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

Paper ID #13742

Eliciting Informed Designer Patterns from Elementary Students with Open-Ended Problems (Fundamental)

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Introduction

Engineering problems in the professional world are messy and ill-defined. Professional engineers often deal with problems that have missing information, vague requirements, and multiple criteria for success.[1] In the classroom, however, students are typically given "textbook" problems that are constrained and well-defined.[2] Most of the research on student engineering practices also deals primarily with these well-defined and constrained problems. In contrast, the Next Generation Science Standards (NGSS) call on educators to create opportunities for students to engage in real-world engineering practices.[3] To better understand students' nascent abilities to solve open-ended problems, we conducted a series of interviews before students engaged in a newly-developed engineering unit. In this paper, we describe our analysis of these interviews, specifically with respect to how students enact NGSS practices as they pursue design solutions to open-ended problems.

Background

The new NGSS standards identify that students in grades 3-5 should show competency in specific engineering practices:[3]

- 3-5-ETS 1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS 1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5 ETS 1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Standard 3-5 ETS 1-1 focuses on students problem scoping, or their ability to transform messy problems into a solvable form through questioning and the identification of constraints. Standard 3-5 ETS 1-2 looks to encourage students to engage in design ideation (idea generation and comparison). Standard 3-5 ETS 1-3 describes how students should test and iterate on their designs.

For the purposes of this study we chose to focus on a task that helped us to understand the first two of these standards. We concentrated on these formative components of engineering design because the literature currently gives limited insight into how children in this age group engage in these practices. One well-known framing of beginning and informed designer patterns is found in Crismond and Adams' formative work, the Informed Design Teaching and Learning Matrix.[4] This framework captures the early stages of design in Pattern A: Understand the Challenge (Problem Solving vs. Problem Framing) and Pattern C: Generate Ideas (Idea Fixation vs. Idea Fluency). Within Understanding the Idea, Crismond and Adams characterize beginning designers as quick to solve a problem and informed designers as those who delay design decisions. For Generating Ideas, they describe beginning designers as getting stuck on their first idea while informed designers practice idea fluency. Though Crismond and Adams claim that their classification of beginning designers includes children, their categorization of beginning and informed designers is supported mainly with research on undergraduate[5,6] and professional engineers[7].

Research specifically looking at children engaged in Understanding the Challenge and Generating Ideas suggests that a stark classification of children as beginning designers does not necessarily hold for all contexts and engineering activities. For example, Welch's study of students building paper towers found that students engaged in little design ideation.[8] This supports Crismond and Adams' characterization of how beginning designers Generate Ideas. However, Welch's problem is well defined with fixed materials (a piece of paper and a specific length of tape), given constraints (keeping the paper tower on the floor), and defined testing criteria (the tower stands for 30 seconds). These types of more well-defined problems are typical within the literature (e.g. MacDonald & Gustafson's parachute challenge[9], R. McCormick et al.'s kite[10]) and often suggest beginning designer patterns. However, Watkins et al. have presented evidence of children engaged in behaviors that represent informed problem scoping (Crismond and Adams' pattern of Understanding the Challenge) and idea generation practices (Generating Ideas) when engaged in a more open-ended problem that required them to identify materials, define constraints, and develop their own criteria for success.[11] M. McCormick and Hynes also showed that students have the ability to expertly navigate an ill-defined problem space by relying on and using their own "lived experiences."[12] This lack of consensus suggests that more work is needed to understand the dynamics of students' engineering practice in these areas, and how they are influenced by the nature of the design problem presented to them. This in turn will require us, and others to look at instruction and assessment for engineering curricula.

The study described in this paper represents an exploratory investigation into how fourth grade students addressed a design challenge that was intentionally open-ended and ill-defined. The analysis is focused around interviews of students, which were conducted prior to engaging in a new engineering unit developed at Tufts University. The original aim of these interviews was to gain a better understanding of the impact that this unit, called Novel Engineering, could have on students' growth in engineering practices. While the impacts of this unit are still being analyzed, it became clear to us that the interview data, conducted in a one-on-one setting, provided a unique and focused opportunity to more closely examine the various pathways that students with little to no prior engineering experience or training, as far as the average elementary student is concerned, undertake to solve open-ended problems.

Study Design & Methods

We interviewed 21 fourth graders (10 girls, 11 boys) in an urban-rim school in a one-on-one setting during the school day. The students were in a single classroom whose teacher would be implementing Novel Engineering, and all had similar educational backgrounds. The school district in which this school is located does not have an engineering curriculum for teachers to use despite the inclusion of engineering standards in the state frameworks. This made this school and the students, who had little to no engineering education, an ideal place to explore. We asked each student the same open-ended question, using a script to ensure that each student was given the same information (Appendix). We told students that there was a dog named Abby at the Tufts University Cummings School of Veterinary Medicine who was having difficulty walking, and that we would like their help in designing a device to help Abby get around. We asked students to design a device that could be constructed using materials and tools found at their home or at school. This was the only constraint given to the students. It was intended to encourage realistic designs on their part, hopefully avoiding elaborate or implausible designs based on technology that wouldn't be available to the average fourth grader. We had developed more problem constraints – that Abby was a dachshund with paralyzed hind limbs, for example – but did not give this information to the students unless asked. This kept the design task purposely open-ended and ill-defined in order to see how students approached the problem space.

After the interviews were conducted, we reviewed video and design sketches from 17 of 21 students. The remaining four students' videos had issues with the image or audio that made them unusable in this analysis. During the review of each student's video, we noted multiple aspects of how he or she addressed the problem constraints that were unknown at the beginning of the activity:

- **Who** identified these constraints – whether the student asked questions him- or herself or if the constraint was identified in a question asked by the interviewer
- **When** the constraints were identified – whether before or during the solution design
- **How** students adapted their design to the new constraints--if the constraints were identified during design.

The answers to these questions allowed us to categorize the degree to which each displayed beginning or informed patterns in two of Crismond & Adams' design strategies: 1) Pattern A: Understand the Challenge and 2) Pattern C: Generate Ideas.[4] We based our analyses on Crismond and Adams' framework because it is the existing primary framework that captures aspects of beginner designer behavior and has clear relationships to NGSS standards 3-5-ETS 1-1 and 1-2.

Findings

Our analysis of the interviews found that there was great diversity in both students' solutions and their approach to the open-ended problem. In the following section we present case studies a deeper illustration of the different behaviors seen. These case studies represent the contrasting ranges in students' design behavior that we observed on the spectrum of Crismond and Adams' Design Matrix. We chose these highlights from among the video data after analyzing each individual interview using Crismond and Adams's Design Matrix and categorizing each student's behavior as showing beginner or informed designer patterns. We reexamined video of a handful of students that clearly demonstrated these patterns looking for specific evidence of these behaviors and saw that there were nuances to each of these levels. The students we highlight below represent this range and some of the nuances we saw in the data. In the following section, we suggest the implications that our observations can have for supporting teachers as they teach engineering, identify how to promote expert behaviors, and foster engineering habits of mind. We also believe that our data emphasizes the need for a deeper evaluation of student's approaches to solving authentic and realistic engineering problems.

Beginning designer patterns in understanding the challenge and generating ideas: John

This case study presents a student, John, who showed beginning designer patterns in his individual interview. John did not ask any questions before designing his solution, despite the interviewer telling him, “I can answer any questions you have about Abby.” Furthermore, he did not ask any clarifying questions during the design process. Instead, he spent approximately 5 minutes designing before the interviewer asked the first question that elicited previously unknown constraints.

The way that John designed for an extended period of time without asking any clarifying questions reflected beginning designer patterns in Understanding the Challenge. He appeared to treat the design problem as a straightforward task, even though it was intentionally vague and open-ended as presented by the interviewer. He did not appear to make any attempt to explore or frame the problem in any greater depth.

John’s solution to help Abby was a wheeled sling that would support her as she walked. This design is plausible for a subset of the constraints. However, this design was tested when the interviewer questioned John as to how his solution would allow Abby to move up and down stairs. This illuminated a constraint that John had not previously uncovered:

Interviewer: So if she had stairs in her house, how do you think that would work?

John: I'm thinking of something but the dog wouldn't be able to do that.

Interviewer: Tell me about it!

John: Well these little things on the side that if the dog rubs up against it will like snap in and pull it up the stairs. And then after at the top of the stairs it still goes on a few inches so it doesn't just drop her and she would probably fall down the stairs or something.

Interviewer: That's cool. Could you draw me that one?

[John draws his new solution]

John: Yeah like so that these are the stairs – I can't draw that very well today.

Interviewer: Take your time. No rush. It's all good.

John: So that's the stairs and there's like a rail or something, like one of the rails that you hold on to. And then on the wall – this is the giant wall – it would be a little thing in here that would have a little motor somewhere built into the stairs that would drag it up. And on the side of the thing – let's just draw it like that – there would be a little side to clip into.

John’s drawing, and further discussion with the interviewer, clarified that he was describing an escalator-like device with gears and a pulley system that Abby’s owner could use to help her ascend and descend the stairs. This response to the interviewer’s question demonstrated beginning designer patterns in Generating Ideas. John were presented with a constraint that his solution was not well equipped to handle, but he force-fit his current design into the new problem space. The result was a modified design that would likely be complicated to design and build, and would require Abby's owners to assist her up and down the stairs.

While John demonstrated beginning designer patterns in Understanding the Challenge and Generating Ideas, others students showed clear evidence of informed designer patterns in one or the other. The next two sections present examples of these students.

Informed designer patterns in understanding the challenge: Andrew

This case study presents a student, Andrew, who clearly displayed informed designer patterns in Understanding the Challenge. After Andrew was presented with the design challenge, he delayed designing a solution for more than 7 minutes. During this time, he asked a number of questions of the interviewer to get a better sense of the problem. Because the interviewer initially specified only that Abby was having trouble walking, Andrew began his questioning by asking more detailed questions about her ailment:

Andrew: Is there like… like any way to fix or are you just going to like... make like an easier way… is there any way like, that medicine can fix her?

Interviewer: …these types of dogs, their spines are really long. And because their spines are so long they often have this problem where something happens to a disc in their spine and then they can't use their back legs. So there really isn't much that we can do to fix her body. […]

Andrew: Um… [pause] Like physically impossible for her to move her legs, like… like what happens when she like tries to move them…

Interviewer: So just her back legs – they're essentially paralyzed so she just can't move them from about the hips down. She can't move her back legs but her front legs work just fine.

Once Andrew understood Abby's disability in more detail, he asked questions about Abby's personality. This helped him to clarify the function that his solution must provide.

Andrew: Does she like… like to go anywhere like if she…

Interviewer: She wants to be able to go outside and play she wants to be able to go like to the vet or even to like the store with her owners. And she definitely wants to be able to get around her house so she can get her water and food or even play a little bit. She wants to be able to chase after like balls and things.

[Interviewer comments about the time]

Andrew:	Does she like… like could you like pull her around in something or does she want to like be able to move around by herself?
Interviewer:	That's a great question. I think because her front legs work she'd be happy to pull herself around but I think… and I think it'd make it easier on the owner.

This period of questioning and thinking about the problem clearly fit Crismond and Adams' definition of how informed designers Understand the Challenge: they "delay making design decisions in order to explore, comprehend, and frame the problem better."[4]

While Andrew displayed informed designer patterns in this particular way, he had more difficulty generating ideas and was hesitant to begin drawing. With time, he used his knowledge of wheelchairs and skateboards to develop a wheeled device that Abby could rest her back legs on while pulling herself with her front legs. Due to the time limits of the interview, the interviewer did not have a chance to ask Andrew about further constraints, such as stairs. So, the nature of his behavior in Generating Ideas was not tested further. Other students did demonstrate expert behavior in Generating Ideas, and they are discussed in the next section.

Informed designer patterns in understanding the challenge and generating ideas: Carla & Sienna

Like Andrew, Carla displayed expert behavior in Understanding the Challenge by asking questions of the interviewer before beginning her design. She clarified that Abby was having trouble walking, and that her task was to "figure out something to help her get around." She also asked how big Abby was. Carla designed a "carriage" in which Abby's humans could push her around. Later in the interview, she showed flexibility with her design when confronted by a previously unknown constraint:

Interviewer:	So could she use this when she's home by herself?
Carla:	Um… I could make something like that. Okay, let me think… If she was home by herself… let me think of an idea for this. I was thinking of this to widen or – can I draw another drawing?
Interviewer:	Sure.
Carla:	Yeah. Ok. So like, instead of like… Or two things. This is for when she's outside and another would bit for at home. If she's home alone.

Carla quickly admitted that her previous design was not well-suited for Abby to get around without help from her owners. So, she decided to create an entirely new design that would specifically address this issue. There would be two devices with different functions – one to help Abby move around outside with her owners, and one to help her move around inside by herself. When designing this second device, Carla realized that she required more knowledge of Abby's disability, which she had not previously asked about.

Carla:	Which part of her legs are… like are all her paws like – kind – hard walking around or like her front or back ones?
Interviewer:	That's a good question. So she's has an injury on her back, like in her spine and um so just her – so her back legs don't work. She has them but they don't work at all. And her front legs are fine.
Carla:	Okay. So like… she could have a… like… almost like this but… it's a little… Kind of like this. [begins drawing] Her legs can go… Her front paws can go in front of here. Her back paws could stay kind of up cushioned on a little – these things. And she would walk with her front paws.

Carla continued on to design a set of wheels that would strap to Abby's back legs and allow her to pull herself along with her front legs. This new design addressed the implied constraint that Abby be able to move independently without the help from her owner, and the explicit constraint that Abby's hind legs did not work.

Like Carla, Sienna also showed great flexibility in Generating Ideas and adapting her initial design solution to developing constraints. Sienna did not initially ask many questions of the interviewer; instead, she started generating ideas right away. She proposed using a bicycle kickstand as a peg-leg, but abandoned that idea because "it might not work because kickstands move." She then proposed robotic legs before finally settling on a wheelchair-like design based on a doll stroller:

Sienna:	This is confusing… and impossible. How small wheelchairs do they have?
Interviewer:	Small wheelchairs… I have no idea.
Sienna:	It's like baby wheelchairs! Well, you could use, like, this – you know when you're little you used to use these – the dolls, you'd stick them in like their little stroller thingy?
Interviewer:	Uh huh!
Sienna:	You could, like, strap her legs, her leg into the stroller, and like it – it would roll around, but she would still walk like this [mimes paddling with her hands].
Interviewer:	OK! Well that sounds like a cool idea.
Sienna:	I – I thought of that because once I saw a dog that had, like this little wheelchair thing, and it's hind legs were hitched up to it, and it would walk like this, but its hind legs would be on the stroller thingy - so I thought maybe that could work? OK now this is really complicated. This stroller thing might work!

After proposing this idea, Sienna realized that she needed to know Abby's size in order to continue fleshing out her design.

Sienna:	Cause probably a dog's leg would be… wait, what breed is Abby?
Interviewer:	Oh, she's a dachshund. Have you ever seen those, they're like – they're, they're the really short ones that kind of look like sausages. So she's only like this long [gestures].
Sienna:	Oh! She's like the – she's really long and skinny?
Interviewer:	Right, long and skinny with the little short legs.
Sienna:	Then that wouldn't work.
Interviewer:	This wouldn't work for that?
Sienna:	No, because if she has short legs, she probably wouldn't be able to, like, lift her legs without breaking the bone.
Interviewer:	Oh, so you think this would be too high for her?
Sienna:	Mhm.

Sienna's decision to base her solution around a doll stroller assumed that Abby was a larger dog with longer legs. Once she learned that Abby was a dachshund, she realized that the seat of the baby stroller would be too high off the ground and would place Abby's body in an uncomfortable and possibly dangerous orientation. As a result, she freely modified her design. Instead of using a baby stroller, she suggested creating a homemade skateboard based design that would be closer to the ground.

Discussion & Implications

In our interviews, we found that students were able to make sense of and approach the open-ended and ill-defined design problem. All of the students developed design solutions, and some students also exhibited informed designer patterns in two of Crismond and Adams' behaviors: Understanding the Challenge and Generating Ideas. While Crismond and Adams recognize that students can display both beginning and informed designer patterns we see the need to enumerate this further in a designer matrix. There are other behaviors and traits of informed designers that are not adequately captured in the two design patterns on which we focused. These traits are equally important and helpful when students approach open-ended design problems.

One example is perseverance in the sight of a seemingly impossible problem, as Sienna stated after she realized her first design is infeasible. Despite this she forged her way forward without the prompting of the interviewer, coming up with a new idea that she also modified further. Another example of this is what M. McCormick saw in her research of third graders relying on their background knowledge and "lived experiences" to help them frame and delimit a problem.[12] Like M. McCormick, we also find students navigating an ill-defined problem by using their lived experiences, which supports their ability to engage in informed designer behaviors. For example, we see that Carla used her knowledge of household materials, baby doll strollers, carriages, and wheels to find plausible solutions to Abby's problem. Sienna also called on her experiences with and knowledge of wheelchairs, and disabled dogs she had encountered previously to aid her in her design solution. Not only did Carla and Sienna delay their design and decision process to frame the problem, their idea fluency was supported by their prior experience with many different materials. This suggests that students, like professional engineers, use their background, knowledge, and "training" to aid them in their design processes.

If one only considers students design behavior based on Crismond and Adams' matrix, one may miss instances when students display these productive beginnings of engineering. We found evidence of this in our interview with John. He displayed beginning designer patterns per Crismond and Adams' matrix in Understanding the Challenge and Generating Ideas, but there is also evidence that he navigated the ill-defined problem space by relying on his knowledge and experiences with the world. John considered materials that they had seen before such as crates, rails, motors, and pulleys in an attempt to solve the problem. Furthermore, while John never explicitly asked about the size of Abby, during explanations of his work he indicated that the size of his design would be dependent on the breed of dog:

> Interviewer: So, right, so I was going to ask you what materials you want to make it out of? So we have a blanket, and what were you saying? A baby blanket?
>
> John: Yeah like - it depends on the size of the dog. Like is it, you know, is it like a lab? Or is it one of those small dogs, or? Because a small dog you need a blanket like this [motions] but a lab you need a blanket like [motions] bigger.

To us, this shows evidence of emerging behaviors that are approaching expert practices. We don't see clear-cut patterns of informed designers in the John's approach, but we do see strengths that can be capitalized on and supported. This is important because it suggests to us that there is need to examine the range of behaviors that students display leading up to the label of "informed designer." We believe that there are still valuable student behaviors occurring which precede this ultimate goal.

Future Directions

Our interviews with fourth graders support a subset of existing literature that shows students engaging in expert engineering practices and approaching problems with more nuance and skill than is often expected of children in grade 3-5.[11,12] This is further supported by an ongoing study in its second year looking closely at teachers' use of textbook based science and engineering curriculum versus teachers using researched project based science, hands on science and engineering curricula that directly addresses NGSS' call for integrating engineering and science.[14] In the first year results of their study, students engaged in the hands-on project based curriculum outperformed their peers in the comparison curriculum, that used textbook based work, on outcome measures aligned to the core practices in the NGSS framework. We want to fuel discussions by other researchers and educators in engineering around the capabilities and strengths of elementary student engineers. Specifically, we feel that discussion is needed regarding the types of design challenges given to young students to tackle, and how to best educate their teachers on how to support them.[13, 14] Both these areas warrant further research and time in order to give the community a deeper understanding and working knowledge of students engaged in engineering. Much like the rich and detailed academy surrounding learning to read and learning mathematics, there is just as much to know about how students learn to engineer and how they can best be supported, taught, and encouraged. This has broad implications for how a teacher would not only set up their classroom, but the types of experiences, materials and maybe most importantly, the tenor and type of conversations they have with individual students.

We clearly believe that students are capable of tackling many kinds of engineering problems, but see that there is need and space to help illuminate what children can do in order to help teachers educate their students in engineering. In this paper we use the matrix detailed by Crismond and Adams, as we can show the expert behaviors students engage in. However, we suggest that this matrix could be a launching point to research a similar design matrix for K-12 students that is based directly on work conducted with this age group. This new matrix would capture emerging behaviors in students that are not seen in the Informed Design Teaching and Learning Matrix such as perseverance and calling upon learned experiences but which, are productive beginnings that lead to informed designer behaviors. The nascent skills students display need to be enumerated to provide research-based information to educators working directly with students in engineering, which will in turn provide them with the necessary understanding, skills, and tools needed to meet NGSS expectations.[12] We can show students in third through fifth grade engaging in expert behaviors expected of high school and college age students, as suggested by M. McCormick & Hynes[12], and M. McCormick et al.[13] This new matrix could be used by teachers as they plan and design curriculum to meet the Next Generation Science Standards for their students, and for administrators and curriculum directors to support the teachers and work to design curriculum that gives students realistic, ill-defined expert problems to solve.

Conclusion

There is a dissonance that is often present in how adults view elementary school children. Adults often see children who are still mastering how to skip rope, memorize multiplication facts, and tie their shoes, which might lead one to wonder if “real world” engineering tasks are age-appropriate and ask how they might be able to navigate such a complicated problem space. But if a child cannot yet skip rope or tie their shoes, it does not inherently follow that they are not yet capable of framing a problem and weighing possible solutions. Our analysis has shown that in fact students can aptly – and in some instances, expertly – ask questions to frame an ill-defined problem, apply their understanding of the natural world to develop solutions, and flexibly modify their solutions to meet the needs of the client or the environment. To this end, we want to encourage educators and researchers in this field to continue to recognize that students are capable of engaging in engineering design that can be challenging, but that we should also collectively enumerate how students engage in engineering in different contexts. As we do this we will have the data and evidence needed to better guide our students and train other educators in supporting and guiding student engineers.

Acknowledgements

This work was conducted at the Tufts University Center for Engineering Education and Outreach. This project is funded by the National Science Foundation DRK-12 program, grant # DRL-1020243. The authors would like to thank the reviewers of this paper for their comments, particularly Mary McCormick.

References

1. Jonassen, D. H., Strobel, J., & Lee, C. B. (2006). Everyday Problem Solving in Engineering: Lessons for Engineering Educators. *Journal of Engineering Education, 95*(2), 139-151.

2. Jonassen, D. H. (2014). Engineers as Problem Solvers. In Johri & Olds (Eds.), *The Cambridge Handbook of Engineering Education Research* (pp. 103 – 119). New York, NY: Cambridge University Press.

3. NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

4. Crismond, D. P. & Adams, R. S. (2012). The Informed Design Teaching and Learning Matrix. *Journal of Engineering Education, 101*(4), 738-797.

5. Atman, C. J., & Bursic, K. M. (1996). Teaching Engineering Design: Can Reading a Textbook Make a Difference? *Research in Engineering Design*, *8*, 240-250.

6. Purcell, A. T. & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies, 19*(4), 389-430.

7. Dorst, K. (2004). On the Problem of Design Problems – Problem Solving and Design Expertise. *Journal of Design Research, 4*(2).

8. Welch, M. (1999). Analyzing the Tacit Strategies of Novice Designers. *Research in Science & Technological Education, 17*(1), 19-34.

9. MacDonald, D., & Gustafson, B. (2004). The role of design drawing among children en- gaged in a parachute building activity. *Journal of Technology Education 16*(1)*,* 55-71.

10. McCormick, R., Murphy, P., & Hennessy, S. (1994). Problem-Solving Processes in Technology Education: A Pilot Study. *International Journal of Technology and Design Education, 4*(1), 5-34.

11. Watkins, J., Spencer, K., Hammer, D. (2014). Examining Young Students' Problem Scoping in Engineering Design. *Journal of Pre-College Engineering Education Research, 4*(1).

12. McCormick, M., & Hynes, M. (2012). Engineering in a Fictional World: Early Findings from Integrating Engineering and Literacy. *Proceedings of the 2012 ASEE Annual Conference and Exposition*. Washington, DC: American Society for Engineering Education.

13. McCormick, M., Wendell, K. B., & O'Connell, B. P. (2014). Student Videos as a Tool for Elementary Teacher Development in Teaching Engineering: What Do Teachers Notice? *Proceedings of the 2014 ASEE Annual Conference and Exposition*. Washington, DC: American Society for Engineering Education.

14. Harris, C. J., Penuel, W. R., DeBarger, A., D'Angelo, C., & Gallagher, L. P. (2014). *Curriculum Materials Make a Difference for Next Generation Science Learning: Results from Year 1 of a Randomized Control Trial.* Menlo Park, CA: SRI International.

Appendix: Interviewer Script

I am really interested in how kids think about problems. I wanted to hear your ideas about a problem that the Veterinarian School at Tufts University is having. The veterinarians at The Cummings School of Veterinary Medicine treat animals with all kinds of problems. Recently they were trying to help a dog, named Abby. Abby is having trouble getting around and they came to us to ask if we could help them figure out a way to help her. I would like you to design something to help Abby using materials you would find around school or at home. I have some paper here so you can draw your ideas and make a list of materials you would need. I can answer any questions you have about Abby. (Does that make sense? Could you repeat the problem back to me so I know you understand?)

Additional Prompts:
If the interviewee seems stuck, unsure or is casting around for something to use…

- What would you want to know if you were going to make something for Abby?
- Can you tell me more?
- I heard you say… did I understand you correctly?

When appropriate or towards the middle/end ask:

- What materials do you think you would make this out of?
- Can you tell me about how your idea would work?
- What other information could I give you that would help you think of something?
- Can you think of what people use when they need help getting around?
- Could that help you think of something?
- Co-design if they are really stuck. "Could we use wheels?"

*Questions for clarification of their design**:***

- How big would it be?
- How would this be used at home?
- How would this work when Abby is alone?
- Will this work everywhere she has to go? Are there places where this would be difficult?
- How does it attach/get into/on to…