Journal of Pre-College Engineering Education Research (J-PEER)

Volume 10 | Issue 1 Article 2

2020

Capturing Children with Autism's Engagement in Engineering Practices: A Focus on Problem Scoping

Hoda Ehsan
Purdue University, hehsan@purdue.edu

Monica E. Cardella
Purdue University, mcardell@purdue.edu

Recommended Citation

Ehsan, H., & Cardella, M. E. (2020). Capturing Children with Autism's Engagement in Engineering Practices: A Focus on Problem Scoping. *Journal of Pre-College Engineering Education Research (J-PEER), 10*(1), Article 2.
https://doi.org/10.7771/2157-9288.1262

Capturing Children with Autism's Engagement in Engineering Practices: A Focus on Problem Scoping

Abstract

In the last two decades, pre-college engineering education has increased, with research on pre-college engineering education emerging as a nascent field. However, limited research, if any, has considered aspects of engineering thinking of children with neurodiversity. In line with calls for broadening participation in engineering education, consideration of neurodiverse children is critical. Among various neurodiverse conditions, the number of children with autism is rapidly growing. In addition, studies have shown that individuals with autism have the potential to perform well in activities that require systematizing abilities. Engineering is one such activity. Prior research has provided evidence of the importance of early engineering learning opportunities in terms of future performance and interest in engineering; therefore, it is critical that children with autism have access to appropriate engineering experiences. We thus need to gain a deeper understanding of how they engage in engineering learning activities. In this study, we conducted a qualitative single-case-study analysis in which we closely looked at ways a nine-year-old child with mild autism engaged in problem scoping along with his mother. We focused on three main components of problem scoping in engineering design: (1) Problem Framing, (2) Information Gathering, and (3) Reflection. The instances that we have seen in mother–child interactions and conversation provided evidence that the child with autism was capable of engaging in all three aspects of problem scoping. The behaviors we have observed were mostly associated with Problem Framing and Information Gathering. However, we have also seen some evidence of Reflection. We believe that the findings of this study lay a foundation for future studies of children with autism and engineering design, and how to effectively engage them in these activities.

Keywords

problem scoping, design, autism, neurodiversity

Document Type

Invited Contributions: Best Papers from ASEE Pre-College Engineering Education

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 10:1 (2020) 12–22

Capturing Children with Autism's Engagement in Engineering Practices: A Focus on Problem Scoping

Hoda Ehsan and Monica E. Cardella

Purdue University

Abstract

In the last two decades, pre-college engineering education has increased, with research on pre-college engineering education emerging as a nascent field. However, limited research, if any, has considered aspects of engineering thinking of children with neurodiversity. In line with calls for broadening participation in engineering education, consideration of neurodiverse children is critical. Among various neurodiverse conditions, the number of children with autism is rapidly growing. In addition, studies have shown that individuals with autism have the potential to perform well in activities that require systematizing abilities. Engineering is one such activity. Prior research has provided evidence of the importance of early engineering learning opportunities in terms of future performance and interest in engineering; therefore, it is critical that children with autism have access to appropriate engineering experiences. We thus need to gain a deeper understanding of how they engage in engineering learning activities. In this study, we conducted a qualitative single-case-study analysis in which we closely looked at ways a nine-year-old child with mild autism engaged in problem scoping along with his mother. We focused on three main components of problem scoping in engineering design: (1) Problem Framing, (2) Information Gathering, and (3) Reflection. The instances that we have seen in mother–child interactions and conversation provided evidence that the child with autism was capable of engaging in all three aspects of problem scoping. The behaviors we have observed were mostly associated with Problem Framing and Information Gathering. However, we have also seen some evidence of Reflection. We believe that the findings of this study lay a foundation for future studies of children with autism and engineering design, and how to effectively engage them in these activities.

Keywords: problem scoping, design, autism, neurodiversity

Introduction

Along with ethnic minorities and women, people with disabilities are also underrepresented in engineering education and the world of practice (National Science Foundation, 2017). Among various disabilities, autism is the fastest growing population. In the next decade, over half a million children with autism will enter adulthood (Roux et al., 2013). Autism is a neurological condition that is associated with certain characteristics that can be categorized as systemizing and empathizing abilities. According to systemizing and empathizing theory (Baron-Cohen, 2009), individuals with autism usually have superior systemizing abilities, but impaired empathizing abilities. Empathizing includes attributes to understand others' emotions and thoughts. Having impaired empathizing abilities generally will result in difficulties in social skills. On the other hand, systemizing refers to the abilities to predict and control the behavior of systems and to analyze and/or build any kind of rule-based systems by identifying the input–function–output rules (Baron-Cohen, 2002).

Literature Review

Engineering for Children

Fostering technology and engineering skills and knowledge in children has become increasingly important. Historically, being technologically and engineering literate was necessary for some specific vocations. However, we are now witnessing a shift to a fluency-based approach to digital literacy (Bilkstein & Krannich, 2013). These skills are necessary for life in the 21st century, which heavily relies on technology. Thus, it is critical for children to be both technologically and engineering literate as they step into adulthood. Pre-college engineering education can play an important role in equipping children with these competencies and skills by providing them with developmentally appropriate engineering experiences.

Children as young as preschool age can engage in engineering activities and are able to solve engineering problems. Children can also engage in competencies that are comparable to those of experienced engineers. These competencies include asking questions, explaining cause–effect phenomena, iterative problem solving, identifying problems, generating ideas, and modeling solutions (Bairaktarova, Evangelou, Bagiati, & Dobbs-Oates, 2012; Dorie, Cardella, & Svarovsky, 2014). Thus, we can argue that pre-college engineering exposure should help children promote these competencies by engaging children in age- and developmentally appropriate activities in and out of school settings.

Engineering design plays a crucial and important role for effective K–12 engineering education (Brophy, Klein, Portsmore, & Rogers, 2008; National Research Council, 2009). However, to implement effective engineering design activities in pre-college settings, we need to know how to successfully implement appropriate engineering design activities for a variety of learners. A 2009 National Research Council report recommends conducting research to determine what works for diverse learners and why. It suggests that before creating any engineering learning opportunities, we should explore how different children develop design ideas and competencies and how educators and researchers can support them.

Meanwhile, the number of children diagnosed with autism is growing (Crim et al., 2014) and they are attending inclusive classrooms more than ever before. To ensure that this population is not excluded from pre-college engineering experiences and from opportunities to develop technological and engineering literacies, it is imperative that we investigate the ways children on the autism spectrum engage in engineering design. Previous engineering education researchers have also called for more investigations on autism and engineering (e.g., Pilotte & Bairaktarova, 2016). However, prior research has mostly focused on using engineering-related activities (i.e., using LEGO bricks, robots, or makerspaces) to improve social interactions in children with autism (Albo-Canals et al., 2013; Koenig, Martin, Vidiksis, & Chen, 2018). Research has yet to explore engineering thinking of children with autism and to identify their strengths and weaknesses in relation to solving engineering problems. Therefore, the focus of this research project is to explore engineering thinking among children with autism. As the first step in this study, we investigate the engagement of children with autism in the engineering design practice of problem scoping.

Problem Scoping

Design problems are usually among the most complex and ill-structured kinds of problems that are encountered in engineering practice (Jonassen, 2000, p. 80). According to Jonassen, Strobel, and Lee (2006), to solve these problems engineers (both novice and experienced) may need to consider sub-problems and rules that can be in conflict with each other and are sometimes unstated and unidentified. These sub-problems can be related to, but are not limited to, understanding and identifying the criteria and constraints of the problem. In addition, the nature and level of “structuredness” adds to the complexity of a problem (Jonassen, 2011), where problems vary across a continuum from well-structured to ill-structured. Engineering design problems often have features and sub-problems and are considered some of the most ill-structured. However, depending on how designers interpret and interact with a design problem, even those problems that are seemingly straightforward and well-structured can be treated as ill-defined with underspecified rules and goals (Thomas & Carroll, 1979). Therefore, many researchers argue that the ill-defined nature of design problems can be attributed to the features given to a task as well as to the way the task is interpreted and scoped by the designer (Watkins, Spencer, & Hammer, 2014).

Problem scoping is the first aspect of engineering design mentioned in a comprehensive matrix that Crismond and Adams (2012) developed by synthesizing research literature on design. Studies of undergraduate students and professional designers have found correlations between problem scoping and the quality of the final solution for designers of different levels of experience (e.g., Atman & Bursic, 1998; Atman et al., 2007). These studies highlighted significant differences between novices and expert designers. In addition, Crismond and Adams (2012) claim that beginning designers treat a design problem as well-structured and straightforward. They posit that beginning designers believe that there is one single correct answer and they can immediately attempt to solve the problem, which is a threat to the quality of their solution.

Crismond and Adams (2012) emphasize the importance of training students to engage in problem scoping and provide strategies for teachers to help students practice problem scoping.

Problem scoping is an important phase of addressing engineering design problems; however, it is understudied for young children (Dorie et al., 2014; English & King, 2017). The limited number of researchers who have investigated children's engagement in problem scoping have provided evidence of children engaging in different behaviors associated with problem scoping during their design activities. In one study, Dorie and colleagues (2014) investigated design behaviors of children aged four to eleven. They observed children engaging in problem-scoping behaviors such as identifying the problem and understanding the goals, identifying constraints, and familiarizing themselves with available material. In addition, Watkins and colleagues (2014) provided evidence of fourth graders engaging in three phases of problem scoping: naming, setting the context, and reflecting. Finally, Haluschak et al. (2018) investigated problem scoping in young children (K–2 grade) during an implementation of an integrated STEM+CT+Literacy curriculum. They found that children can participate in meaningful problem scoping in all three phases mentioned by Watkins and colleagues.

While these previous studies provided evidence that children in different preschool and elementary grade levels are capable of engaging in problem scoping, children with diverse abilities (e.g., those on the autism spectrum) have not been a point of conversation. Through this study, we are taking an important first step to explore engineering design thinking of children with autism whose abilities may be different from those of the majority of the population.

Purpose of the Study

This paper is a part of a bigger research project that aims to characterize engineering design thinking of 8- to 10-year-old children with autism. In this study, we focus on problem-scoping behaviors of children with autism. The question that we seek to answer is:

> *What does problem scoping look like when enacted by a 9-year-old child with mild autism as he engages in design tasks with different structures?*

Theoretical Framework

Building on previous studies, we believe problem scoping includes two actions that Crismond and Adams (2012) describe as "understanding the challenges" and "building knowledge." Consistent with previous empirical studies, in this study, we call these actions problem framing and gathering information, respectively. Additionally, we consider the importance of reflection in problem scoping as stated by Schön (1983). All three of these actions of problem scoping are also embedded in the model provided in the study by Watkins and colleagues, which investigated participants of the same age as in this study. Therefore, the problem-scoping framework of this study includes all three actions. We have then added behaviors that can be associated with problem-scoping actions by reviewing findings of empirical studies that investigated design in children, undergraduates, and adults (i.e., Atman et al., 2007; Dorie et al., 2014; English & King, 2017; Svarovsky, Cardella, Dorie, & King, 2017), and characteristics included in the matrix of Crismond and Adams (2012) and Next Generation Science Standards (NGSS Lead States, 2013). Table 1 illustrates this framework.

While we acknowledge that drawing a boundary between each of these actions is not always easy, children utilize different cognitive behaviors and tasks when engaging in these actions. For example, exploring a material may seem similar to evaluating its properties. However, exploring a material is when children gather information about the material to which they have access, while evaluation of the properties of a material is when they decide whether or not they can use the material to solve the problem.

Methods

Research Design

Case and Light (2011) called for the need to consider more diverse methodologies to conduct research in engineering education. Adding to that call, Watkins and colleagues (2014) showed how narrowing the focus of research to a very small group of participants can uncover what participants are able to do. Therefore, in this study, we have conducted a qualitative single case study across multiple challenges to investigate a child with autism's engagement in problem scoping. Previously, many studies have utilized single case studies in science, technology, engineering, and mathematics education research, and particularly engineering education. For example, Stewart and Jordan (2017) explored the experience of one

Table 1
Problem scoping framework.

Understanding the boundaries of the problem	Problem scoping aspects	Behaviors
	Problem Framing	a) Reading, rereading, rehashing, or reframing understanding of the problem statement and/or the goal b) Identifying and restating limitation of materials, space, and resources (constraints) c) Identifying and restating desired features of a solution (criteria) d) Adding/considering meaningful context
	Information Gathering	a) Exploring material b) Gathering information/building understanding of how a system/mechanism works and its users c) Gaining domain-specific knowledge through group collaboration d) Identifying pieces of information in a problem that span across different categories e) Considering interactions among problem requirements f) Balancing and prioritizing the different components and interactions in a problem
	Reflection	a) Evaluating the properties and behaviors of supplied material b) Explicitly acknowledging and evaluating the problem space and the decisions made about what to consider and prioritize

girl during a robotic after-school program and provided insights on her learning and the barriers to it. In addition, Scolnic, Spencer, and Portsmore (2014) examined engineering learning moments of children with disabilities.

Case study is an empirical inquiry which can provide an in-depth exploration of a phenomenon within a "bounded system" that is called a "case" (Yin, 2009). Case study analysis can be conducted employing one individual case when in-depth and descriptive evidence is provided to interpret critical events (Flyvbjerg, 2006). In addition, in a case study the investigation should be conducted in a specific context (Powell, Francisco, & Maher, 2003).

In this study, the phenomenon under exploration is problem scoping within the bounded system (case) of a dyad of parent–child with autism. While the focus of the study is the child's engagement in problem scoping, we also look at the parental interactions and conversation that help facilitate this. The context of the study is an engineering design activity, consisting of four different challenges that have the same theme but are different in nature and structure. We investigate the child's engagement in problem scoping across all four challenges, which provides a rich description of how the child engages in problem scoping.

Participants

A family consisting of a mother and a male child with autism participated in this study. The child was nine years old. He attended fourth grade in a public school but received some individualized educational programs at school. The child was diagnosed with mild autism (historically called high-functioning autism). The child falls on "systemizing brain" based on the Autism Spectrum Quotient (Auyeung, Baron-Cohen, Wheelwright, & Allison, 2008) which indicates his autistic traits are above average.

Based on the information we received from the mother's and child's interview and survey, the mother indicated that she is very involved with her child's education and thinks she knows how to help him with designing, creating, and building ideas and skills. The child's favorite game is a computing game called Minecraft. He has previous experience playing and building things with LEGO blocks and daily plays with toys that allow him to "design, create, or build." The child has an older sister who is in eighth grade who came to the study site but decided not to participate. They have identified their race as "White." In this paper, we refer to the mother as Mom and have given the pseudonym John to the child.

Design Activity: Design a Rollercoaster

The family was asked to try out an engineering design activity in which they had to design and build a rollercoaster for an amusement park. The activity was designed considering autism characteristics (Ehsan, Gajdzik, & Cardella, 2019), including the least-to-most strategy (Neitzel & Wolery, 2009). The activity was done in and out of school settings in the laboratory of a research institution. In this activity, the family received two letters from the director of a hypothetical amusement park. The first letter stated the problem, which was a need for a rollercoaster in the park. It introduced the context of the problem and provided instructions about the next steps. The second letter specified criteria and constraints of the problem. The family had to

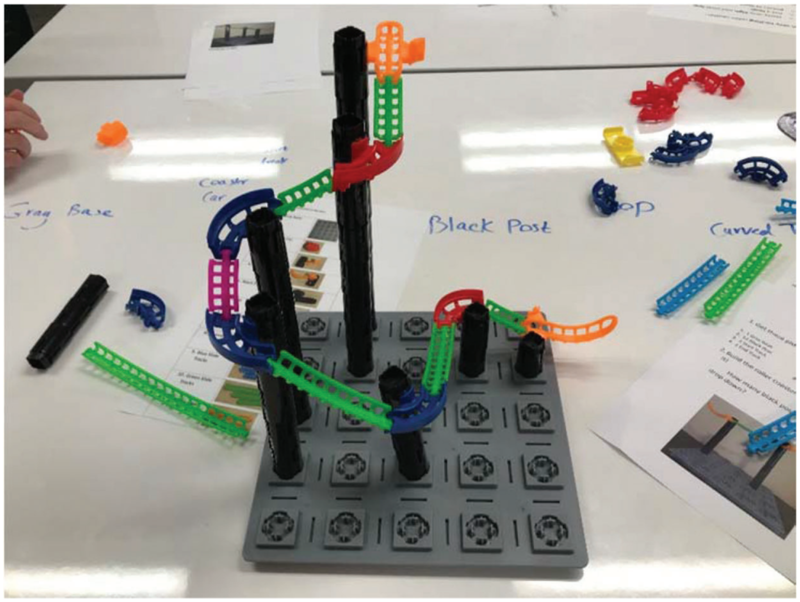

Figure 1. Rollercoaster built by the child.

use a construction kit (Figure 1) to build their solution, but markers were also provided to sketch their ideas if necessary. The activity was organized into four challenges that ranged from well-structured to ill-structured. More information about the activity can be found on the website for Purdue's INSPIRE Research Institute for Pre-College Engineering.

Quality of Research Design

The same as any other modes of inquiry, the quality of qualitative case studies should be ensured when conducting the study. Yin (2018) has identified different quality tests related to validity and reliability, and recommended that researchers conducting case studies use them when applicable to their studies. In this study, we ensured the construct validity by collecting multiple sources of evidence that allowed for triangulation of the data (see the next section for data sources). External validity includes determining the applicability of the study to other contexts. We have provided detailed descriptions of participant interactions and conversations in the findings. Therefore, readers should be able to determine if the findings of this study are applicable to different settings and contexts. The thick descriptions also ensure reliability of the findings, as they help readers understand how we have interpreted participants' interactions.

Data Collection and Analysis

The data sources that we used for this study were video and audio recordings of the family while interacting with the activity. We stationed two video cameras across the room in which the study was conducted. The researcher who collected the data also took field notes about what she observed. The video data were of 50 minutes' duration, in which both child and mother were deeply engaged in solving the problem and designing the rollercoaster. To conduct video analysis, we utilized a video analysis process suggested by Powell et al. (2003). Following this process, we engaged in (1) attentively viewing the video data, (2) describing the video data, (3) identifying critical events, (4) transcribing, (5) coding, (6) constructing a storyline, and (7) composing a narrative. One of the researchers was mainly involved in analyzing the videos, While both authors were involved in the process of inter-coding agreement, constructing a storyline, and composing the narrative. Step 5 was when we coded the narrative while watching the video if needed. We coded the video against different behaviors mentioned in the framework by focusing on what the child did (interactions with the kit) and what he said (dialogue with his mother and talking out loud). The codes (i.e., behaviors) were then classified into the main three actions of problem scoping. The last two steps happened as we were making sense of the findings and writing the paper.

Findings

In this study, we aimed to explore how a child with autism engaged in problem-scoping behaviors across different design challenges. The structure of the challenges varied from well-structured to ill-structured. The activity started with an initial letter from the director of an amusement park and continued with four challenges. The first challenge asked the child to build the same rollercoaster model provided in the problem. Building from this, the second challenge asked the child to construct a rollercoaster that was steeper than the first one. The third challenge was to build a rollercoaster with a turn of the car before it stopped. Finally, the last challenge was when the child received a second letter with three criteria and two constraints. Below, in a narrative way, we describe events in which the child engaged in problem-scoping behaviors. Within each narrative we have included codes in parentheses, which refer to the action and a certain behavior. In addition, the narratives include descriptions of what was happening and exact transcriptions of what the child ("John") and the mother ("Mom") said.

Letter One

The family read the letter quietly ***(Problem Framing-a)***. While neither Mom nor John talked about the letter or its proposed problem, they engaged in problem scoping through exploring material. The mother facilitated her son's engagement by asking him to find the pieces and identify what each piece does.

> *Narrative 1: Mom and John start exploring the material. Mom looks at the kit guide that has labeled images of the pieces and asks John to find each piece. Mom points to one of the pieces, and asks her son: "Do you know how we can use the tunnel?" John rotates the piece and then says, "I know how." He then grabs the gray base and demonstrates how he can use this piece (**Information Gathering-a**).*

Challenge One

Challenge One was a well-structured building task. The child received a simple model of a rollercoaster and was asked to build it using the provided construction kit. As was expected, we observed limited behaviors related to problem scoping. The child took the problem straightforwardly and started building the rollercoaster. However, after he started building, he realized some sub-problems that needed to be defined. The narrative below includes examples of problem scoping.

> *Narrative 2. John and Mom look at the problem (**Problem Framing-a**). John loudly says, "I know how to do this," looks at the picture carefully (**Information Gathering-d**) then quickly grabs two black posts and places them on two sides of the gray base. Then, he starts counting how many black posts he needs for each tower based on what he sees in the picture (**Problem Framing-c**). After he builds the towers at both sides, he looks for the start and end tracks and chooses them based on their color. After failing to attach one, he rotates it and looks carefully first at the picture, then at the pieces he has in his hand, and realizes he chose a wrong piece. He picks up the other two orange pieces, places them next to the picture, and whispers, "here." He tries to attach them to the towers and Mom says, "Correct, just rotate it." Without saying anything, the child looks at the pieces again and rotates one and is able to attach it (**Information Gathering-a/b**).*

As seen in the narrative, John identified a criterion for his problem that the rollercoaster should be built with the exact pieces provided but also the same number of pieces. He engaged in information gathering as he determined what he needed to build the same roller coaster as the given model, identifying the necessary pieces (e.g., same shapes and numbers) and exploring how each piece worked with the other ones.

Challenge Two

Challenge Two was less well-structured than the first challenge, as the child was not given an image of the model. The challenge asked the child to build a rollercoaster that was steeper than the first one. The challenge also directed the child by suggesting some pieces that he could try. We observed different behaviors of problem scoping exhibited by the child.

> *Narrative 3. John reads the challenge (**Problem Framing-a**) and says "Okay." He knocks down his previous model and keeps one tower. He quickly starts adding to the tower.*
> *Mom: Do you know what you have to do?*
> *John: Steeper (**Problem Framing-a/c**)*
> *Mom: Do you know what steeper is?*

*John says "yes" and illustrates it with his hand. Mom then shows her arm and says it needs to have an angle (**Problem Framing-c**).*

*John builds a high tower and then a lower one and explores different slides to see which one can be attached to the two towers (**Information Gathering-a/b**) before he finally finds one that best fits. He tests it and the rollercoaster car falls off the track. Mom says, "Why did it fall out, John?" John says, "Oh, no, not safe" (**Problem Framing-d**) and he fixes the rollercoaster.*

As with the first challenges, John engaged in exploring what pieces he could use in his design. He also added context (and a criterion) to the design after realizing the coaster car could fall off. Keeping the car on the track was a sub-problem that came up after he tested the first version of his prototype.

Challenge Three

Challenge Three was even more ill-structured than the previous ones. The challenge provided an open-ended problem: "Build a rollercoaster that turns before it stops." During this challenge, we saw more evidence of the child engaging in problem-scoping actions through conversation with his mother.

*Narrative 4. John reads the challenge, nods, and then grabs two turn tracks and tries to connect them together (**Problem Framing-a** and **Information Gathering-a**). After some minutes of trying, Mom asks, "Do you think these two can go together?" John works with the pieces and then leaves them (**Reflection-a**). Then John grabs different slide tracks and sees which one can be attached to the turn track (**Information Gathering-a**). When he is able to attach a slide to the turn track, he builds a tower between the two he had from the previous model. He then tries to connect them together using the attached turn track, slide, and a couple of other pieces. He tries different pieces of the kit before finally asking for help.*

John: We need something to hold this [pointing to the slide that is attached to the turn track and should be attached to the middle tower].

Mom: I don't think this works this way, dude.

John: Never mind. This holds it [leans the turn slides on the tower].

Mom: Turn it around, it is the other way round.

*Mom hands John a different turn track. John looks at it, rotates it, and replaces it with the other turn track (**Information Gathering-b**).*

As John read the problem, he engaged in gathering information and framing the problem. He realized that he had to use turn tracks, then explored how those turn tracks could be attached to other ones and how he could use them in his design. In addition, after Mom asked him a question about the two pieces he was trying to put together, it is possible that he engaged in evaluating the way these pieces could be used (evaluating how the supplied materials work, see Table 1). Throughout the activity, he showed that he knew the problem and restated the criteria.

*Narrative 5. John builds the rollercoaster and tries it, but the car stops before it gets to the end. John says, "It counts, because it turns before it ends, it counts!" (**Problem Framing-a/c**). Mom agrees that he met the criteria for this challenge. However, he says, "No, wait, I have an idea." He removes some pieces and tries it. The rollercoaster car turns and stops at the end track.*

This is an example of the child restating the criteria of the problem, but also adding to it. Although he thought that his design met the specified criteria, he pointed to an unspecified criterion that the rollercoaster should start and end at the specified tracks and found a solution for that.

Challenge Four and Letter Two

Challenge Four was when the child received the second letter from the director of the amusement park. The challenge was ill-structured and open-ended with three specified criteria and two constraints. The three criteria were that the rollercoaster should: (1) start very high and end very low, (2) have one loop, and (3) have one tunnel. Limited space and material are mentioned as constraints. In addition, at the end of the letter the child was reminded to build a fun rollercoaster that would be the steepest and fastest yet. At this point, children were expected to have explored the material and have ideas in mind for how to build this rollercoaster.

In this challenge, we observed many instances of the child engaging in problem scoping, and conversation and interaction with the mother increased.

*Narrative 6. Mom hands the letter to John and asks him to read it aloud. He looks at the letter very briefly and says, "Challenge accepted! I know what to do." Mom then reads the letter and says, "Hey, they are asking you to start very high and end low." John says, "and a loop and a tunnel" (**Problem Framing-a/c**). While John is knocking down what he built in the previous challenge, Mom says, "John, all the posts have to be on this gray thing." John responds, "Ha, okay" (**Problem Framing-a/b**).*

*Mom then asks, "John, do you have a picture in your head on how you want to build it? You can also draw your idea, John" (**Problem Framing-a**).*

*John, while trying to assemble the loop, responds, "Mom, can you help me with this [assembling the loop]?" (**Information Gathering-a** and **Problem Framing-a**).*

*Mom tries to assemble the loop, but it seems to be broken. She tells the researcher that the piece is broken. Suddenly John says, "do you have a spare?" Mom says, "Even if they don't, we will make this." He responds, "No, it says a loop, we need a loop" (**Problem Framing-b/c**). The researcher assembles the loop and returns it.*

We can see in this narrative that the mother read the problem and tried to explain the criteria to the child. The child showed that he was planning to consider them and even restated some of the criteria. He explored the loop and tried to assemble it, which also shows that he was considering the criteria; we consider this to be problem scoping rather than solution modeling, because he seemed to be engaged in exploring the problem criteria and materials available more so than creating a specific solution. He realized the constraint of having only one loop and seemed to know that without the loop he could not solve the problem according to its criteria.

*Narrative 7. Mom tells John, "Think about the rollercoasters we have been on, how do they work?" John responds, "They always go up first and should start very high. All go very high and then [go] fast" (**Information Gathering-b**, **Problem Framing-c**, and **Reflection-b**). "I have an idea." He puts several black posts on top of each other to create a very tall tower.*

The mother helped the child by referring to their previous experience riding rollercoasters, information which he could use for his design. The information he remembered was consistent with the criteria of the problem. This information seemed to help him reflect on his design solution by prioritizing the features in his solution. This was obvious in his conversation when he mentioned a rollercoaster "should" start very high and "then" go fast. We also see that right after this dialogue he built a very tall tower, which probably indicates that he thinks that starting high is the most important feature of a rollercoaster.

*Narrative 8. A few minutes later, after some unsuccessful attempts, John gets frustrated and says, "I cannot do this, I can't." Mom affirms that he can, and says, "Let's talk about it first and see how we want the rollercoaster to look like. Do you want it to start with a loop, you said?" (**Problem Framing-a/c**). John says, "I have an idea." He gets engaged in building out a new idea. After a few minutes of building and having conversation with Mom, his rollercoaster starts very high and comes down and has a turn track at some lower levels. John attaches the loop backward (down to up). Mom tells him, "Do you think this works?" John says, "yes." She then says, "Think if you have ever seen a loop in a park." John, a few minutes later, says, "Like a giant slide?" Mom says, "Yes, this does look like a giant slide. Do you think that a giant slide can go down to up? It needs gravity, it can't" (**Information Gathering-b/c**). John looks at the loop and tries the car in it, which doesn't move. He agrees and takes the loop out (**Reflection-a**).*

In this narrative, the child got frustrated while designing his solution. Mom's encouragement and soliciting input helped him to get back on track. She restated the goals her child had for the design which reminded him of the problem and criteria. The son–mother conversation included some scientific principles which helped the child reflect on his use of given material, ultimately resulting in a different solution.

*Narrative 9. Toward the end and after a few rounds of building, testing, and troubleshooting, John builds some small towers next to the track and says, "I know, it falls down. When it falls down, this keeps it. It is safe." Throughout the activity, Mom and John restate the criteria several times. They also remind themselves of other criteria, including that it should be safe and the car should go all the way through (**Problem Framing-c**).*

Discussion

In this study, we investigated problem-scoping actions enacted by a nine-year-old child with mild autism during an engineering design activity. The instances that we saw in these mother–child interactions and conversation provided evidence that the child was capable of engaging in all three actions of problem scoping. The behaviors we observed were mostly associated with Problem Framing and Information Gathering. We observed limited instances that could be associated with Reflection, which primarily happened during the ill-structured challenge. In addition, although the aim of this study was not to examine parental influences on a child's engagement in problem scoping, we noted that the mother played a stronger role as the activities became more ill-structured and open-ended. This was obvious through the amount of conversation between them.

The child engaged in problem scoping differently in different challenges. During the first challenge, the child's problem scoping was mostly limited to reading the task (problem statement) and exploring the materials. He also added a criterion, which was to build the same rollercoaster as featured in the picture; this was evidenced by him counting the number of pieces and making sure that the rollercoaster looked exactly like the picture. However, we could see that in the last challenge, with the help of the mother, the child restated the criteria many times, gathered information by making connections to his previous experiences and scientific knowledge, evaluated the way materials worked together, and added context to the problem. In addition, problem scoping was investigated solely and not at the same time as other engineering design actions. However, following the suggestion of Watkins and colleagues (2014), we ensured that the instances we captured were those connected to scoping a problem and developing a solution.

The process of engineering design is usually captured and taught in a cycle with sequential actions, which may contribute to the misconception that design is a linear process. Problem scoping is typically the initial action in that cycle and educators are encouraged to engage students in that action first (Crismond & Adams, 2012). However, the findings of this study showed that the child did not naturally engage in problem scoping as the first design action. We observed that, as the challenges were becoming more ill-structured, problem scoping was happening throughout each activity and in a nonlinear order of engineering design actions. In the well-structured activity (Challenge One), problem scoping happened at the beginning. However, in the final challenge, which was an ill-structured problem, problem scoping happened as the child was working and building the solution. On several occasions, problem scoping happened after testing and troubleshooting; problem scoping helped with fixing the solution, generating new ideas, and conducting the final evaluation. This finding is similar to those from other empirical studies of design, which show that children and adults engage in an iterative design process and that problem scoping does not necessarily happen at (only) the very beginning (e.g., Atman et al., 2007; Dorie et al., 2014).

Conclusion and Implications

In line with broadening participation in engineering education, we need to provide opportunities for underrepresented populations to be exposed to and practice engineering and engineering design. However, to help children get the most out of these experiences, we need to design appropriate engineering activities while considering their needs, assets, and individual potential. Since no engineering intervention for children on the autism spectrum has been designed and evaluated by research (Ehsan, Rispoli, Lory, & Gregori, 2018), we need to first characterize their engineering experiences, explore their strengths and weaknesses in relation to working on engineering problems, and find out ways adults and peers can support them. As the first step to support neurodiversified engineering education, this study focused on one child on the autism spectrum and his mother, exploring the ways in which he engaged in problem scoping. The aim of this study was not to compare children with autism to children without autism, but to explore if and how children with autism can engage in engineering design.

In this study, we have observed many instances where the child with autism engaged in different problem-scoping actions and behaviors. These instances highlight the capability of this child in scoping a design problem. Many of the instances captured in this study are similar to ways children engaged in problem scoping in the studies of Watkins and colleagues (2014) and Dorie and colleagues (2014). We expect that these findings are not limited to this child, and that the series of activities can be seen in other children with autism.

We believe that children with autism, with or without the support of adults, need to be exposed to engineering design activities and opportunities to practice their design skills and competencies across a range of well- and ill-structured problems. We believe that the structure of this series of activities, designed for a child with mild autism, played an important role in the child's persistence in problem scoping and engineering design overall. The series of engineering design challenges, with various structures but the same theme, helped the child move away from spending too much time on spatially exploring the material and instead focus on the main problem as it grew in complexity. Therefore, while further

http://dx.doi.org/10.7771/2157-9288.1262

research is needed, we believe that similar series of activities may help other children with autism engage in and build solutions for engineering design activities.

In this study, we observed challenges and moments of frustrations that the child faced but was able to overcome with the support of his mother. We have also seen moments that the child independently engaged in problem scoping and even initiated conversation about the solution with his mother. We argue that other children with autism may also face these challenges and exhibit these strengths, which should be supported appropriately by parents or educators. While this research project is in its early phases, these preliminary findings shed light on the importance of developing appropriate design activities for this population, where accommodations for addressing their needs are also considered.

Future Studies and Limitations

Previous literature has investigated and synthesized expert–novice differences in design (e.g., Atman et al., 2007; Crismond & Adams, 2012) as well as design processes and practices more broadly. As an example, literature suggests that, depending on the problem solver, a well-defined problem can be interpreted as ill-defined and many unspecified features can be examined to address the problem (Thomas & Carroll, 1979). In this phase of our study, our intention was not to examine the similarities and differences of the child's behavior compared to novice or expert designers. In our initial findings, we did not observe the child considering unspecified components of the problem during the first challenges, nor did we observe the mother facilitating more interpretations of the problem. However, given some similarities of instances enacted by the target child in this study with children of the same age in Watkins and colleagues' (2014) study, we believe that children with autism may exhibit some behaviors more closely aligned with those of experts when attending to design problems (like engaging in reflection). In future studies, we will examine the child's problem-scoping behavior in more depth and consider making more comparisons to other groups.

As mentioned above, we believe our series of activities helped the child to scope the problem, engage in the design activity, and develop his solution. Further studies should be conducted to explore children's engagement in different types of well- and ill-structured design problems with shorter or longer narratives. To characterize engineering thinking of children with autism, we also need to focus on other aspects of engineering design. In this study, given the nature of the tasks, we observed that problem scoping occurred simultaneously with modeling. We need to explore if we can draw a clear boundary between the design actions, or if the behaviors can be associated with more than one engineering design action. In addition, to fully capture problem scoping of children with autism, future studies should be conducted to examine problem scoping (and other engineering design actions) in different settings and contexts.

Author Bios

Hoda Ehsan is a PhD candidate in the School of Engineering Education at Purdue University. Hoda conducts research to examine engineering thinking of young children, including those with special needs, across informal and formal learning settings.

Email: hehsan@purdue.edu

Monica E. Cardella is a professor of engineering education at Purdue University. Dr. Cardella conducts research on how children learn engineering in informal settings, as well as on engineering design processes and practices across preschool through professional practice.

Email: cardella@purdue.edu

Acknowledgments

This paper was selected as the Best Diversity paper by the Pre-College Engineering Education division of the American Society for Engineering Education. Therefore, this paper has previously been published in the *Proceedings of the 2019 American Society for Engineering Education Annual Conference & Exposition*.

This material is based upon work conducted while Monica Cardella was serving at the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Albo-Canals, J., Heerink, M., Diaz, M., Padillo, V., Maristany, M., Barco, A., … & Heilbron, S. (2013). Comparing two LEGO robotics-based interventions for social skills training with children with ASD. In *RO-MAN, 2013 IEEE* (pp., 638–643). IEEE.

Atman, C. J., & Bursic, K. M. (1998). Verbal protocol analysis as a method to document engineering student design processes. *Journal of Engineering Education*, *87*(2), 121–132.

Atman, C., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education*, *96*(4), 359.

Auyeung, B., Baron-Cohen, S., Wheelwright, S., & Allison, C. (2008). The autism spectrum quotient: Children's version (AQ-Child). *Journal of Autism and Developmental Disorders*, *38*(7), 1230–1240.

Bairaktarova, D., Evangelou, D., Bagiati, A., & Dobbs-Oates, J. (2012). The role of classroom artifacts in developmental engineering. In, *Proceedings of the American Society for Engineering Education Annual Conference*, San Antonio, TX.

Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends in Cognitive Sciences*, *6*(6), 248–254.

Baron-Cohen, S. (2009). Autism: The empathizing–systemizing (E-S) theory. *Annals of the New York Academy of Sciences*, *1156*(1), 68–80.

Bilkstein, P., & Krannich, D. (2013). The maker movement and FabLabs in education: Experience, technology, and research. In *IDC 2013 Proceedings of the 12th International Conference on Interaction Design and Children*, New York, NY.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P–12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.

Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186–210.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, *101*(4), 738–797.

Dorie, B. L., Cardella, M., & Svarovsky, G. N. (2014). Capturing the design thinking of young children interacting with a parent. In *Proceedings of the American Society of Engineering Education Annual Conference*, Indianapolis, IN.

Ehsan, H., Gajdzik, E., & Cardella, M. (2019). Design an amusement park: Engineering for children with autism. NSTA Journal of Connected Science Learning. (May 2019 Special Issue 10: Serving Youth with Special Needs).

Ehsan, H., Rispoli, M., Lory, C., & Gregori, E. (2018). A systematic review of STEM instruction with students with autism spectrum disorders. *Review Journal of Autism and Developmental Disorders*, *5*(4), 327–348.

English, L. D., & King, D. (2017). Engineering education with fourth-grade students: Introducing design-based problem solving. *International Journal of Engineering Education*, *33*(1), 346–360.

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245.

Haluschak, E. M., Stevens, M. L., Moore, T. J., Tank, K. M., Cardella, M. E., Hynes, M. M., … & Lopez, R. D. L. P. (2018). Initial problem scoping in K–2 classrooms (fundamental). In *Proceedings of the American Society of Engineering Education Annual Conference*, Salt Lake City, UT.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63–85.

Jonassen, D. H. (2011). Design problems for secondary students. National Center for Engineering and Technology Education.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education*, *95*(2), 139–151.

Koenig, K., Martin, W., Vidiksis, R., & Chen, Y.-L. (2018). IDEAS: Inventing, designing, and engineering on the autism spectrum. Presentation at the International Society for Autism Research, Rotterdam, Netherlands.

National Research Council. (2009). *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

National Science Foundation. (2017). *Women, minorities, and persons with disabilities in science and engineering*. Arlington, VA. www.nsf.gov/statistics/wmpd

Neitzel, J., & Wolery, M. (2009). *Steps for implementation: Least-to-most prompts*. Chapel Hill, NC: National Professional Development Center on Autism Spectrum Disorders, Frank Porter Graham Child Development Institute, University of North Carolina.

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

Pilotte, M., & Bairaktarova, D. (2016). Autism spectrum disorder and engineering education—Needs and considerations. In *Frontiers in Education Conference (FIE), 2016 IEEE* (pp. 1–5). IEEE.

Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *Journal of Mathematical Behavior*, *22*(4), 405–435.

Roux, A. M., Shattuck, P. T., Cooper, B. P., Anderson, K. A., Wagner, M. & Narendorf, S. C. (2013). Postsecondary employment experiences among young adults with an autism spectrum disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *52*(9), 931–939.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.

Scolnic, J. M., Spencer, K., & Portsmore, M. D. (2014). Viewing student engineering through the lens of "engineering moments": An interpretive case study of 7th-grade students with language-based learning disabilities. In *Proceedings of the American Society of Engineering Education Annual Conference*, Indianapolis, IN.

Stewart, O. G., & Jordan, M. E. (2017). "Some explanation here": A case study of learning opportunities and tensions in an informal science learning environment. *Instructional Science*, *45*(2), 137–156.

Svarovsky, G., Cardella, M., Dorie, B., & King, Z. (2017). Productive forms of facilitation for young girls during engineering activities within informal learning settings. In *American Educational Research Association Annual Meeting*.

Thomas, J. C., & Carroll, J. M. (1979). The psychological study of design. *Design Studies*, *1*(1), 5–11.

Watkins, J., Spencer, K., & Hammer, D. (2014). Examining young students' problem scoping in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)*, *4*(1), 5.

Yin, R. K. (2009). *Case study research: Design and methods (applied social research methods)*. London and Singapore: Sage.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: Sage.