacts guard walking*]
		Colin:	[*Turns to audien*ce] We included the Balcony Lounge.
		Ben:	[*Turns to teacher*] And we also figured something out. The higher up the box is, the longer they'll have to run and they'll have more time. So if the box is really low, they wouldn't have as much time, but if it was, um, really high, they would have more time to, to escape the clerk.

As the group is describing their idea, they blend the classroom and story frames, describing, showing, and evaluating their idea in both contexts. They evaluate the functionality of the mechanism based on tangible and testable measures in their classroom, including the reliability, durability, and efficacy based on the mechanism providing a sufficient amount of time for a ten-year-old to run an estimated distance. They simultaneously evaluate their design based on how it is working in the story, spontaneously embodying characters to show how their design will work using classroom materials. When the box of money falls, Ben bends down to pick up the money (acting as the guard); Colin begins to run (acting as Claudia); Chico runs behind Colin (acting as Jamie). Colin and Chico run to an area in the classroom that they propose would be the Balcony Lounge in the museum setting, while Ben continues to stroll in the area where the money had dropped to show that the money held the guard's attention long enough for the characters to sneak to the safe hiding area. Their simultaneous evaluation of the design in both contexts is evidence of *blended* framings: they use their bodies, their artifact, and pronouns interchangeably as they describe and enact their design. Their blended framing reflects Goffman's (1981) notion of lamination, occurring when individuals layer or collapse multiple frames with unique and different characters and contexts.

When Colin arrives at the Balcony Lounge, he announces that they "included the Balcony Lounge." His vocal register shifts from a *describing/pretending* tone to one of *telling/announcing*, breaking the fluency of their current frame. Although subtle, his framing shifts from being *blended* to *classroom-oriented*, with an awareness of the classroom expectations (i.e., knowing specific facts from the book). Colin's declaration of the Balcony Lounge location triggers a corresponding shift in Ben's framing. No longer acting as the guard, Ben stands up straight and positions his body to face his teacher, announcing that they "figured something out." He then describes the time-distance relationship that they explored in constructing their design: the higher the box (height from ground), the longer it will take to fall to the ground, and the longer the characters will have to escape the night guard.

Discussion

In this study, we showed how students fluidly shift and evolve in their framings of the design situation, drawing from their experiences of interacting with stories and being students in a classroom to develop a solution that optimally met both sets of expectations. At times, the students prioritize the features and demands of classroom, as evidenced in their attention to being evaluated: they focus on correct vocabulary, consider how their project will be evaluated by teacher and classmates, highlight considerations that will show their knowledge of the book. At other times, they foreground the story: they take the characters' perspectives to simulate and evaluate their solution and consider contingencies in the story (such as the guard noticing). Often, they shift between and combine aspects of story and classroom frames, layering and hybridizing evaluation criteria, as they interact with each other, the materials, and the features of the classroom setting.

In the following, we argue that the multiplicity of frames support and is evidence of student engagement in engineering design in two ways: first, within their local framing stabilities, students engage in epistemic activities (e.g. ideating, analyzing, reasoning about trade-offs) that reflect disciplinary engineering; second, in their coordination and negotiation of frames, they navigate the social and technical dimensions of their own design processes. In the following, we speak to both of these points, first examining students' epistemic engagement within locally stable frames, and then zooming out to look at their sociotechnical coordination of frames.

Engineering in local framing stabilities

While the students' early ideating about how to keep Jamie and Claudia from being seen in the museum may look like the students are drifting off task, there is value in what they are doing as it pertains to their learning and engaging in open-ended design activities. As the students examine the map of the museum, they bounce solution ideas off each other, some of which give rise to new considerations regarding their objectives for the task, the criteria, and the constraints, including feasibility in the story versus (or in conjunction with) feasibility in their classroom. In their shifting between design contexts, they students consider criteria to meet Jamie's and Claudia's needs (i.e., staying hidden, proximity to bathrooms) as well as those in their immediate classroom (i.e., how they will test and communicate solution ideas), while adhering to implicit design constraints (such as limited tools and materials). By articulating the different dimensions of the problem space, they begin to build on each other's ideas and to converge on a shared sense of purpose.

Every design situation presents unique complexities, many of which are unanticipated and emerge as engineers interact and negotiate with involved others, the design context, and solution possibilities[58,59]. The students' early ideating within a complex design situation reflects practices of designers and engineers. Accounts of engineers in practice indicate that the work of engineering design is not solely a matter of identifying problems and developing solutions as part of an *a priori* design process; the process is much more messy and complex, involving intricate arrangements and coordination of social and technical aspects of the situation[60-62]. As Schon (1983) describes, "In real world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations, which are puzzling, troubling, and uncertain" (p. 40). Like the students, engineers constantly generate and redefine task goals and constraints, often "jumping" to ideas for solutions (or partial solutions) before they fully formulate the problem[59,63].

In the second episode, the students use multiple forms of representation (sketches and scaled models) to interact with, co-construct, and evaluate aspects of their design. In doing so, they manipulate the objects and artifacts in their immediate setting, referring to them as if they are in the museum setting; in this way, the students use representations both as a way of seeing the world and of envisioning alternatives[64]. The sketch and the model allow them to collaboratively articulate and negotiate features and relations within their design; their interpretations and uses of representations also initiate a reconsideration of their overarching purposes and objectives. The students use multiple representations to optimize their design concept for the fictional clients, communicate their ideas to each other, and to articulate their work to immediate clients (here, their teacher, classmates, researchers).

Colin and Ben share not only an understanding of what the representation stands for, but recognize the utility in using representations to explore alternatives and to communicate their design ideas with fluidity and flexibility[60]. Like engineers, they align framings[65] to bring their different perspectives and experiences into coherence to determine their shared pursuit[36]. The process of alignment, in which engineers establish coherence among divergent visions, resonates with Stevens and Hall's (1998) notion of "disciplined perception." As Stevens and Hall (1998) point out, learning to "see" form and interpret shared focal phenomena through tools and representations. This typically occurs when two or more individuals see different entities in the same representation, and then communicate, adjust, or shift perspectives to view, communicate, and align their ideas. According to Bucciarelli (1988), this is a central challenge in engineering design. His ethnographic work illustrates that engineers working on the same project may see the design context and aspects of the design through different lenses, as shaped by their previous experiences and technical expertise, and must align their perspectives in jointly constructing solutions.

In the third excerpt, we see the group of students evaluating and presenting their design. As the students simulate their design to show how it will work in the story context, they enact different modes of engineering thinking and acting: they evaluate their design solution according to multiple sets of criteria and communicate how their solution functions, making explicit the qualitative distance-time relationships they used to optimize their design. By exploiting representations to test how their design would function in the story setting, they engage in a "reflective conservation with the situation"[66], adapting their design based on the situational feedback. For example, by testing their design using different string lengths and body positioning, they determine a system that would provide Jamie and Claudia with the longest run time.

Engineering as coordinating frames

By developing a coding scheme to capture the dynamics of students' framings, we illuminated emergent coherences and local stabilities according to their context-specific frames (i.e., story and classroom). Above, we evidence how students' local framing stabilities interacted with and supported their engagement in engineering reasoning and actions. Here, we argue that the students' collective framing is, in itself, a productive practice for beginning engineers.

Engineering involves the management and coordination and negotiation of frames, accounting for multiple dimensions of the problem, engineering involved in design must join together to plan, decide, critique, and integrate their efforts[36]. Bucciarelli (1994) describes, "the overall design process requires that all of the individuals involved join together to plan, decide, critique, and integrate their efforts in their attempts to make rational what experience shows is highly uncertain and ambiguous concatenation of events" (p.110). Thus, in collective design, engineers must cohere in their sense of the task – they must negotiate, coordinate, and align their framings throughout the design process as they continually reflect on the design situation, articulate implicit constraints, and prioritize the optimal criteria. Bucciarelli (1988) uses the phrase "object worlds" to refer to engineers' respective areas of technical specializations, dialects, systems of symbols, metaphor and models, and craft sensitivities" (p. 162). In his view, individuals working on the same design may inhabit different worlds composed of unique meanings, linguistic elements, and narratives, and must establish continuity and coherence in forming a shared vision for a design solution[60,68,69]. We relate "object worlds" to the students' unique frames of the experience: in making sense of the design situation, each student draws from his or her own schema, communicates and negotiates with others to establish a shared sense of purpose in design, and enacts his or her own abilities and reasoning strategies in developing a solution.

The chronological episodes in the presented case reflect emergent patterns across the entirety of their design process: in the early stages of the task, they oriented to the story setting; in the middle (during construction phases), they more fluidly shift and combine aspects of the story and classroom; and towards the end, they become stable in blended framings of story and classroom. We believe the inner logic to their overarching sequence may resemble real-world engineering design work: in brainstorming phases, engineers have freedom in imagining big ideas, and are not necessarily bound by the reality of their immediate situations; in developing partial solutions, they may learn about new criteria and constraints of the design situation, technical or manufacturing limitations, and their immediate resource availability; in testing and presenting design ideas, they may evaluate solutions from clients' perspectives.

Conclusion and future work

The students' work, much like ethnographic accounts of engineers in practice, show that engineering design at an elementary level is, by its very nature, a creative, complex, and uncertain process that involves many actors, multiple contingencies, and unidentified constraints[60-62]. Although this paper is based on only one case study, we believe the findings are promising and lay the groundwork for future research. We intend to follow up with this work along three lines of research. First, while this study provided insight to the interactions in students' local framings and their engagement in engineering, we believe that these interactions should be examined across groups and activities. This examination will involve applying (and possibly adapting) the coding scheme to track other groups' trajectories through Novel Engineering design activities. Second, we would like to further explore the emergent patterns over the courses of students' design trajectories; namely, do patterns involving story-oriented, story/classroom shifting, and blended framings persist across groups? Third, we intend to explore how these framings interact with specific epistemic activities (e.g., brainstorming, evaluating, trade-offs), specifically when students are solving open-ended, ill-structured design problems. Ill-structured problems invite new complexities having to do with increased number of external factors related to functions and variables, the number of problem solving acts, and the changing relationships among problem solving acts[70]. For professional engineers and children alike, increased problem complexity demands greater cognitive processing load[79], which may be challenging given the limitations of working memory[71]. We would like to explore if/how specific framings enable students to more easily coordinate complex design situations.

Acknowledgements

This work is a collaborative effort among members at the Center for Engineering Education and Outreach at Tufts University. The Novel Engineering project is funded by the National Science Foundation DRK-12 program, grant 1020243. Any opinion, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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