Zooming into a Tinkering Project: The Progression of Learning through Transitional Objects

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Cover Page Footnote

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Abstract

The Maker Movement has been received by the field of K–12 education with great enthusiasm as a way of teaching STEM content to children. We call attention to and identify learning opportunities in children's projects created in a playful, informal environment with easily available materials. In keeping with research in the field of maker education and learning sciences, we describe tinkering as a constructionist learning activity in which meaning making is captured through transitional objects (Bamberger, 1995). First, we examine one specific tinkering project and identify transitional objects within the project. Next, we discuss the process of meaning making as captured through the transitional objects and identify the significance of children's emerging views of scientific concepts. Finally, we discuss implications for adopting the concept of transitional objects for capturing children's meaning making and learning in the domains of K–12 science and engineering education.

Keywords: tinkering, learning, maker movement in education, problem solving, technology

Introduction and Background

Recent research in the educational maker movement has focused on makerspaces as learning environments (Halverson & Sheridan, 2014; Litts, 2014), making as a collaborative learning practice (Brahms, 2014), STEM learning through making and tinkering (Bevan, Gutwill, Petrich, & Wilkinson, 2015), and making and tinkering in engineering education (Blikstein, 2013). Like these studies, our work too is based on a constructionist view of learning while creating and sharing artifacts, but instead of investigating making and tinkering in a formal makerspace, we examine children's maker projects created playfully without any predetermined educational agenda. Such informal projects have long been seen as important sources of informal learning about the world and a foundation for naive understandings of scientific concepts (National Research Council, 2007). However, in the rush to adopt making as an educational practice, we have given insufficient attention to these more casual forms of making and their potential, for example, to offer insight into children's evolving intuitions about scientific phenomena. In the following sections, we describe what it means to tinker and more importantly to learn while tinkering with technology, before moving on to build a theoretical framework for studying such learning.

What It Means to Make and Tinker

That humans have always made and tinkering with materials and tools is widely accepted. Making and tinkering, in the context of the recent surge of interest, however, revolve around the use of some newly available technological tools to create projects (for example, Vossoughi & Bevan, 2014; Vossoughi, Hooper, & Escudé, 2016). Such kinds of making and tinkering are richer than mechanical assembly of parts (Vossoughi & Bevan, 2014) and use a combination of technological components like circuits, robotic appendages, and 3D printed components, to name a few, and everyday materials like cardboard, fabric, and plastic. As of 2017, a clear distinction between making and tinkering is yet to be explored in educational research. However, there is consensus

that tinkering is a branch of making that emphasizes impro-visational, bricolage-style problem solving (Bevan, Gutwill, Petrich, & Wilkinson, 2014; Resnick & Rosenbaum, 2013). Tinkering with materials and tools involves playfulness, thinking on one's feet, reflective iterations, continual reassessment of goals, and reimagining possibilities (Resnick & Rosenbaum, 2013). For the purpose of this paper, we describe children's spur-of-the-moment toy building projects as tinkering that emerged in a context of a library tinkering space while messing around with materials and tools.

Tinkering with Technology

Although a common goal of maker education is STEM literacy and fluency, the clear distinction between science, technology, engineering, and math, and the unique affordances of learning through the use of technology has been left unexplored. While science is widely accepted as knowledge of the natural world and technology as human manipulation of the natural world, how one is used to inform the other is key to understanding and utilizing nature and natural elements to solve problems. Learning science through tinkering with technology is not a straightforward process (for example, Cajas, 2001; Seiler, Tobin, & Sokolic, 2001); the difficulty of such learning becomes apparent when we acknowledge that identification of the varied representations of scientific phenomena requires both familiarity and expertise. These issues are rarely explored in the K–12 years, but activities such as tinkering and making might provide children with material, conceptual, and social resources to draw on for an understanding of STEM and the relationship between science and technology. Tinkering with technology, with an understanding of what technologies are based on, as well as differentiated knowledge of their unique affordances and constraints, can help us address this gap in STEM education. How to further develop this possibility is a rich research topic.

Theoretically Framing Learning While Tinkering with Technology

We propose a study of learning while making and tinkering through *making meaning* (Schwartz & Bransford, 1998; Sawyer, 2003; Schoenfeld, 1998; Schön, 1992). Children's making and tinkering projects sometimes are taken up to duplicate a standardized and already successful plan (like loom bands), while others satiate a spur-of-the-moment creative urge, and yet others are invented accidentally while handling materials and tools. These projects are the outcomes of different trajectories, serve a range of purposes, and are unique as learning opportunities; problem solving with loom bands is quite different from problem solving with glue. Emerging design plans result in artifacts and meaning. Accordingly, in this

analysis, we narrow our focus to the role of *meaning making* as reflected in the process through which projects emerge in children's engagement with informal maker projects.

Our analysis is informed broadly by Resnick's (2007) concept of the creative learning loop that connects steps of the process of making—imagining, creating, playing, sharing, and reflecting. These steps inform each other like feedback loops in which observations from one action feed into a decision about a later action. Building on the work of Schön (1983), such reflection can take place during as well as after the process of making and is prompted by action on components of the design situation, such as materials and tools. Our purpose is to define and explore the nature of *transitional objects* as instantiations of children's thinking and as objects for reflection during the process of making and learning.

Transitional objects (Bamberger & Schön, 1983) are intermediaries in the process of meaning making within a design situation. Each project has a number of transitional objects that capture the outcome of actions and feedback in the process of making and tinkering. The importance of transitional objects is revealed once we acknowledge that experts and adults are aware of how things work and avoid making unconventional choices, but children are unaware of conventional uses or common knowledge in particular disciplines and may interpret problems in different ways (Bamberger, 1995). Transitional objects are reference entities that demonstrate a child's meaning making process; tracking transitional objects reveals to us the children's reasoning, meaning making, and learning progression, which simply looking at maker projects does not. Children's projects and meaning making while making and tinkering might seem inconspicuous to observers; transitional objects reveal why the overall outcome is not.

The effect of meaning making is seen in further actions on the artifact, and we see this as the feedback loop. From the moment an idea is conceived, it passes through several phases of change until a final form is decided upon by the maker and all further progress is temporarily stalled. To understand the process of learning while making we focus on the process of making an artifact, making meaning, and the transition of both the artifact and meaning.

We see each project as consisting of multiple frames (Berger & Luckmann, 1966). Meaning is constructed by the maker in each frame and is temporarily frozen; the form that the project assumes in each frame is seen as a transitional object. Tracking transitional objects reveals the evolution of projects through feedback loops and ways in which naive understanding is manifested through choice of and action on materials and tools. A log of meaning making reveals the ways in which children interpret and respond to these manifestations. Although the nature of development of conceptual understanding of scientific concepts in children is debated,

research shows that early understanding is important. The ability to combine formally and informally acquired knowledge to build on constructed understandings is important, and people who understand science better have more differentiated knowledge instead of knowing more content (Atran, Medin, & Ross, 2004; National Research Council, 2007).

Methodology

We framed our study as a design experiment (Cobb, Confrey, Lehrer, & Schauble, 2003) meant to explore the practical and theoretical implications of learning while making. We avoided using any of the maker movement–related recent advanced technologies like 3D printers, robotics kits, or microcontrollers, and instead used everyday materials, art and craft supplies, and broken toys, and created an atmosphere of playful making and tinkering. Our personal and professional experiences, backed by ample research in art education (for example, Burton, 2000; Burton, Horowitz, & Abeles, 2000), prompted us to believe that children are naturally prolific makers and tinkerers and that plentiful learning opportunities arise through engagement in these activities without explicit ties to instruction and educational goals.

Setting and Participants

Our research site was a children's play space in a public library in the Southwest and not a formal makerspace. We called it a pop-up makerspace and made use of a cart full of supplies, odds and ends like bottle caps, ice cream cups, cardboard tubes, a tub full of discarded, broken toys, and a work table. Ninety-minute sessions were offered twice a month during the school year and were based on a general theme, like toys that move or fly. Participants were asked to make toys related to the theme, and they were allowed to take them home after the session. Over two years of the program, 216 children (106 girls and 110 boys) between the ages of 4 and 12 participated in the sessions. Some children attended only one session while others came to multiple sessions. Some adults who accompanied children to the sessions participated in tinkering alongside the children, while others observed or left to pursue other activities in the library. Adult participation took varied forms; we are exploring adult-child collaboration in a separate analysis and will not discuss it further in this paper. Consent was requested from all accompanying adults, and assent from the children. We protect their identities by using pseudonyms for all participants.

Data Collection and Analysis

We recorded ethnographic field notes throughout the duration of each workshop and captured the progression of tinkering projects through photographs, brief video clips, and conversations with participants. Participants were asked to describe their projects and explain their choice of materials, tools, and processes. We have been analyzing data from the sessions in several ways, exploring in detail the evolution of individual children's design processes and understandings, as well as examining the role of various contextual factors, such as participant interactions, in the dynamics of learning during the sessions. For the purpose of this paper, we use a case drawn from microgenetic analyses of children's individual projects, in which we focused on tracing the children's actions, manifestations of their naive understandings of "how things work," and corresponding changes in the designed object(s). In these analyses, we constructed a chronological, or sequence, narrative as our initial interpretation of the data and to provide a rich description of the design process (Lavelli, Pantoja, Hsu, Messinger, & Fogel, 2004). These "explanatory stories" (Polkinghorne, 1995) can stand alone as one aspect of our findings. In a subsequent step, following Lavelli and colleagues (2004), we used the narratives as our data set for further analysis of the role of transitional objects in the children's developing understandings. For each narrative, we identified frames that represent various manifestations of the children's designs and corresponding actions, and used the frames as a basis for discerning the beliefs that informed the children's actions. In a final stage of analysis, not reported here, we are conducting cross-case analyses using a coding scheme intended to reveal potential patterns in activity, beliefs, and the role of transitional objects across the children's projects.

Findings

To demonstrate the role of transitional objects in the process of meaning making, we chose a project created by Kiernan, age 10, who found a dinosaur head in the toy tub and wanted to make a whole dinosaur using other materials from the supplies cart. We chose Kiernan's project among several others because it involved a number of modifications and thus offered particularly rich examples of transitional objects. Additionally, Kiernan was eager to share his insights related to the process of tinkering with us as well as his peers. He spent 70 minutes working on his project and changed his design plan twice. By the end of the 90-minute session, the parts of the toy had fallen apart, upsetting Kieran greatly. He took some extra supplies with him to rebuild the dinosaur at home. We first present our sequence narrative of Kieran's project, including images of transitional objects. Following the narrative, we present our second-stage frame analysis in Table 1.

Kiernan's Design Process

When Kiernan found a dinosaur head in the toy tub, he really wanted to use it in a project. The goal for the session

was to create toys that can fly, so he decided to make a dinosaur with wings that flap. For the body of the dinosaur he chose two paper bowls and glued them together (see Figure 1). He poked a hole at the top of the bowl and inserted the dinosaur head into it. For the wings, he first glued paper plate cutouts to the side of the bowls, replaced them with larger paper plate cutouts folded repeatedly in triangles (see Figure 2), and finally, inspired by another participant's project, built a rubber band–straw–paper plate wing system.

The model for Kiernan's wing system was created by a seven-year-old girl, Zoe. She punctured a plastic ball in two places and inserted a straw through one hole and a paper clip that she untwisted through the other hole. She then attached a paper flag to the paper clip (see Figure 3, next page). When Zoe pushed the straw into the ball, it struck the paper clip and created the appearance that the flag was being waved. Humorously, she called her creation Orangeade, saying, "It does have an orange head, now say it real fast, get it?"

Instead of a using a paper clip, Kieran cut a rubber band and stretched it out like a string. He attached a straw to the middle point of the rubber band (see Figure 4, next page).

Kieran took the paper wings off his model and tied each end of the rubber band to a wing. He punched holes in the paper cup arrangement—one at the bottom for the straw to pass through, one hole on two opposite sides of the bowl where the wings are. Next, he pulled the ends of the rubber band through the holes on each side and tied them to each wing. When he pulled the straw gently, the wings flapped.

While trying to make the wings flap better (see Figure 5, next page), similar to the project that inspired him, Kieran pulled the straw with great force and the paper plate wings

were ripped off. When asked, he described three main reasons for this failure:

1. The wings of his dinosaur were longer than the wings on the model.
2. His dinosaur had a paper body, while the other toy had a plastic body and was sturdier.
3. Paper clips work better as a part of the wing system than rubber bands. Paper clips don't wiggle much themselves, unlike rubber bands.

According to Kieran, the rubber band itself moved so much that it could not force the wings to move sufficiently, which was the key difference between Zoe's project and his own. In Zoe's project, the wing system was supported by a straightened paper clip with a straw attached to the center;

Figure 2. Transition objects with designs for wings. (a) Paper plate cutouts as wings with one fold to be glued onto the body. (b) Paper cutouts with four folds. One fold is still used to glue the wing onto the body, but the subsequent folds are meant to give the effect of a flapping wing.

Figure 1. The first transitional object—a dinosaur head on paper bowls. The hole on the side of the bowl is where the head was initially inserted.
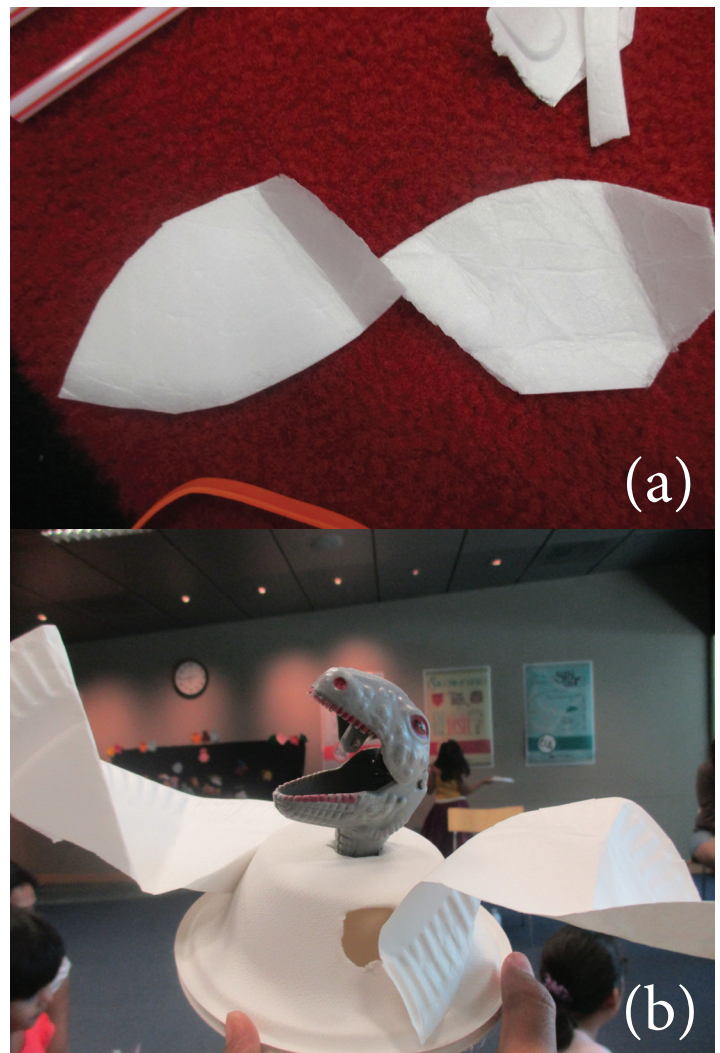
Figure 3. The original wing system—Zoe's Orangeade.

Figure 4. Rubber band and straw wing system that replaced the folded paper plate wings.

when the straw was tugged the paper clip moved as well while the rubber band wiggled. Kiernan's observation was tied to the transitional object that used the new wing system. As he modified his project, giving rise to more transitional objects, the basic structure of the dinosaur remained the same but the wing system kept failing in spite of several modifications. There were several problems in his design, but Kiernan saw the wiggling rubber band as the biggest problem. Through modifications of the wing system, Kiernan authored knowledge for himself—rubber bands and metal wires do not transfer motion in the same way. While a metal paper clip does not move much itself and transfers motion efficiently, the rubber band itself moves too much. He was unaware of the molecular structure of rubber and steel, or the basis of transfer of energy transfer through matter, but he built a naive understanding of the phenomenon through his experimentation.

Transitional Objects as Frames for Meaning Making

Our analysis of the evolution of Kiernan's project and his emerging understanding of scientific phenomena are presented in Table 1. Similar to the approach taken by Bamberger and Schön (1983), we looked for markers in his process of "something new happening" (p. 68) that reflect a shift in how he was making meaning of the problem at hand. We identified five such phases, or frames, in Kiernan's project, each associated with a transitional object and a set of intentions and actions. For each of these frames, we sought to discern evidence of Kiernan's evolving beliefs and assumptions. The latter category is admittedly provisional since these beliefs typically were implicit, and Kiernan did not necessarily have the language to articulate his sense-making process, at least in scientific terms. It is these beliefs and understandings, we argue, that can serve as a basis for

Figure 5. The final transitional object with the rubber band, straw, paper wing system.

more formal science instruction, if they are recognized and recruited by educators.

The initial phase of Kiernan's project was defined by his discovery of the dinosaur head, and how it prompted him to reinterpret the more general problem of "create a toy that can fly" as "create a flying dinosaur." This initial framing of the problem served as an overarching frame for Kiernan's project as a whole, and can be seen as particularly relevant in his first attempt to make a body for the dinosaur. He chose paper bowls as the material with which to create the dinosaur's body primarily due to their size and shape; when glued together they seemed to Kiernan to be a reasonable body size in relation to the dinosaur head. When he first positioned the head, he was mainly concerned with appearance and how closely his

construction represented his sense of what a dinosaur should look like (not like a duck). However, when he sought to reposition the head, another property of the bowls became relevant and "visible"—their ability to support the head. As Bamberger and Schön (1983) suggest, a shift in goals and the use of materials can "liberate" new features or properties of these materials as they become salient to the task at hand. Aspects of transitional objects, like the placement of the head on Kiernan's dinosaur body, can serve as *reference entities*; these reference entities stand for an emergent property or relationship among elements that is recognized but not yet formally named or defined during the making process (Bamberger & Schön, p. 71).

The significance of Kiernan's conceptualization of the design problem as creating a flying dinosaur continues to be apparent in subsequent phases of his design work. His initial construction of wings for the dinosaur (Transitional Object #2) was again based primarily on appearance; that is, he created wings of a size and shape that looked appropriate for his dinosaur, with attention to how they would be attached to the body but with little consideration of other features of wings that might be salient. When he tested the wings, however, they did not flap—a feature that, in Kiernan's vision of a flying dinosaur, was crucial. For Kiernan, flying dinosaurs must have wings that flap; they don't just glide, nor do they have wings like an airplane, which are fixed. He created new

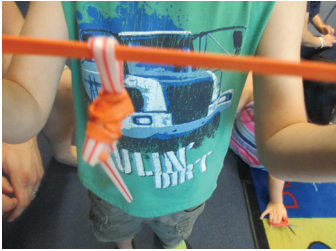*Table 1.* Transitional objects and frames for understanding.

Transitional Object	Description	Intentions and Actions	Problems Encountered by Kiernan
Transitional Object 1	A dinosaur head on paper bowls	Kiernan wanted to create a body for the dinosaur head. He glued two paper bowls to each other. He first cut a hole in the side of the top bowl for the head, but thought it looked more like a duck than a dinosaur. He moved the head to the top of the bowl, but had to adjust its position to keep it balanced.	Balancing a heavy dinosaur head on very light paper bowls proved to be difficult. Kiernan felt a shift in the center of gravity when he moved the head and intuitively used this feeling to adjust the head's placement.
Transitional Object 2	The initial set of Styrofoam wings, with single folds for the purpose of attachment only	Kiernan wants to make a dinosaur that can fly to find food. He cuts two pieces of Styrofoam into wings. He folds one side of each wing to create a surface for glue. Kiernan glues the wings to the sides of the bowls. He runs while holding the dinosaur and the wings don't move much. He wants the wings to flap, so he decides to change his design.	Kiernan needed to identify an appropriate surface size for attaching the wings. His initial design had a wingspan that looked appropriate but did not allow adequate flapping of wings without the use of thrust.
Transitional Object 3	Larger and more elaborately folded wings	Kiernan removes the original wings. He chooses paper plates cut in half and folds each half repeatedly in triangles. He attaches the new, larger wings. When he runs with the improved model of the dinosaur, the wings flap.	The larger wingspan and the folds made the effect of the flap more visible.

Table 1, cont'd. Transitional objects and frames for understanding.

Transitional Object	Description	Intentions and Actions	Problems Encountered by Kiernan
Transitional Object 4	The rubber band and straw wing system 	Kiernan moves around the space to share his design with other young tinkerers. He is very proud of his flying dinosaur and lets others play with it. He too plays with other children's toys, and encounters Zoe's project that uses a straw and untwisted paperclips to move a flag. Kiernan wants to try this design. He cuts a rubber band and stretches it like a string. He attaches a straw to the middle point of the rubber band. Next, he takes the paper wings off his model and ties each end of the rubber band to each wing. He punches holes in the paper cup arrangement—one at the bottom for the straw to pass through, one hole on two opposite sides of the bowl where the wings are. The ends of the rubber band pass through the holes on each side and are tied to the wings.	This modification introduces thrust to his design, similar to bird wings with muscle-powered thrust. Kiernan is primarily interested, however, in creating a more realistic flapping movement.
Transitional Object 5	The last flying dinosaur created in the session, moments before it falls 	When Kiernan pulls the straw gently, the wings move a little bit. Trying to make the wings flap better, he pulls the straw really hard and the contraption falls apart. The rest of the dinosaur is full of holes from repeated modifications and only the plastic head can be salvaged. Kiernan plans to use a paper clip contraption for future wing-related projects, and takes home more materials.	Testing Kiernan's model allows a comparison of rubber bands versus paper clips as a means of transmitting energy. The composition of a material affects how energy moves through it, and how it responds to external forces like a pull.

wings that were longer and had folds (Transitional Object #3), and these wings did flap when he ran while holding aloft the new version of the dinosaur. Again, the features of the wings served as reference entities for properties of wings and flight that Kiernan cannot yet put into words. Notably, he combined a focus on appearance—creating folds that represent the action of flapping—with a focus on function, by creating longer wings in the hope that they would move more noticeably. This is a rather significant shift, since the meaning of wings for Kiernan, at least in this project, is defined by what they can do as well as how they look.

In his next design phase, Kiernan was inspired by Zoe's project. He shifted from a process largely dependent on materials-based reasoning to a more example-based reasoning

approach (Worsley & Blikstein, 2016). For another person, Zoe's flag-waving Orangeade figure might seem to have little relevance to the design of a flying dinosaur, but for Kiernan, it prompted a spontaneous insight into the mechanics of flapping wings. While he didn't copy Zoe's design with the same materials, he used approximations of her design to create a mechanism that made his dinosaur wings flap through thrust, evident in Transitional Objects #4 and #5. Once again, the attributes of the rubber band and straw construction became reference entities, instantiating his implicit understanding of how the mechanism created force to move the wings. Differences in the properties of rubber bands versus paper clips didn't become visible to Kiernan until he tried to make the wings flap more powerfully, and

discovered that "wiggling" makes rubber bands less effective in achieving the desired flapping effect.

If we considered only Kiernan's initial goal and the collapse of his final design, we might have considered his project a failure and questioned what, if anything, he learned from the process. However, by identifying and tracing the evolution of transitional objects in his design process, we can see how his understandings of materials and their properties changed, and just as importantly, the potential of these shifts in understanding as opportunities for the introduction of more formal scientific and engineering principles. In particular, Kiernan started to "see" materials and designs in different ways, shifting his attention from surface features to their potential for specific functions within the framework of meanings that he constructed through his project.

Discussion

In the context of the excitement around making and tinkering, we argue that while the increased availability of maker tools has facilitated children's participation in activities that require advanced skills, activities such as making and tinkering in simpler, more playful contexts can enable children to engage in foundational STEM learning. Even in activities with loosely defined and open-ended design goals like those we describe here, the creativity, innovation, and problem solving with design and materials demonstrated by the children are conducive to the teaching and learning of engineering habits of mind, among other goals (see, for example, Lucas & Hanson, 2016). These forms of making offer opportunities for K–12 educators to provide authentic experiences that engage students in the practices of engineering and engineering design without the need for costly equipment or training (Blikstein, 2013; Honey & Kanter, 2013; Martin, 2015; Vossoughi & Bevan, 2014; Worsley & Blikstein, 2017). More specifically, we can identify the value of greater attention to *transitional objects* in two core areas: first, in making more explicit the merits of playful tinkering with a variety of easily available materials as a STEM-rich learning activity (Bevan et al., 2015), and second, in demonstrating how such activities can be useful in the K–12 pre-engineering curriculum.

Playful STEM-Rich Tinkering

The process through which children playfully tinker is analogous to the design process (Resnick, 2006). Learning while constructing, debating, evaluating alternative solutions, and responding to failure, within the unique context of a concrete situation, problem, and approach is a rich, multidimensional experience (Lehrer, Schauble, Carpenter, & Penner, 2000). Owing to its playful, exploratory, and experimental nature, tinkering nurtures a "what if" orientation and can introduce

children to the kinds of causal explanations and procedures used to answer scientific questions (Callanan & Jipson, 2001). This orientation is readily apparent in Kiernan's project, as he experimented with different placements of the dinosaur head, modified the size and shape of the wings, and ultimately adapted Zoe's model for his own design. Identifying learning in such scenarios is difficult, in part because children might not be able to articulate their design aspirations or what motivates the "what ifs"; aspects of their idea generation, testing, and refinement process might remain hidden from mentors. Transitional objects make some of these attributes visible and, hence, lend themselves to efforts to document the nature of learning while tinkering. For example, naive scientific understandings such as Kiernan's understanding of the design of the paper plate wing system and its role in the resulting effect play a significant role in children's science learning. Tracking his transitional objects, we can see that Kiernan used paper and rubber bands in different ways—paper bowls formed the base of the T-Rex structure as well the flapping wings, rubber bands were used to tie things together as well as to hold wings together and yet maintain a taut stretch with enough tension. The iterations of his design also show that he struggled with the use of rubber bands in the design. We understand and acknowledge the difficulties that lie in making sense of the flow and transformation of energy in rubber bands or the polymeric nature of the structure of rubber in rubber bands for children of Kiernan's age, but would like to draw attention to the importance of such experiences for future science learning. Conceptual learning may be facilitated by teachers and other mentors through identifying, supporting, and building on children's concrete and differentiated experiences with materials in design projects that extend across formal and informal learning situations.

For now, we cannot claim that Kiernan learned specific science content through this experience but would like to point to what diSessa (2004, p. 294) calls a child's native capacities. Such capacities enable children to create and re-create flexible and fluid forms of representation that are independent of instruction (diSessa & Sherin, 2000). Research in the area of metarepresentational competence (see, for example, diSessa, 2004; Lehrer & Schauble, 2006) suggests that if Kiernan prefers rubber bands to create wing systems, his representation of the T-Rex's wings will provide a basis for and shape his science learning and reasoning. Developing a repertoire of designs around the behavior of rubber bands in a wing system might enable Kiernan to more deeply appreciate their qualities and apply this more nuanced understanding to future tinkering projects.

From Playful Tinkering to K–12 Engineering

Design activities such as tinkering, owing to their highly iterative nature and focus on problem solving, are widely

advocated as an approach to teach engineering skills (Committee on K–12 Engineering Education, 2009; National Research Council, 1998). It is well accepted that the field of engineering encompasses a lot more than content and calculations. Making sense of complex problems to create solutions (National Academy of Engineering, 2008), various habits of mind (values, attitudes, and thinking skills associated with engineering), and the broad pursuit of making things work better are all included in the domain of engineering (Committee on K–12 Engineering Education, 2009). For children, design processes like the design loop can be seen in tinkering and play (Resnick, 2007) and can be a suitable domain for K–12 engineering curricula. Tinkering and making as design-based activities could be appealing means of engaging children in engineering skills such as critical thinking and problem solving, communication, collaboration, and creativity and innovation (Martin, 2015; Vossoughi & Bevan, 2014; Worsley & Blikstein, 2017). For example, Kiernan's design process included several iterations during which he tried to understand problems in his design; brainstorm solutions; explore the implications of solutions; create, test, and evaluate prototypes; and test, iterate, and refine them. The transitional objects that we identified reflect this process. Students' transitional objects in general can be leveraged by mentors in two ways. One way is instructional: to demonstrate the iterative nature of engineering design, to promote collaborative problem solving, to foster a systems view of design projects, and to encourage the pursuit of improving on existing designs of toys and other familiar artifacts. A second use is for assessment: to document and evaluate children's progress and learning through tinkering.

Conclusion

In this paper, we have attempted to demonstrate the potential value of paying closer attention to transitional objects as evidence of children's evolving understanding in making and tinkering projects. Using transitional objects from a single case of one child's project, we illustrate the varied opportunities for STEM learning through children's self-directed tinkering with everyday materials. Not all tinkering projects will offer such potentially rich possibilities for learning, but we suggest that transitional objects offer a means of refocusing our attention as educators and scholars on children's thinking and insights that might otherwise go unnoticed and unappreciated.

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