2014

Capturing the Design Thinking of Young Children Interacting with a Parent

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Capturing the Engineering Behaviors of Young Children Interacting with a Parent (Work in Progress)

Abstract

Building towers out of blocks, taking things apart and figuring how things work are a part of childhood and have been considered to be important precursors to engineering thinking. However, there is not yet consensus on what engineering thinking looks like for young children. Is engineering too difficult for young children to understand? Can young children engage in design and if so, what does that look like? How can we differentiate "design" activity that children engage in from normal everyday play? Several design models have taken into account the developmental stages of young children, but they are not always based on empirical evidence of children's actual design activities. In this paper, we describe a framework for identifying design thinking activities that children might engage in. This framework is based on existing models for engineering design for young children, existing literature on adults' design thinking behavior as well as empirical evidence from our own research on 4-11 year old children's engagement in design activities.

Background

Children are sometimes referred to as "natural engineers" whose creativity and curiosity about the world around them evokes comparisons to skills used by professional engineers. Empirical observations of preschoolers playing with blocks show that children engage in what was labeled as "precursors to engineering behavior".[1-3] These precursors include asking questions/stating goals, explanations, construction, problem solving and evaluating design.[4] However, as "children" grow up and enter undergraduate engineering courses, many of these behaviors are now absent, until developed again through the undergraduate engineering curriculum and professional work experience.[5]

Recently, several design process models have been developed for younger children, including those put forth by the Next Generation Science Standards (NGSS)[6], the PBS television show *Design Squad*[7] and the Museum of Science in Boston's *Engineering is Elementary* curriculum[8] (to name a few). Within NGSS, engineering design is integrated throughout the document, with a focus on define, design and optimize as their central core ideas.[6] However, the specific standards for each of these ideas range in complexity based on grade level (separated into K-2, 3-5, 6-8, and 9-12). One noticeable omission at the K-2 level is the lack of any problem scoping behavior (that doesn't occur until 3-5th grade level). The design process that *Design Squad* uses contains identification of the problem; brainstorm; design with a cyclical build, test/evaluate and redesign process; and finally share the solution.[7] Lastly, the *Engineering is Elementary* program uses a cycle of ask, imagine, plan, create and improve.[8] While these three design processes have both similarities and differences, they all tackle the task of what is developmentally appropriate (or not) for young children.

Likewise, the models of the engineering design process that are used to teach undergraduate students as well as to conduct research on how students and practitioners engage in design vary tremendously.[9] When Atman began studying undergraduate engineering students' design processes, she began by conducting a review of seven prevalent engineering textbooks used to teach the design process to undergraduates. This review yielded a model of engineering design consisting of ten activities (identify a need; problem definition; information gathering; idea generation; modeling; feasibility analysis; evaluation; decision; communication and implementation) distributed across three major phases (problem scoping; developing alternative solutions; project realization).[10] Because this model is based in engineering textbooks, but has also been used to describe the processes that students and practitioners engage in[5], it is considered to be both prescriptive and descriptive. Building on the work of Atman and her colleagues, as well as other design researchers[11-12], in addition to models set out by pre-college educators, the focus of this work is to describe a model of engineering design that is (a) developmentally appropriate for children, (b) grounded in theory, and (c) grounded in empirical findings. To accomplish this, we have reviewed existing literature and collected new data to answer the questions: *In an informal environment, how do kids design in an open-ended engineering activity with their parents? What engineering behaviors do children engage in, and what are they most prompted to do?*

Methodology

The GRADIENT (Gender Research on Adult-child Discussions within Informal ENgineering environmenTs) study is a collaboration between Purdue University and the Science Museum of Minnesota with a focus on understanding how young girls engage in engineering. There are two different settings within the science museum that were used in this study, a program for preschool-aged children called "Playdates" and a separate "Engineering Studio" exhibit open to all visitors to the museum. The once a week Playdates program is intended for preschool aged children (3-6, and consists of several different stations where young children and their parents can engage in hands-on activities. For the purposes of this study, the parent-daughter dyads participating in Playdates were asked to complete two different engineering challenges: first to build a tower out of large foam blocks (see Figure 1-A), and then to build a second tower out of Dado Squares (plastic interlocking squares; see Figure 1-B). The two challenges were selected to facilitate variation in familiarity with the building materials; the children are typically familiar with the foam blocks, but not familiar with the Dado Squares.

The second setting is within "Engineering Studio", an engineering exhibit at the museum that is open to all visitors. The area we focused upon was a pneumatic ball run activity with children 7-11 years old. The pneumatic ball run consists of a series of magnetic frames with piston assemblies, hinged ramps and movable supports and ramps (see Figure 1-C), where the goal was to design a ramp system that would ensure that the ball successfully travelled from the start to the finish position, where the finish position is higher than the start position.

Figure 1. A) Playdates with foam blocks, B) Playdates Dado Squares, C) Pneumatic Ball Run.

In each setting, 30 dyads (half of the parents male and half female) were video recorded and the transcribed verbal and non-verbal segments (identified with either the child or parent as the speaker/actor) were first open and then axially coded for engineering talk and action using both the transcript and the video recording. One lead researcher conducted the majority of the coding with five additional researchers coding a subset of the data.

Inclusion of parents in this study

With young children, a majority of their out-of-school time is spent with their parents.[13] Not only can parents affect young children's interest and curiosity in engineering and science, but they also can help students to improve their scientific reasoning skills. Nooourbakhsh el al. (2006) found that parents act as a bridge between museum exhibits and children by assisting and guiding in children's understanding.[14] This is similar to the developmental theories that hold that parents provide scaffolding consistent with the level of their child.[15] Therefore, parents in this situation may provide scaffolding for their child to complete the task. Additionally, in our investigation of the types of engineering behavior that children *can* engage in, we are not concerned with what the children can do independently so much as what the children can do with or without support from parents (or others).

Findings

While the data we have collected provides rich insights into not only early engineering behaviors and engineering thinking but also the different ways that parents interact with their daughters in these activities[16], in this paper we focus on how (and when) children engage in specific engineering behaviors, and how the children's ways of engaging in specific engineering behaviors may differ from the ways that adults engage in the same behaviors. We narrowed our focus to four main behaviors: problem scoping, idea generation, revision, and evaluation (see Table 1; also see Cardella et al 2013 and for a previous version of the coding scheme[16]). These behaviors were chosen based on (a) the literature on precursors to engineering thinking, (b) other models of engineering design, and (c) observations based on our video data. While other models of the engineering design process include a "modeling" activity, we excluded this activity due to three main reasons: (1) the sheer prevalence of that code due to the nature of the tasks, (2) the "modeling" activity we observed very closely resembled typical children's play (thus it is harder to argue that children were engaging in engineering during those times), and (3) previous research suggests that there are no significant differences between novices, post-novices, and experts in how they engage in modeling.[5] Beyond the four main behaviors that we focus our discussion on, we also looked at testing, reflection, prediction, and material property codes.

Table 1. Main codes for Playdates and Engineering Studio engineering behaviors.

Problem Scoping	Idea Generation	Design Evaluation	Revision
Understanding the boundaries of the problem.	*Contains elements of imagining, brainstorming and planning.*	*Evaluation of the current design (not of a single item).*	*Looking at changes to the design as a result of feedback.*
• Identify constraints • Restate goal • Look at feasibility of problem • Add context • Understanding goal (instructions) • Familiarize w/ materials • Identify/assign roles	• Formulation of ideas (before action occurs) → Brainstorm • Committing to a strategy → Planning • Decision making process	• Assess goal completion	• Increase efficiency by making a physical change • Iterate base on feedback (verbal or physical) • Optimization

Problem Scoping behaviors observed included identifying the constraints, restating the goal, looking at the feasibility, familiarizing with goal & materials and also assigning roles. Research suggests that experts tend to spend more time engaged in problem scoping activities compared to novices, and that this additional time spent scoping the problem leads to higher-quality engineering design solutions.[5] Additionally, we noticed that in the preschool program setting children were more apt than their parents to add in additional context to the situation. For example, a young girl related the tower to an apartment building of many floors and talked about how the "tower" needed to have room as well. Both the child and the parent were also the ones to restate the goal; mostly when the other person was off-task. With the Dado Squares and the pneumatic ball run, there was an initial period where the dyad had to acquaint themselves with the unfamiliar materials – a majority of the participants would engage heavily in problem scoping behaviors such as familiarizing with materials and understanding the problem. Those dyads that didn't engage in this problem scoping behavior early tended to be frustrated with where to begin. It was also interesting to note that the parent assisted more with the Dado Squares than with the foam blocks in the preschool setting.

Idea Generation encompasses several different engineering behaviors such as idea formulation, brainstorming, planning, and the decision making process. We had originally separated out these different activities, but found that they overlap without clear boundaries. We did notice that the younger children in the preschool activities participated in planning, though it was in a rudimentary form as compared to older children and experts.[17]

Design Evaluation was observed as behavior that identified with the entirety of the design, not just of the separate material pieces (see "material codes" below). Though not as common as the other codes, design evaluation occurred most frequently towards the completion of the activity. However, with the preschool activities, the foam blocks in particular, the children would set additional goals for themselves to complete, such as getting the tower even taller than the goal point or trying to use every single block. In some cases with the pneumatic ball run, the dyads were unable to get a ball from the starting to finish position.

Revision – Research also suggests that experts tend to engage in more iteration that novices – both in terms of cognitive iterations (movements between different design activities—that is, spending time defining the problem, then working out details of the solution, then going back to reconsider how the problem is defined) and in terms of number of versions of the solution.[18]
In the preschool program, we also see variation in the number of different versions of the towers different families completed, as well as "movement" between different design activities (e.g. problem definition and solution detailing). This was also evident in the pneumatic ball run, as dyads frequently "tweaked" different sections both prior to and after testing. Finally, the recent NAE report on K-12 Engineering suggests that optimization is a key aspect of engineering that differentiates engineering from science.[19] Preliminary analysis of our video data shows that children engage in optimization strategies as part of their design-build processes, such as trying to minimize the amount of space between the different shapes (trying to fit shapes together like a puzzle while building the tower with foam blocks) or in other cases trying to maximize the amount of space between shapes (to make use of negative space to create a taller tower).

Testing was more prevalent in pneumatic ball run than with the building activities in the preschool program potentially due to the instantaneous feedback (i.e. it falls) when building the different tower. Testing with the pneumatic ball run occurred both at a segment level as well as the complete run. Also with the pneumatic ball run, if the child actively engaged in modeling (i.e. creating the ball run), often the parent would be the one to physically "test" the run.

Reflection & Prediction were two codes that came up more often than we expected. In both settings, a portion of the children would reflect on a piece of their design, stating how they should do it differently (without actually making that change). Sometimes this would apply to the design itself or even the approach that the dyad took in the design. Prediction also occurred when the child (and sometimes the parent) would extrapolate feedback based upon an intended action.

Material Codes were also a large part of this study. In addition to the material exploration that was included in the problem scoping behaviors, the dyads also evaluated the pieces individually, talked about certain requirements of the materials, and discussed how the materials behave.

Conclusion

We found that children engage in the engineering design process in ways that are similar to other models of engineering design, that include problem scoping, idea generation, evaluation and revision. We also found that children engage in both predictive and reflective behavior, and often add context to the problem. However, we want to acknowledge that the way children engage in engineering thinking is different from the way that adults do (especially with idea generation and revision).

Children are participating in design as "natural engineers" through self-motivation and through scaffolding from parents. These engineering behaviors are similar to what previous studies have seen with novice and expert engineers[5]. This work lays a foundation for future research, as understanding how children engage in the design process can help us understand how children learn engineering design skills, and how people develop engineering design skills across pre-college, undergraduate, and professional practice. The work also has implications for the development of learning experiences in both school and out-of-school settings as we consider how to teach and facilitate engineering design thinking.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. (HRD-1136253). 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. We would also like to acknowledge the contributions of GRADIENT research team members Zdanna Tranby and Scott Van Cleave, as well as the Science Museum of Minnesota and INSPIRE at Purdue University.

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