AC 2012-4154: ENGINEERING IN A FICTIONAL WORLD: EARLY FINDINGS FROM INTEGRATING ENGINEERING AND LITERACY

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Engineering in a Fictional World: Early Findings from Integrating Engineering and Literacy

Introduction

Over the last few years, several organizations have called attention to the need for introducing engineering earlier in curriculum frameworks, and have recommended grounding the concepts of engineering more deeply in engineering design and scientific inquiry[1, 2, 3, 4]. Many researchers have since investigated elementary students' conceptions of engineering and what an engineer does, illuminating the widely held notion among children that *engineering* is an activity involving fixing, building, making, or working on things with tools, while an *engineer* may be a mechanic, laborer, or technician [5, 6, 7, 8]. Although these studies have provided meaningful evidence regarding students' conceptions *of* engineering, there remains a need to better understand students' abilities to *do* engineering. To develop effective methods of integrating engineering into elementary curricula, we must first identify, understand, and describe what the beginnings of engineering look like among children. In doing so, we may uncover features of classroom activities and environments that naturally cultivate engineering thinking and practices within children. Our current research explores the learning affordances of integrating engineering and literacy. As we describe in this paper, we are finding that this unique integration provides a rich, multidimensional context in which students demonstrate and develop engineering thinking and practices.

Background

Until the last few years, integration of engineering into elementary classrooms has been a novel, uncharted endeavor for numerous reasons. As summarized by Capobianco, Diefus-Dux, Mena, and Weller (2011), many teachers who would like to bring engineering into their classrooms are continually impeded by environmental and emotional barriers, such as the lack of curriculum space for teaching engineering, and teachers' overall discomfort with their abilities to teach engineering [8, 9, 10]. However, many teachers have been able to overcome these barriers by using comprehensive engineering units, such as the Engineering is Elementary (EiE) units, developed by researchers at the Boston Museum of Science. The EiE units are designed to incorporate a science topic, an engineering discipline, and a design challenge, and provide guidance for students to learn about and use the engineering design process consisting of five steps: ask, imagine, plan, create, and improve[10]. Our current research project at Tufts University, entitled Integrating Engineering and Literacy (IEL), takes a similarly integrative approach to engineering in elementary curricula, but aims to empower teachers to incorporate engineering activities into the literature they are already using in their classrooms. We also aim to empower students as budding engineers, creating the space for them to be agentive in identifying and pursuing the problems they want to solve, rather than presenting them with pre-determined design tasks. We are currently implementing our IEL approach in fifteen classrooms (Grades 3, 4, and 5) in rural, suburban, and urban schools in Massachusetts. Although our research team is analyzing data through multiple lenses, the focus of this paper is to demonstrate how a literary context fosters student engagement in engineering practices, highlighting what we believe to be the beginnings of engineering in children.

In the case study presented, we illustrate how a fictional context may catalyze engagement in engineering practices among fourth-graders in a classroom setting. We first describe the nature of engineering design, elucidating features of engineering design thinking and practices, rather than adopting the premise that engineering exists solely as a linear sequence of steps as in the engineering design process[11]. By presenting transcriptions and describing actions of the two students in our case study, Harvey and Matthew, we provide evidence of the beginnings of engineering in children. We posit that when children are situated in an imagined, literature-based context, which is often fraught with multiple, complicated, implicit problems and constraints, they may spontaneously practice engineering as they iteratively design and construct a solution.

The nature of engineering design

Definitions of engineering design abound, stemming from multiple perspectives and formed with unique objectives[12]. The National Academy of Engineering[2] describes engineering as a profession in which engineers "discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward thinking ways" (p. 5). Inherent to this definition is the ability of engineers to integrate different types of skills and knowledge to solve ill-structured problems that meet human needs[12]. Similarly, Vincenti (1990) refers to engineering as the practice of organizing the design, construction, and operation of any artifice to transform the physical world around us to meet a recognized need[13]. In John Robinson's (1998) synthesis on engineering thinking and rhetoric, he suggests that engineers seek optimal solutions to problems by applying scientific knowledge and mathematical analysis to the solution of practical problems, which may involve designing and building artifacts, seeking optimum solutions according to well-defined criteria, and using abstract and physical models to represent, understand, and interpret the world[14]. These overlapping notions of engineering allow us to better understand the professional role of engineering; however, to ascertain *how* engineers "create bold new solutions" or "solve ill-structured problems that meet people's needs," we must dissect the practice of engineering to identify underlying characteristics of engineering design and problem solving practices.

Engineering in context

Design, as the central theme in engineering, denotes both the content of a set of plans and the process by which those plans (and products) are iteratively produced[15]. The engineering design process may encompass continual iteration through problem framing and reframing, idea generation, planning, constructing, revising, and communicating optimal solutions. Characteristics of design thinking that occur throughout the process are seen as continuous transformations of abstract conceptualizations and engineering knowledge informing subsequent steps in the process[16]. Vincenti (1990) observed that this entwined coevolution of questioning and thinking reflects the process by which engineers and designers add to their repertoire of engineering knowledge[13]. Because engineering knowledge intrinsically evolves throughout the design process, Vincenti (1990) contends that an engineer's knowledge is not an end in itself nor is it the central objective of the profession, but is rather a means to "a utilitarian end, or several ends" (p. 6). An engineer is continually conditioning his/her knowledge by balancing a multiplicity of objectives and requirements, testing, experimenting, and redeveloping artifacts to minimize cost and time, while optimizing performance, functionality, and feasibility according to the client's needs. This multidimensional balancing, or optimization, reflects the fact that design does not take place for its own sake or in isolation, but guides artifactual design within a real world context in accordance with a practical set of goals intended to serve human beings. Moreover, the context-specific requirements for engineering design, such as clients' needs, setting, feasibility, and cost, govern design and the engineer's pursuit of knowledge. Thus, the practice of engineering design is, by necessity, deeply entrenched in a contextualized multidimensional problem space.

The practices of design cannot be disentangled from the problem space in which it occurs; the complex, ill-structured problem, infused with uncertainties, constraints, and assumptions, comprise the nature of engineering design. In seeking an optimal solution, engineers integrate (and learn) specific skills and knowledge within varying degrees of freedom to iteratively generate, construct, and evaluate designs unique to the problem space. Findings from previous research indicate that the systematic questioning involved in a designer's inquiry and thinking processes differs from epistemological inquiry, leading researchers to infer that a designer's thinking process may have unique, identifiable characteristics[17]. The systematic and iterative questioning, thinking, and reasoning that occur in engineering design are rooted in the design situation itself. For a given question in an engineering problem, there exist multiple unknowns, constraints, and alternative solutions[12]. Engineers must navigate the blurry, ambiguous interface existing between problem space and solution space, handling uncertainty while maintaining a big picture perspective, and using judgment to determine the optimal solution.

A nonlinear process

Despite the commonly accepted premise that iteration is an integral part of engineering design, the cognitive process of mental iteration remains widely unexplored[18]. While Adams and Atman (1999, 2000) conducted a study to examine the differences between freshmen and senior college students pertaining to iteration in engineering design[19, 20], Jin and Chusilp (2005) focused on the cognitive behavior in mental iteration, highlighting differences arising from problem type and constraint conditions[18]. In a related theory-based paper on "Engineering Design, Thinking, and Learning," Dym et al. (2005) suggest that design thinking occurs in the continual interplay between convergent, deep reasoning, and divergent, generative questioning[12]. Dym et al. (2005) further posit that these convergent-divergent "habits of mind" include considering system dynamics, reasoning about uncertainty, making estimates, conducting experiments or testing (p. 106). In his earlier book on synthesizing engineering design, Dym (1994) contends that the mental iterative process in engineering design is continually informing and informed by the engineer's interaction with plans, designs, and artifacts (collectively, representations), as well as through communication with other human beings[16] such as clients and peer professionals. As such, Dym (1994) argues that representation is central to design, and that the "multiplicity or diversity of representations" *enables* reasoning and analysis about function, form, and intent[16]. As an engineer develops, interprets, and interacts with representations, the engineer may respond by retracing the problem objectives and constraints, deciding to revise or improve parts or the whole design, or test and evaluate the design. The representation, existing at the boundary of abstract ideas and real application, becomes a roadmap for the engineer to navigate the design process according to the design context.

Although our objective in this study is not to unravel the dynamic cognitive processes in engineering design, we have highlighted previous findings on engineering design that we believe are salient to our study. We take the position that engineering design involves an iterative process of convergent-divergent reasoning and questioning that is heavily influenced by the multidimensional context of the problem. Moreover, the engineering design process evolves through a nonlinear series of overlapping and/or interconnected steps, which may include framing the problem, planning and sketching potential solutions, managing uncertainty, constructing representational artifacts (from sketches to prototypes), testing and evaluating potential solutions according to objectives and constraints, and communicating with others. While striving to reach a stable, optimal solution, the engineer must also remain aware of costs, time, and indirect impacts on the environment or surroundings. The complexities inherent to every engineering problem are unique; consequently, the engineer's design process may be different for every problem. However, regardless of specific sequence of steps, the engineer is always attempting to optimize a design for a need given the constraints imposed by the situation. Optimization often requires the engineer to think both divergently (considering the myriad possible solutions) and convergently (justifying a single, best solution) to most effectively and efficiently meet the client's needs.

How should engineering look in classrooms?

The cloudy, multidimensional context in which engineers solve problems is an intrinsic characteristic of the design process[12]. However, despite the research on engineering design, students in classrooms rarely solve problems to which there is more than one right answer. Moreover, they are rarely provided the autonomy to engage in the "messy," individualized engineering design process; instead, they are often given explicit instructional steps to guide them through engineering design with one built-in iteration. Dym et al. (2005) suggest that the divergent thinking component of engineering design is typically not recognized or performed well in engineering curricula, stating that students are "expected to engage in a convergent process by formulating a set of deep reasoning questions and working to the unique answer" (p. 105). Not only is this method of teaching engineering contradictory to engineering as it is practiced in the real world, additionally, literature suggests that it does not coincide with children's natural problem solving processes [21, 22]. Further, as numerous researchers, teachers, and parents have noticed, children "engineer informally" on a daily basis, iteratively designing and constructing solutions to complex problems[10]. The complexities of engineering problems often require the engineer to exercise “considerable imagination” in brainstorming creative solutions when practicing divergent thinking. Previous literature has indicated that children have a natural capacity for creative, imaginative thinking[23]; paradoxically, in school settings, especially in math and science classes, students’ imaginative responses are often discouraged because they do not match the one *right* answer [24].

Our challenge as educators and researchers is to create a learning context in school in which children are able to access and strengthen their engineering abilities. We believe that such a learning context will be inherently “messy,” allowing students to be agents of problem formulation as well as problem solving, and will foster the development of engineering thinking and practices. Our current research on the IEL project explores the use of fictional literature to create context-rich engineering challenges to have the beginnings of engineering to emerge in an elementary school setting.

Methods

In this paper, we examine the discourse and activities of two fourth-grade boys, Harvey and Matthew, who are participating in an IEL unit in their class. By highlighting excerpts of their conversations and describing their purposeful actions, we aim to illustrate an early emergence of engineering they engaged in during this literature-based activity as a case of what engineering we believe students can do. The data we have selected to present in this study include Harvey and Matthew framing a problem from the literature to which they will engineer a solution, discussing ideas, design criteria, and constraints, and constructing, testing, and modifying their design to optimize functionality and performance for their fictional clients.

Setting

Harvey and Matthew are both students in Ms. J’s fourth-Grade class, which is in a public school within a suburban district in Massachusetts. Ms. J, who had previously attended engineering workshops at Tufts University, expressed enthusiasm for pilot testing IEL in her class. Although IEL team members provided support to Ms. J as needed, she was eager to adopt the project for her class, recognizing potential literacy and engineering advantages. IEL members collected video data and provided classroom support and material resources during all IEL activities, which occurred for approximately one or two hours per week for a six-week period.

The novel that Ms. J had selected to read with her class was From the Mixed-Up Files of Mrs. Basil E. Frankweiler by E.L. Konigsburg. The story involves a brother and sister, respectively named Jamie and Claudia, who run away from home and hide out in The Metropolitan Museum of Art in New York, NY. While living in the museum, the brother and sister encounter a range of challenges, from concealing their identities, to sleeping, eating, and budgeting, to their biggest challenge - solving a mystery in the museum about a statue named Angel.

After Ms. J had read aloud up to Chapter 7, she led a group discussion to introduce engineering to the class. Rather than showing them a model of the design process, she asked students to think about the wide range of problems that engineers solve and the types of strategies they use in solving problems. She then led the class in collectively brainstorming the challenges that Jamie and Claudia face in the story that might be solvable using engineering. When the class had brainstormed a list of problems that Jamie and Claudia encountered, Ms. J. proposed that each pair of students choose a problem from the list to solve as engineers. She did not provide clarity regarding any of the problems, intentionally leaving problems ill-structured, vague, and subject to different perspectives or interpretations.

Data Analysis

By employing a case study approach, we were able to more deeply examine the types of discussions and actions of one group over the course of an IEL unit. We selected a pair of students, Harvey and Matthew, because we were able to capture much of their discourse and activity on videotape. Our analysis of this case study involved transcribing the video data and analyzing their interactions with each other, their teacher, and their artifacts in a research group setting. We attended to the questions they asked and the activities in which they spontaneously engaged during their design process, such as narrowing and framing the problem, discussing and iterating on their design, and thinking about feasibility and functionality in literary and classroom contexts. In the following, we highlight four episodes that capture the nature of the engineering task and illustrate Harvey and Matthew's strategies for finding a solution.

Findings

1. Episode 1: Identifying the Problem and Framing the Task

After Ms. J asked the students to form groups of two, she tasked each pair with discussing and selecting a problem to solve using engineering. As shown in the transcript below, Harvey and Matthew, like many other students in the class, choose and rank problems based on solution feasibility, on how well a potential solution will meet the characters' needs, and, most importantly, how "cool" they believe the solution will be. As their discussion unfolds, Harvey and Matthew begin to notice that problem framing in the context of this activity may involve more than simply choosing a problem from the class list; they must also make assumptions regarding cost, materials, feasibility, and client needs.

Harvey: How about "how to collect more money from the fountain"? (Referring to a problem listed on the board.)
Matthew: We could get a bag. (Pretends to put something into a bag.)
Harvey: (Laughs.)
Harvey: A padded box! (Pounds fist on table.) A soundproof, padded box.
Matthew: (Looks curiously at Harvey.)
Harvey: So we take cardboard – a small cardboard box.

Matthew: (Nods.)
Harvey: You know that like Styrofoam stuff?
Matthew: Yeah.
Harvey: We can put that on all sides and so it makes more insulated and harder to hear. And then we could put in on a car…or on a strap?
Matthew: Put is on um one of those tiny little, put it on a miniature car. (Matthew makes hand gestures.)
Harvey: Oh…
Matthew: But we need a water hose and a remote controlled car.
Harvey: (Thinking it over.)
Matthew: So…what's the problem? Carrying money from the fountain?
Harvey: I don't know. I don't know if they wanna do…(referring back to the characters' objectives).
Matthew: I was thinking of how to keep…
Harvey: Oh let's do "See Angel"!
Matthew: See Angel?
Harvey: Yeah, "How to See Angel"! (Referring to another problem listed on board.)
Matthew: The vent system.
Harvey: The what?
Matthew: The air vent system?
Harvey: Oh, I was thinking that (giggles)…Ok, so let's write that one down.
Matthew: Wait, no, that's…what about I wanna do "Communicating." (Selecting another problem listed on the board.)
Harvey: Ok, fine.
Matthew: We could do like um…walkie-talkies wouldn't work.
Harvey: (Shakes head.)
Matthew: Little headphone walkie-talkies?
Harvey: Yeah, but they would still end up talking.
Matthew: No, you put the little headphones in and it's like iPod, but it's a walkie-talkie. You could put headphones *inside* a walkie-talkie.
Harvey: Yeah, but then it'd scar my eardrum from talking.
Matthew: No…
Harvey: Yeah, because they would have to talk. (Referring to Jamie and Claudia.)
Matthew: (Covers mouth with hands and pretends to talk.)
Harvey: (Laughs.)
Matthew: Ok.
Harvey: Um. How about we try the um the "How to see Angel?" So I was thinking we could um do…I know how to make it, but I was thinking we could do a periscope.
Matthew: Yeah we could (hand gestures to show holding periscope). Yeah, but they could still see the periscope.
Harvey: Yeah, but it's not like they wouldn't have to… (shrugs)
(Both boys appear to resume imagining air vents and pretending to crawl through the air vents.)
Matthew: Ok, the Angel one sounds cool. That's our final one.
Harvey: Are you sure? Ok (writes while talking). How to See Angel.
Matthew: How to See Angel.

As Harvey and Matthew explore the problem space, they are framing the problem in two overlapping dimensions: (1) constraints imposed from the classroom context regarding classroom objectives and feasibility, and (2) objectives and rules they extract from the context of the fictional story. With each of their potential problems, Harvey and Matthew shift between creative, divergent thinking (offering imaginative solutions) and convergent thinking (evaluating potential solutions) considering constraints imposed by both the classroom and story contexts. For example, as they brainstorm how to solve the "How to collect money from the fountain" problem, Harvey imagines a padded box transported by a remote controlled vehicle; however, Matthew argues against the idea because "we do not have a water hose or remote controlled car." Matthew is implicitly framing the classroom activity by suggesting that their designs must be buildable with materials available to them. When they transition to a second possible problem to solve, "Communicating" (i.e., how to help Jamie and Claudia communicate in secret), Matthew imagines walkie-talkie embedded iPods. It is interesting to note that he has dismissed the classroom feasibility constraint that he placed on the first solution, which is characteristic of divergent thinking. This time, Harvey critiques the design idea because it "might scar my eardrum from talking." Harvey assumes that since a loud iPod might scar his eardrum, it might also scar Jamie's eardrum; consequently, he does not accept the design because it might inflict harm on the characters. Here, Harvey appears to be introducing a constraint from the context of the story relating to the character's needs (to not have scarred eardrums) and is not concerned with classroom feasibility constraints (procuring an iPod). Lastly, Harvey suggests the "How to see Angel" problem, and offers the potential solution of a periscope. Matthew thinks critically about the idea in terms of the story context, even acting out Jamie using a periscope to see the Angel statue in the museum. Matthew argues that this solution might not meet the objective of maintaining the characters' need to be inconspicuous because other museum visitors might see them holding a periscope. Harvey recognizes this possibility, and attempts to come up with an argument in favor of his proposal. At this point, it seems that both boys realize the time constraint that is inherent to classroom activities, and decide to go with the periscope idea because it is feasible in both the classroom and story contexts, and will be functional under certain conditions of the story. Through their short conversation, Harvey and Matthew navigate uncertainty, constraints, and objectives by making necessary assumptions in a vague, multidimensional problem space.

2. Episode 2: Designing and Planning

In the second episode, Harvey and Matthew are designing and planning their periscope, considering the most appropriate use of materials for their design. They are again negotiating the rules of the activity, shifting between frames of whether their design is feasible and functional for them to build and test in the classroom, and whether it will be feasible and functional for Jamie to build and use in the context of the story. As their conversation ensues, Harvey and Matthew iteratively loop through the pros and cons of different materials in both contexts, balancing trade-offs of cost, structural soundness, and feasibility, while more clearly defining their engineering objective and problem boundaries.

Harvey: So we would have them. Do you want to make this out of wood?
Matthew: Hmm…wood would be more artificial, but it would take longer [to make].
Harvey: It would take longer [to make], but it would be stronger.
Matthew: But how would, um, they…how would *they* get the wood? (Referring to Jamie and Claudia.)
Harvey: Do they have to?
Matthew: Yeah, but if they get...if...you know how Jamie is really cheap?
Harvey: He is.
Matthew: So if they wouldn't probably get the wood. They would probably get cardboard. Cause…
Harvey: Yeah. I see what you're saying. I see what you're saying.
Matthew: Cause Jamie's cheap and that would probably cost a lot more than cardboard.
Harvey: But then cardboard wouldn't be as sturdy, and um, you, you know how flimsy cardboard is? (Shrugs.)
Matthew: But then they...once they get the wood they'd have to get the cardboard. They'd have to get glue. They'd have to get all this other stuff.
Harvey: Why not just nails?
Matthew: Yeah, but nails cost money also.
Matthew: But we could still use wood but it would have to be [inaudible]. (Smiles.)
Harvey: I don't think it has to be something that's in our class.
Matthew: Ok.
Harvey: I think that's. I don't think it would be like they have to pay for it.
Matthew: OK.
Harvey: (Draws.) So I think it's just something they would have…[unclear].

Harvey is initially focused on structural soundness and durability of the periscope, suggesting that the time they spend constructing it out of wood will be outweighed by the strength and durability of a well-built periscope. Faced with competing constraints, Harvey thinks critically about the advantages and disadvantages of multiple alternatives. Matthew then calls into question whether this design is feasible in terms of the story context. He reframes the problem as something that Jamie would have to be able to construct in the story, and in doing so, introduces an entirely new set of competing constraints, namely Jamie's ability and desire to find, buy, and use the materials. Harvey considers this new set of constraints, and handles the uncertainty by making assumptions to clarify the problem space. He assumes that their engineering solution does not necessarily have to be something that Jamie will need to be able to build in the story, but, rather, may simply be a tool for Jamie to use.

In their conversation, Harvey and Matthew construct a shared understanding of what is possible and not possible to bring clarity to the vague problem space that blends classroom and literary contexts. In doing so, they are able to productively engage in engineering reasoning by balancing costs, availability of situational resources, structural properties, and client's needs. Furthermore, they maintain a big-picture perspective of their ultimate objective, while iteratively weighing competing constraints and product trade-offs.

3. Episode 3: Interacting with representations

The third episode of Harvey and Matthew's work on helping Jamie and Claudia from the story From the Mixed up Files of Mrs. Basil E. Frankweiler takes place after they constructed a prototype of their periscope. At this point, they had reasoned about how to orient the mirrors for the periscope to work, and had figured out how to make the periscope structure collapsible so that Jamie would be able to see a range of heights, while still being able to transport the periscope stealthily. Harvey continues to improve his design by creating handles for carrying it. As he is attaching the handles, an IEL researcher in the classroom suggests that the collapsed periscope with handles resembles a lunchbox. Harvey excitedly takes up the idea of a "lunchbox periscope," recognizing that it is even more inconspicuous and more effectively meets the design objectives.

IEL Researcher: How's your periscope coming?
Harvey: Good we um we think we're pretty much done. So...
IEL Researcher: Alright.
Harvey: So we put handles on it.
IEL Researcher: Oh, cool.
Harvey: And then we [unclear] it here.
IEL Researcher: Oh, ok.
Harvey: So you just pull this out. (Showing how handles and collapsibility mechanisms work.)
IEL Researcher: So, it's like [unclear] carrying their lunch around?
Harvey: (Nods, proudly grinning.)
IEL: Does it work? Alright, cool.

After the IEL Researcher walks away, Harvey excitedly grabs the lunchbox-disguised periscope and walks around the classroom, pretending to be Jamie carrying his lunchbox.

Harvey: Liam, Liam! (Calling to a friend.) It's a lunchbox!
Liam: Wait, you… How does it get open? Right? Cause I mean…(Holding Harvey accountable for developing a tool that functions.)
Harvey: You just unlock this! (Referring to the latch that opens the lunchbox.)

Shortly after, Harvey describes the lunchbox feature to other members of his class.

Harvey: And to make it less suspicious, you can lock it so it sort of looks like a lunchbox. And it's hollow so you can put food in it.

An engineer's interaction with a representation or artifact plays a dominant role in design and construction[16]. Kaput (1991) articulates the interaction as a bidirectional, "signifier-signified" relationship; in one direction, the designer or engineer may actively and purposefully create the artifact based on his or her imagined representation, while in the other direction, an artifact or representation may trigger new ideas within the designer or engineer[25]. Harvey and Matthew's experience exemplifies this fluid interaction as they iteratively improve their design. They are able to externalize an abstract image of a design idea by constructing a testable prototype; by interacting physically with the prototype, and seeing others' reactions to the prototype (such as the IEL researcher's reaction), they are able to revise and improve their design and prototype to optimize objectives within the problem constraints. Harvey, after being prompted by an IEL researcher, recognizes that the lunchbox feature satisfies two additional design requirements; it makes Jamie less conspicuous in the museum, while providing a way for him to carry lunch around in the museum.

4. Episode 4: Testing and Evaluating

Harvey and Matthew's primary requirement throughout their design is functionality both in classroom context and in the story context. In this excerpt, Ms. J asks the boys to test their design to see if it works in the classroom context.

Ms. J: Can I see it in action? I haven't seen it yet.
(Harvey holds up the periscope.)
Ms. J: So once you see something tell me what you're seeing.
Harvey: I see a Liam.
Ms. J: You see Liam?
Harvey: And I see Matthew!
Ms. J: Alright, we're gonna have to test you…like, how many fingers are they holding up, ok?
Both: OK.
Ms. J: Alright, sounds good.
Matthew: How many fingers am I holding up?
Harvey: Stop, Matt. Too close.
Matthew: Oh .
IEL Researcher: Do you wanna show her how it expands?
Ms. J: Oh yeah!
Harvey: Four. (Responding to the finger test.)
Matthew: Oh, there it is.
Ms. J: Oh ,wow!
Harvey: Where are you Matthew?
Matthew: How many fingers am I holding up?
Ms. J: How about can you see the whiteboard?
Harvey: Yeah.
Ms. J: So, this I could conceivably use for people sitting in the back of my classroom who need to see the board. Love it. Alright, great job.

Harvey and Matthew are able to demonstrate functionality of their design in the classroom using the "how many fingers test." Their evaluation of the periscope aligns with their initial framing of the problem that implicitly addresses both real world and fictional constraints. In showing that the periscope passes the "how many fingers test," Harvey and Matthew are able to verify that the periscope can be used in the classroom context and as Ms. J suggested, may even be useful for students in the classroom who cannot see the board. That is, it could even be useful beyond the original intent of the tool. She insightfully places value on the utility of their product as a real tool. Although Harvey and Matthew are not able to test the periscope in the story context, they are able to imagine how it would work for Jamie and Claudia in the museum; the collapsible periscope that doubles as a lunchbox will allow Jamie to more easily see the Angel statue, while supplementing his clandestine disguise as a normal museum visitor.

Discussion and Conclusion

Through these four windows into Harvey and Matthew's IEL experience, we see them framing an ill-defined problem, iteratively designing a solution based on implicit problem constraints, optimizing their solution for their client, and testing feasibility and functionality of their design. Rather than filling out a worksheet or solving a problem to which there is one right answer, or even a problem previously chosen or defined by the teacher, they agentively frame and solve an ill-structured problem (i.e., "How to see Angel") implicitly considering design and setting constraints in multiple contexts—classroom and fictional story. They navigate uncertainty by negotiating assumptions, reflecting and gathering information from their lived experience and from the characters' experiences in the text. They iteratively design and construct a functional prototype by discussing the most efficient use of materials, how aspects of the design will work, and what will be feasible for them to build in the classroom as well as for characters to use in the story, and how to optimize their design to meet the client's need (height requirement for visibility, clandestineness of tool). Throughout this process, they are continually improving their constructed prototype to externalize their ideas, while embracing the ideas that are triggered by their design (such as the lunchbox). In addition to managing the constraints imposed by the story context, they comply with the constraints that exist in their classroom (time, materials, tool-sharing). Within these overlapping dimensions, Harvey and Matthew demonstrate convergent-divergent thinking skills, balancing numerous creative possibilities and design solutions with considerations of functionality for characters in the story (and, as they discover during the "how many fingers test," the classroom), feasibility for them to build and for characters to use, material strength, costs, and availability (for them and for the characters), and ultimately optimizing their solution in the given amount of time.

Based on our initial findings from the IEL project, we contend that ill-structured and somewhat complex problems created within a rich literary context, which offers a webbed multiplicity of complexities stemming from the nature of the problem, client needs, feasibility, and functionality, can foster the emergence of engineering thinking and doing in the classroom. Although we are still in the early stages of the IEL project, we are eager to more deeply investigate the engineering affordances related to literature genres, classroom environments, and implementation strategies. We aim to examine engineering thinking and doing through different lenses, focusing on specific attributes and skills and how they are fostered during the experience. Our research team is also exploring the synergy between engineering and literacy, investigating not only how students are learning engineering in the context of a book, but also how students may strengthen literacy skills through engineering.

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