Understanding the Practices and the Products of Creativity:

Making and Tinkering Family Program at Informal Learning Environments

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ABSTRACT

This study investigates how families' sociomaterial experiences influence the creative practices of novel idea generation and feasible solution generation and the products during family workshops using littleBits as prototyping tools. We conceptualize creativity as a distributed and materially-grounded activity. Methods are interaction analysis on video-based accounts of 31 families' activities and creativity assessment metrics to analyze the novelty scores of families' products. We take an exploratory approach to understand families' sociomaterial interactions in high and low novelty score groups. Findings illustrate that collaborative idea exchange and ongoing generative tinkering with materials support the emergence of novel ideas and feasible solutions.

CCS CONCEPTS

• Applied computing → Education; Collaborative learning; Interactive learning environments

• Social and professional topics → Informal education; Children

KEYWORDS

Creativity; Engineering Design; Family learning; Informal Learning; Sociomateriality

ACM Reference format:

Soo Hyeon Kim and Heather Toomey Zimmerman. 2019. Understanding the Practices and the Products of Creativity: Making and Tinkering Family Program at Informal Learning Environments. In *Proceedings of IDC 2019, June 12-18, 2019.* Boise, Idaho, USA. 7 pages. https://doi.org/10.1145/3311927.3323117

IDC 2019, June 12-18, 2019, Boise, Idaho USA

ACM ISBN 978-1-4503-6690-8/19/06...$15.00.
DOI: https://doi.org/10.1145/3311927.3323117

1 INTRODUCTION

There is a growing consensus that making and tinkering can provide opportunities to engage in STEM learning [9,19,22,44] and creative problem-solving [8,44] through the use of material and digital fabrication tools. Past studies have examined activities, tools, and interactions that support meaningful making [5,29–31,45]. In particular, making is a gateway to engage learners in creative engineering design [32] as it provides opportunities to solve real-world problems in multifaceted ways in which there are more than one solution [17]. Recently, the field has widened its focus to include the family as an important unit of analysis [11,36]. While many studies highlight the creative process in making, the definition of creativity has not been fully operationalized. Furthermore, the nature of creative making practices and how these practices might be supported, particularly within families, remain unanswered. In our study, we sought to explore the nature of creativity by examining both the novel idea and feasible solution generation practices and the products at a family engineering workshop using littleBits prototyping tools in libraries and a museum.

This study builds upon a growing body of literature on creativity support tools that is concerned with designing and exploring the effectiveness of collaborative ideation systems [16,33,42] and appropriate design of physical tools that support creativity and imagination [12–15]. The majority of these studies define tools as having properties of a technologically-enhanced physical or virtual device. This study adds to this literature by investigating how learners' experiences can support families' creative practices and products. Our research answers the following question: *How do families' sociomaterial experiences influence the creative practices of novel idea generation and feasible solution generation and their creative products in making and tinkering programs at informal learning environments?* Our exploratory study findings suggest that learners' experiences of collaborative idea exchange and ongoing generative tinkering act as sociomaterial *tools* that influence both the creative practices and the products.

2 THEORETICAL FRAMEWORK

2.1 Conceptualization of Creativity

We connect the distributed and sociomaterial views of creativity with the assessment of creative products. We build from these areas to explore the sociomaterial interactional processes of creativity in families.

2.1.1 Creativity as a Distributed and Materially-Grounded Activity. Our study builds upon distributed creativity [37,38] to expand creativity beyond an individual's cognitive outcome and also adopts a material views of creativity [20] that consider the interaction between people and materials. Bridging these two perspectives, we then conceptualize creativity as a distributed and materially-grounded activity that is pertinent and pervasive in everyday life. To explore engineering creativity, we focus on activities that give rise to externalized forms of novel and appropriate ideas or solutions when families address the design problem in engineering workshops.

2.1.2 Creativity as a Product. To assess the products of creativity, we adopted Shah, Vargas-Hernandez, and Smith (SVS) metrics [40]. The SVS metrics acknowledge every idea and solution that learners incorporate into the design stages as meaningful — regardless of how small. With the SVS metrics, novelty is measured as the infrequency of an idea compared to all the ideas present.

2.2 Sociomaterial Facilitators of Creativity

Our work is concerned with exploring how learners' situated experience with the social and the material influence their creative practices and the products. We take a sociomaterial perspective in which the social and the material are neither independent nor interdependent entities [25,34], which resonates with Schön's view of design as a reflective practice that involves engaging in "conversation with the materials in a situation" [39:5]. It also aligns with Ingold's view of reading creativity forwards to attend to the "lines of becoming into texture of material flows" rather than backwards to trace the origin of an artifact to an agent with a design intention [23:96]. In our work, we take the sociomaterial perspective to explore how the sociomaterial is configured in practice and enacted in families' creative practices of idea and solution generation.

We conducted a literature review to anchor our study in relation to previous scholarly work. Given the limited literature at the intersection of making, family learning, and creativity with sociomaterial views, we focused on family informal science learning and making literature to generate conjectures related to learners' sociomaterial experiences that facilitate creativity. Previous work on family science learning showed that dialogic inquiry supports youths and families to sustain understanding, articulate observation, make interpretation, and engage in science practices [1–3,7,24,46]. Within the context of making, scholars have highlighted the importance of maker educator's facilitation moves during children's making practices [10] and advocated future research to articulate the links between the learning dimensions and maker educator's facilitation moves [21]. Deitrick, O'Connell, and Shapiro's [18] study illustrated that collaborative discourse (defined as having instances of accepting and discussing ideas during collaboration) predicted product novelty. Other studies have emphasized the importance of providing tools and materials visibly, accessibly, and abundantly to support participants' interaction and collaboration during making [11,31,35]. In accordance with this body of work, we conjecture that quality of collaborative discourse and collaboration from the family members could potentially influence creativity during the engineering workshops.

3 VIDEO-BASED METHODOLOGY

3.1 Data Collection

This study is part of a three-year design-based research (DBR) project [4] called *STEM Pillars* that supports families with elementary-aged children (6-10 years) to engage in hands-on and inquiry-based STEM learning on five topics. This study focuses on the engineering workshops during the second DBR iteration in 2017. The engineering workshops took place in five libraries and one museum in northeastern United States. It was an hour-long workshop led by two engineers: Maximus and Aimee (pseudonyms). Overall, there were 75 consented participants (42 children; 33 adults). Families were filmed during one-hour workshops using littleBits as prototyping tools. Overall, 33 parent-child pairs' interaction was collected (approximately 21 hours of video data). A few children outside our target age range also participated (i.e., 4, 11, 16 years old); however, the majority of children were 6-10 years old (88.1%).

The engineering workshop was structured by four activities: 1) sharing a story about how the engineer became an engineer, 2) open exploration with littleBits, 3) simple design challenge, 4) complex design challenge. littleBits were distributed during open exploration. The littleBits provided magnetically-connectable electronic blocks with four different color-coded functions. The research team configured our own workshop kit; it was not a commercially purchasable littleBits kit. Each family had a kit that contained a battery, cord, power, bright LED, DC motor, servo, button, fork, screw driver, motor mate, and two wires. (Families with siblings sometimes had two kits.) We also provided craft materials such as scissors, tape, felt, pipe cleaners, construction paper, cardboard, cups, and cupcake liners to create the design examples in simple design challenge. The simple design challenge illustrated four design examples (i.e., lantern, flashlight, tickler, waver) without any instruction. The complex challenge asked families to build an interactive toy for a sick neighbor in the hospital.

3.2 Data Analysis

We conducted the analysis in multiple stages. The unit of analysis was parent-child pair. We first created content logs [27] and invention logs (a graphic overview of products created during a workshop by each parent-child pair) for 33 parent-child pairs that were filmed. Given our approach to explore both the products and the practices, we excluded cases if the final inventions were not completed or families spoke a foreign language. Consequently, we focused on 31 parent-child pairs. Then, we identified the episodes of complex challenge for each parent-child pair; these episodes were transcribed and became the focus of our analytical attention.

First, we assessed 31 parent-child pairs' inventions using the SVS metrics [40]. According to SVS metrics, the creativity is assessed by evaluating the quantity (total number of ideas), variety (a measure of the explored solution space during the idea generation), quality (a measure of how close an idea meets the design specifications), and novelty (a measure of the infrequency of an idea compared to other ideas). In our study, participants generated one type of idea and did not consider design specifications. Thus, we only focused on measuring the novelty following the approach of previous researchers that focused on some of the SVS metrics based on the condition of the design task (e.g., [41,43]).

The purpose of the SVS metrics is to measure the degree of agreeability between the raters given the same rating scheme. Consequently, two raters, the first author of this paper and an instructor at the college of engineering at a public university with five years of creativity rating experience, collaboratively established the rating scheme. Both raters had prior training on the rating process and experience using the SVS metrics in research. Two raters followed the feature tree approach developed by Shah et al. [40]. The feature tree had four levels: 1) purpose, 2) electronics, 3) craft materials, 4) embodiment. The weights for each level were as follows: f_1= 0.4, f_2= 0.2, f_3= 0.2, f_4= 0.2. The feature tree uses the novelty of individual feature to compute the feature novelty, f_i. If a feature is frequently incorporated in other inventions, the feature novelty score will be lower. We used the equation (1) to calculate the feature novelty (T is the total number of inventions in the data set and C_i is the total number of inventions that incorporated the feature i).

$$f_i = \frac{T - C_i}{T} \quad (1)$$

We computed the novelty of each invention using the equation (2). The novelty of the jth invention in the dataset, D_j, is calculated as the ratio between the sum of the feature novelty (f_i) and the sum of f_i in an invention. Two raters individually rated 31 inventions using the feature tree. The Cohen's Kappa (inter-rater reliability) was 0.867.

$$D_j = \frac{\Sigma f_k}{\Sigma f_i} \quad (2)$$

The 31 inventions were categorized into four groups based on their novelty scores to strategically sample family cases from low and high novelty score groups to compare their sociomaterial interaction. SVS results showed that families' inventions were skewed toward low novelty score (low: n=17, medium-low: n= 10, medium-high: n=2, high: n=2). This study took an exploratory approach with a goal to formulate a conjecture for future investigation, and sampled all 17 cases from the low novelty group and 2 cases from the high novelty group for further analysis.

The next level of analysis used interaction analysis [28] to explore the families' sociomaterial interaction in high and low novelty score groups during idea and solution generation. Bringing the transcriptions to a qualitative data analysis software called ATLAS.ti, the first author identified moments when a family experienced an idea spark on what to design and solution spark on how to feasibly translate the idea into a solution. Initially, we planned to attend to the parent-child collaborative discourse and use of materials around these moments and employ open-coding to characterize families' sociomaterial interaction. However, many family cases in the low novelty score group created something similar to what they designed during the simple design challenge. As families continued with a similar design, the moments of idea and solution sparks were often quick or missing as they were already familiar with how to create the design. For two family cases in the high novelty group, the first author created additional analytical accounts given the multiple instances of idea and solution sparks. Each analytical account provided a timeline of the family's design trajectory with texts and screenshots from the video-records to describe the family members' discourse, gestures, and use of tools around each moment of idea and solution spark. The first author held multiple video-viewing sessions with the second author as well as other researchers where videos and transcripts of preliminary findings were shared. The research team met to discuss and review emergent trends over multiple sessions to confirm findings. In this paper, we focus on two overarching categories of sociomaterial interactions that influenced novel idea generation and feasible solution generation.

4 DATA AND FINDINGS

Our analysis illustrates that collaborative idea exchange and ongoing generative tinkering with materials supported the emergence of novel ideas and feasible solutions. Families in the low novelty group lacked collaborative sharing or improvisatory tinkering as they engaged in straight-forward design pathways with clear design goals. We present key patterns of families' sociomaterial interaction in high and low novelty score groups by presenting two cases—Louise from the high novelty group and Aaron from the low novelty group—that illustrate our findings.

4.1 High Novelty Score Group

Our analysis illustrated that novel ideas and feasible solutions emerged through collaborative idea exchange and ongoing generative tinkering with materials in the two cases in the high novelty score group. We present an excerpt from Louise (10 years) and her mother who created a mood maker that gives light and shows different emotions. Prior to complex challenge, they designed a waver, a flashlight, and a drawing robot. The drawing robot was not included as an example. They connected a crayon at the end of a straw and connected it to a motor to create a drawing robot. When complex challenge was introduced, Louise and her mom expressed enhancing their original design, by adding more crayons to the drawing robot for their final invention: "We decided to make a little drawing buddy…make a moving multiple colors." However, as we will demonstrate in the episode below, this initial design idea of a drawing buddy evolved into a mood maker through multiple instances of idea exchange and tinkering with materials.

This episode occurred after the family created a drawing buddy with multiple crayons but through testing, found it was too heavy. As a result, their first prototype fell apart. Observing that their drawing robot was too heavy, Louise tinkered with the flashlight that they previously made.

Louise: We need one of these … Where's the
flashlight? Flash-flashlight, we need the flash-
flashlight. Wait, wait, there we go.
((points flashlight at paper and observes))
Hey, I've got an idea!
Mom: Oh, a little show? A little puppet show that
you see shadows? Hey! What if we just put
like ((brings the drawing robot on the paper))
paper shadows, in the thingy? How do we get
the shadow? ((folds paper))
Both: ((discuss about how to create shadow))
Mom: ((takes a waver created with a pipe cleaner))
That's gonna be a turkey man, and then you're
gonna do a shadow. And we're gonna do a
shadow show, a shadow show, right? With
the thingy, there's a thingy that moves, here.

As Louise pointed the flashlight towards a piece of paper (line 4), a new idea emerged (line 5). Mom, who observed Louise pointing the flashlight towards the paper, asked if Louise was thinking of making a show (line 6). Mom excitedly expanded this idea into a puppet shadow show (line 6-7) by putting their drawing robot underneath a piece of paper to create shadows (line 8). After noticing their waver made out of a pipe cleaner (line 12), mom changed the shape of the hand into a different shape, which she referred to as "a turkey man" (line 13) that could move to create shadows (line 16). As such, the sociomaterial interaction (i.e., pointing the flashlight towards paper, bringing drawing robot on the paper to create shadows, changing the shape of the pipe cleaner into a turkey man) was pivotal in novel idea generation. After this episode, Louise and mom tested if puppet shadow show was feasibly working. Noticing that the paper was turning too quickly to capture any shadows from the flashlight, Louise and mom experienced similar episodes of idea and solution generation that inspired them to draw happy, sad, and mad faces on the paper to represent different moods (Figure 1). As such, the design of the mood maker emerged through an unexpected turn of events, which resulted from collaboratively exchanging ideas and continuously testing and tinkering with materials to problem solve issues.

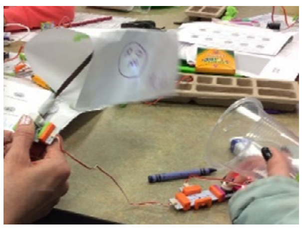

Figure 1. The mood maker by Louise (10 years) and mom.

Although Louise's family started with one design goal, they allowed new inspirations to guide their design process as they worked closely with the materials around them. Louise's case illustrates how the social and the material were closely linked— their tinkering with readily available materials created new meanings for the materials and the meanings changed as the family engaged in new practices. In this regard, the creative practices of idea and solution generation cannot be attributed to the learners alone; their creative intentions were mutually influenced by their "conversation with the materials"[39:5]. We saw a similar pattern in the other family with a high novelty score. As such, our finding illuminates how novel ideas and solutions emerged as learners collaboratively engaged in idea exchange and generative tinkering with materials.

4.2 Low Novelty Score Group

In contrast, our analysis illustrates a pattern among 17 low novelty score groups in which learners did not engage in improvisatory tinkering with materials or collaborative idea exchange. We present Aaron's case to highlight this difference. Aaron (8 years) came to the workshop with his dad, Nicholas. Similar to other parents, Nicholas read the descriptions on the challenge handout and asked prompting questions to help his son brainstorm ideas. This excerpt illustrates the way Aaron and his dad engaged in idea generation.

01	Dad:	Well go ahead. What kind of toy do you want
02		to make? What's it gonna be?
03	Aaron:	Let me get, I will ask for some ((motions
04		airplane wings with two arms))
05	Dad:	Huh? What is it?
06	Aaron:	You can tell. ((motions airplane and hums))
07	Dad:	An airplane?
08	Aaron:	Yeah.
09	Dad:	Okay, well, go ahead.

When dad asked what he wanted to make (line 1-2), Aaron immediately generated the idea of an airplane (line 3-4, 6) and did not generate further ideas. Instead, they began their design process with a clear goal in mind (line 7-9). This episode highlights the limited collaborative idea exchange and a straight-forward design process that were visible in low novelty score groups.

Analysis also demonstrated that families in the low novelty score group worked with a limited number of littleBits and craft materials; as families engaged in design with clear goals in mind, they also had clear materials in mind. Screenshots of Aaron's family during complex challenge illustrate the consistent use of one type of material to create their invention (Figure 2).

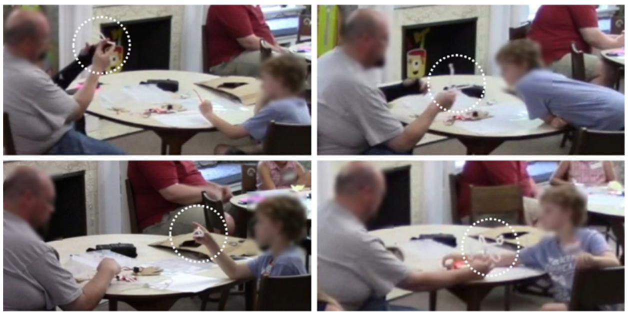

Figure 2. The use of one type of material by Aaron (8 years) and dad. The dotted white circle highlights the pipe cleaner that the family continued to use to create their invention.

Overall, Aaron's family had limited material interaction — they worked with one type of material (i.e. pipe cleaner) to create all the product features of an airplane and only incorporated the littleBits motor to create the turning movement. This case highlights the common pattern among the low novelty score group in which learners did not engage in improvisatory tinkering with multiple materials.

5 DISCUSSION

Our findings have theoretical and practical implications for researchers and educators. While there are multiple definitions of creativity, our study adopted the distributed and sociomaterial views of creativity and demonstrated how creativity becomes manifested through mutually constitutive practices of collaborative idea exchange and ongoing generative tinkering with materials. Creative ideas and solutions emerged when learners experienced moment-to-moment evolving interaction with social and material resources. Our work brings empirical grounding to the growing conversation on creativity as a socially-distributed [37,38] and materially-grounded activity [20] rather than an accumulation of individual cognitive outcomes, and highlights the reciprocal sociomaterial relationship in which evolving practices between the learners and the materials inform the creative practices [23,26,34].

Considering our DBR study, our research suggests implications for the design of engineering workshop curricula for families in libraries and museums. We found that ongoing generative tinkering with materials and collaborative idea exchange allowed for serendipitous moments of unexpected discoveries that consequently supported novel idea generation and feasible solution generation. In alignment with prior literature on family science learning that highlight how learners' everyday situated activities acted as channels for engaging in science learning [6,47], families' everyday practices of exchanging ideas through questioning and dialoguing facilitated families' creative practices of idea and solution generation. Our findings demonstrate the importance of designing for a family experience that gives space and time to allow both the parents and the children to engage in collaborative discourse with one another. Furthermore, study findings suggest that a variety of materials beyond the necessary tools for the purpose of the workshop could potentially facilitate more imagination and creativity. We suggest that practitioners should carefully consider the arrangements of the materials and tools to make it visible and readily available for all learners to engage in ongoing generative tinkering with materials.

This study focused on exploring families' sociomaterial experiences in high and low novelty score groups at intergenerational engineering workshops in informal learning environments. Given that this research was an exploratory study with a small sample size, the study findings are not generalizable. We also recognize that other factors such as families' prior experience and family culture may influence their creative practices; however, it is out of the scope of this paper. Our study provided two cases of high novelty score groups in which collaborative idea exchange and ongoing generative tinkering with materials reciprocally influenced one another in influencing families' idea and solution generation, and 17 cases in which families produced less creative products when these two components were compromised. As such, the findings from this exploratory study suggest a conjecture that the quality of collaborative idea exchange and ongoing generative tinkering with materials in parent-child interaction would influence both families' creative practices of novel idea and feasible solution generation and their products. For future research, we will extend our analysis to look more specifically at the verbal and gestural interactions within family participation structure that open or close opportunities for supporting the development of idea exchange and tinkering with the materials. Finally, we advocate for future research to integrate advancements from creativity research in other fields, such as cognitive sciences and sociocultural psychology, to build a solid base on which theorization of creativity can expand.

ACKNOWLEDGMENTS

We sincerely thank all the participants, experts, and our library and museum partners for permitting the study. The work is supported by the Institute of Museum and Library Services under Grant No.:#MG-77-16-0137-16.

Selection and Participation of Children

Families self-selected to attend the engineering workshops that were advertised by participating libraries and the museum. Researchers explained to incoming adults that the workshop is part of a federally funded research project and will be filming families' interaction; however, their participation is voluntary. Researchers guided them through informed consent form and obtained consents from adults. After parents' consent, children were individually assented. Families who chose not to consent could still attend the workshops by sitting at tables without recording equipment.

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