Summer of Tinkering: Sociocultural Views of Children's Learning

while Tinkering in Social and Material Worlds

by

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ABSTRACT

As interest in making and STEM learning through making and tinkering continue to rise, understanding the nature, process, and benefits of learning STEM through making have become important topics for research. In addition to understanding the basics of learning through making and tinkering, we need to understand these activities, examine their potential benefits, and find out ways to facilitate such learning experiences for all learners with resources that are readily available. This dissertation is a study of children's learning while tinkering inspired by the Educational Maker Movement. It is motivated by the projects that children playfully create with broken toys, art and craft resources, and other found objects, and the connections of such activities to learning. Adopting a sociocultural lens this dissertation examines eight to twelve-year-olds' learning while tinkering in collaboration with friends and family, as well as on their own.

Using a case study methodology and studying interactions and transactions between children, materials, tools, and designs this study involves children learning while tinkering over a week-long workshop as well as over the summer in the Southwest. The three hallmarks of this study are, first, an emphasis on sociocultural nature of the development of tinkering projects; second, an emphasis on meaning making while tinkering with materials, tools, and design, and problem-solving; and third, an examination of the continuation of tinkering using newly acquired tools and skills beyond the duration of the workshop. In doing so, this dissertation contributes to the ongoing discussion of children's playful tinkering, how and why it counts as learning, and STEM learning associated with tinkering. Implications for future learning and the ways in which tinkering connects to children's everyday fabric of activities are considered.

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CHAPTER 1

INTRODUCTION

To think of making as a special kind of activity associated with learning is difficult. By nature, all humans are makers; when have we not made things? Despite the deluge of tools that promise to do away with the need to make things, we continue to find things to make, even learn to make new things. Of course, some of us make more than others, but we make because it is such an integral part of who we are, which is why it is difficult to think of making and learning. How can something so everyday, so pedestrian, be a way of learning? At antipodes from such everyday making is the idea of a special kind of making that only few participate in. Weavers make fabric, potters make pottery, engineers make machines and tools, cartographers make maps; such kind of making requires expertise and skill that few possess. These skills need to be learned, expertise needs to be developed over time.

The Maker Movement, a wave of powerful, easy-to-use technology inspired creation and innovation, challenges this very distinction. First, because of widespread enthusiasm about making and DIY generated by the movement, people (by this I mean lay-people like us) have become aware that things around them have more purpose to them than is commonly perceived. Second, when tried in the right way (and there are *right* ways of doing things) they can replicate these effects and even create new ones. Third, with the right materials and tools, assistance, and the spirit of troubleshooting they can be successful makers. Makers, as participants are called, make artifacts, share designs, and create a shared capital for all to use. Because of the emphasis on tool usage and innovation, a connection to STEM education has been assumed but not proven. Enthusiasm and interest in the Maker Movement has reached far and wide, schools and public libraries have made room for makerspaces for school-age children, maker toys and kits have reached store shelves, and workshops have been offered. It is now time for us to investigate the connection between making and learning.

This dissertation is about what children make, and because children are inquisitive and adventurous, tinker. In the design of the study, I have tried to capture both the everyday and the expert ways of children's activities. I describe their activities as tinkering as opposed to making because they are characterized by meaning-making-on-the-go and the absence of a strict adherence to a goal.

Recommended maker projects for youth are very diverse, and can range from light-up cards, machines that draw, programming musical instruments, and toys from recycled parts (Martin, Panjwani, & Rusk, 2016). Proposed benefits are equally diverse, ranging from increased awareness of the design process and problem solving, to learning to collaborate with peers and experts. While some of these projects require considerable adult assistance and intervention, and are not completely directed by children, others require a set of directions to be followed closely. Although this wide range of activities is described as making by several researchers and practitioners, tinkering has also been addressed as a subset of maker activities (e.g., Gabrielson, 2015; Wilkinson, 2014; Tishman, 2013). I describe tinkering as open ended, playful exploration of materials and tools that follow an emergent plan and position it as an activity that is a rich and authentic learning activity. In the proposed study, I see making as a wide range of activities, include tinkering. I adopt the view that Making needs to be seen as more than 'assembly of parts' (Vossoughi & Bevan, 2014) and normal design (Faulkner, 1994), and should include the iterative process children engage in while creating experimental projects like shoebox guitars and such (Gabrielson, 2015). Such activities are characterized by open-ended exploration of materials and objects readily available in a child's surrounding, and an emergent plan for the object of design. One feature of tinkering activities that make them a great opportunity for learning is the emphasis on solving ill-defined, real-world problems. Since tinkering is playful and does not follow strict directions and plans, problems emerge during the process are difficult to define; the process of *identification* of problems, *finding solutions* to problem, and *choosing a solution,* is a learning opportunity. Additionally, interacting with tools and materials is instrumental to tinkering. Observing how materials respond to actions, what makes tools work, and how both tools and materials can be manipulated may lead to understanding how natural forces, materials and tools respond to human actions. In the context of expert scientific practice, difficulties emerging in such sense-making involving material and human agency in a complex and constrained situation has been studied and described as a mangle (Pickering, 1995). Observing and making sense of situations in which mangles emerge independently as well as in collaboration is important for science learning.

Research on children's learning while making is in its infancy and despite the strong advocacy statements suggesting that making or maker-centered learning experiences lead to STEM proficiency, how such proficiency and learning develops over time has been left unexplored. In fact, Brahms and Crowley (2016), based on content analysis of MAKE Magazine, insist that becoming expert in making does not necessarily involve developing practices that foster expertise in STEM disciplines. The Agency by Design group through their collaboration with practitioners found that maker experiences are valuable because they help students "learn to pursue their own passions and become self-directed learners, proactively seeking out knowledge and resources on their own" (Ryan, Clapp, Ross, &

Tishman, 2016). The outcome of making as an activity takes second place to iterative problem-solving, risk-taking, and using failure as an opportunity. Going through the process of making enables students to see themselves as personal and social agents of change. As David Clifford (as cited in Ryan, Clapp, Ross, & Tishman, 2016) explains, making is not about learning to use tools, but seeing the tools as “catalysts for developing goals.” Although some researchers (for example, Berland, 2016; Kafai, Fields, & Searle, 2014) suggest that making may help students develop interest in design and engineering practices, others explain how making develops students’ identities and dispositions as creative thinkers and problem solvers (Martin & Dixon, 2016), and students’ sense of belonging (DiGiacomo & Gutiérrez, 2016; Vossoughi et al., 2013).

In the field of science education, the constructionist framework has been used to explore students’ learning of physics and engineering concepts (Kolodner et al., 2003) and their engagement in the design process and problem solving (Fortus et al., 2005; Kolodner et al., 2003). In a departure from STEM learning, Halverson (2013) examined the relationship between the art-making process and meta representational competence - an understanding of tools and ideas as reciprocally related, which is a construct valued not just in art making but across STEM fields (diSessa & Sherin, 2000). I use the idea of awareness of affordances and constraints of materials and designs to explore learning.

A summary of the dissertation study

Inspired by the Maker Movement in education and the interest it has generated among educators, librarians, researchers, parents, and children, I set up a small tinkering workshop at a local public library. The goal of this workshop was to encourage children to tinker with broken toys, everyday materials, art and craft supplies, and LEDs and batteries to make new toys to take home. I worked with the kids to create toys they liked, taught them about simple circuits, how to use tools safely, recorded their reactions, and talked informally with their parents. Analysing children's projects from the workshop, their descriptions of their projects, and their tinkering experiences at home, I began to understand the general nature of their tinkering activities. This experience primed me to look for learning in situations of tinkering. Overall, I adopt interaction analysis (Jordan & Henderson, 1995) as an analytic method to emphasize the importance of the interactions between children and materials, tools, and designs in their surroundings, as well as social interactions with friends, family, and mentors. I present one primary project created by each of three children as a case and present modifications of this project as embedded units.

Researchers have explained learning in everyday situations (for example, Dierking & Falk, 1994; Anderson, Lucas, & Ginns, 2003; Luce, Goldman, & Vea, 2016; National Research Council, 2009), learning while doing (for example, Papert, 1983; Osborne & Wittrock, 1983; National Research Council, 2000; cite) long before the Maker Movement came about. This body of literature describes what it is to learn science and math using materials and tools, learning while engaging in a hobby, and learning to think about learning. I use combinations of these ideas to describe what and how children learn while tinkering and making. In the following paragraphs, I will describe the choice of materials and tools, and learning situations and then briefly introduce each of the three chapters of the dissertation, the choice of theoretical framework, and how it contributes to the Current body of research on learning while making and tinkering.

Choice of learning situation. Tinkering, as several tinkerers note, is a preferred sense-making experience for some, inventors are often professional tinkerers. Many scientists, designers, and inventors describe their childhood experiences of tinkering, artists and art educators describe such playful messing around with materials as rich learning experiences for children (for example Bevan et al., 2014; Foege, 2013; Gabrielson, 2015; Resnick & Rosenbaum, 2013). I too tinkered and made a lot of stuff-out-of-stuff throughout childhood and adolescence; my projects ranged from repurposed clothing, redesigned pens and markers, repair of household appliances, and a collection of things so random that they cannot be grouped as a category. These accounts indicate that some children like to tinker as a hobby, some tinker out of curiosity, yet others tinker to explore and that these do not occur in unique moments in their lives, but are in fact, quite everyday in nature and frequency. I intended to study children's tinkering in such everyday situations. Keeping practical requirements of a research study in mind, I studied children's activities in a week-long workshop format of ToyLab, and continued to study two siblings' activities over the summer and beyond.

Choice of materials and tools. Since the study is inspired by children's everyday tinkering and learning that results from it, I used materials and tools that children are familiar with. Although the Maker Movement has facilitated the popularity and spread of use related know-how of some awe-inspiring materials (for example, heat-sensing fabric, pre-made breadboards) and tools (for example, portable vinyl cutters and 3D printers), these are not yet available in an affordable price-range suitable at the local craft store. On the other hand, hardware (home to soldering kits, precision bit sets, a variety of torches and cutters, and circuit components other than LEDs) and craft stores (home to sewing and knitting supplies, a variety of fabrics, glue of different strengths, paint, paper, art and printmaking tools) are. More importantly, more people are familiar with working with them, in fact, glue, paint, and toolboxes are household staples. Such familiarity, as McDermott and Webber (1998) explain, is an important aspect of learning; just like scientists are familiar with what they are working with and architects are familiar with building materials. I use these materials with circuit components to keep with two trends in Current research - high-low tech craft (Beuchley, 2008) and e-textile-circuitry (Kafai, Searle, & Fields, 2014).

A brief overview of the three chapters

In Chapter 2, I describe children's ways of problem solving while tinkering. For this purpose, I adopt a broad constructionist theoretical perspective (Papert, 1983) that frames learning as active meaning making while working with digital and physical constructions. Tinkering projects created by children sit at the intersection of personal and public, physical and intellectual, and enable the navigation of a social dynamic as well. Specifically, I examine how children develop their tinkering projects and solve emerging problems. I choose three cases to discuss, each case is unique in terms of the tinkering and problem-solving process, nature of materials used, and the social interactions that support it. I also look into the nature of children's problem solving while tinkering and their social, material, and intellectual interactions around the projects. I connect findings to research in the area of problem solving while designing and tinkering and consider opportunities for K-12 education.

In Chapter 3, I dive deep into children's meaning making and learning within specific tinkering projects. I use Pickering's (1995) idea of mangle and material puzzles to track children's negotiations with affordances and constraints of materials and designs while tinkering. I choose the same projects as in chapter 2, but explore them in greater depth and include modifications of each project that were created by participants. I discuss the implications of such learning experiences and consider future trajectories for technology education as well as science education.

I draw from a different data-set in Chapter 4, the journey of two brothers through a summer of tinkering. I track the boys' participation over eight weeks and draw on diSessa's (2000) fabric of learning and Azevedo's (2011) lines of practice to describe what influences their tinkering activities and how. Broadly, I consider the connections of their open-ended, free-choice tinkering activities to their other hobby-based activities and their unique socio-cultural context. I discuss the implications of such participation for the boys' future learning activities.

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CHAPTER 2
TINKERING, PROBLEM-SOLVING, AND LEARNING WITH FRIENDS IN A SUMMER WORKSHOP

Tinkering with machines and tools has long been valued as a rich context for learning Science, Technology, Engineering, and Math (STEM) by virtue of its popularity among scientists and engineers like Leonardo da Vinci, Alexander Graham Bell, Barbara McClintock, Richard Feynman, among many who rely on the process. These great scientist and inventors, among several others, emphasize the importance of tinkering in the sense-making process. Even in the field of STEM education, researchers and learning theorists suggest that tinkering is a personally meaningful and rich context to explore a phenomenon, and identify potential problem areas before devising solutions for them (For example, Resnick, Wilensky, Papert). In the context of the recent Maker Movement in education, much has been said about the merits of making and tinkering as a way of STEM learning with Maker Faires and Makerspaces leading the movement with a new generation of technologies and tools. While these technologies and tools are instrumental in bringing a host of manufacturing and modification tools to the lives of artists, tinkerers, crafters, designers, educators, and even families, they are not the only tools we use. This is particularly true of individuals in communities with little or no access to present-day conveniences for reasons ranging from geographic isolation to restrictive finances (Dougherty, 2012; Vossoughi, Escude, & Hooper, 2017). Fixing things and creating alternatives affords individuals a practical education that is often undervalued in formal settings. Tinkering as a hobby might stem from many different needs, for example the need to give material form to an idea, to fix a favorite toy just because it is a favorite, or the need to make something that all the other kids are making; the need for persistence, collaboration, resourcefulness, and exploration of materials and tools, however, remains unchanged. In this paper, I answer two questions related to the process that children engage in while working on tinkering projects based in a tinkering workshop conducted at a local public library Makerspace with children aged six to twelve:

(1) What prompts project ideas, choice of materials, and design decisions when children tinker?

(2) How do children solve problems that arise during the process of design?

I first establish tinkering as a learning activity and build the theoretical foundations of a view of learning while tinkering.

Theoretical Framework

The Maker Movement celebrates thinking critically and looking closely (Tishman, 2016), as well as making sense of complexity, finding opportunity, collaboration, and learning constantly and on the move. Although Maker Movement and activities inspired by it are not explicitly focused on K-12 education or what children are learning, they are associated with the ideas of Dewey's progressivism (1938) and Papert's constructionism (1980, 1993). Making, like learning, is an experience, an experience of making something, creating form and function out of disparate materials. —that encourages a project-based, experiential approach to learning. This approach has reinvigorated the interest in learning through inquiry and doing.

Understanding tinkering as a type of making. Tinkering is a style of making that is playful, exploratory, iterative, and reflective. Tinkering projects begin with making changes to things without committing to one particular form (Resnick & Rosenbaum, 2013).

Learning while tinkering takes place while exploring the consequences of actions, negotiating design aspirations and constraints, and considering possibilities (Bevan et al., 2014; Resnick & Rosenbaum, 2013). The tinkering process is messy, tinkerers tend to situate their calculations and decisions in a particular situation. Within these situations, tinkerers work on emergent goals while they mess around with materials and have "conversations with the material" (Schon, 1983). Based on these interactions, tinkerers adapt and renegotiate their plans based on their interactions with the materials and people they are working with. From scientists to artists, many have described the foundations of their work and ideas in tinkering, but educators are skeptical about its potential learning benefits. Common critiques include focus on creation of artifacts without a clear grasp of underlying STEM concepts, the messiness of the process, and the time required to work on tinkering projects. Given the recent surge of interest in tinkering and its practice in K-12 schools, libraries, and homes, it is time to describe and detail what and how children learn through tinkering. The most notable aspect of the experience of tinkering is the interaction between the tinkerer and his tools and materials (Renick & Rosenbaum, 2013). Through inquiry arising from these interactions, the tinkerer constructs knowledge as opposed to knowledge that is 'just there' (Perkins, 1986), learned previously and recalled and applied in a familiar context.

Research on learning while tinkering. Recent research on learning while making and tinkering is based on a Constructionist framework (Papert, 1980), a modification of Piaget's Constructivism that has been used to describe how children learn using computational tools as well. Within this framework, cognition is situated 'in the head' and 'in the world' bridged and mediated by a construction (Papert, 1993). Learning happens when children make, build knowledge instead of getting knowledge from peers or mentors (Kafai & Resnick, 1996). The understanding that designed artifacts have an existence beyond the material and the intellectual world is not unique to constructionism (for example, Habraken, 1985; Schon, 1983), but constructionist theorists set a precedent for studying virtual and material artifacts designed by children and describing how these objects sit at the "intersection of Cultural presence, embedded knowledge, and the possibility for personal identification" (Papert, 1980). The emphasis on both the individual and social aspects of the construction is clear – once an idea is conceptualized by an individual and expressed through a construction, it is worked out by yet other individual minds in the same context. While individuals tinker in microworlds - interactive, incubator-like learning environments, they work out real-world problems by exploring, constructing, and testing hypotheses (Papert, 1980; Kafai & Resnick, 1996; Kafai 2006). The personal-intellectual aspect of the construction is alive in the microworld where an individual is a builder, a bricoleur, having a conversation with the environment, solving a problem. Both this process and its trace are objects of study (Collins & Brown, 1986).

Methodology

The goal of this chapter is to locate and illustrate children's learning through tinkering while participating in a week-long tinkering workshop. Specifically, I am looking for the process children engage in while tinkering – what prompts their ideas and choices, and how they solve problems that arise. I focus on both the artifact they tinker with as well their participation in the social space as mediated by the artifact.

Setting. The study was conducted as a four-day (two hours a day from Monday to Friday of one week in June) tinkering workshop at a public library during the summer of

2017 for eight children aged between eight and twelve. Pre-registration was required for participating in the workshop and each session lasted two hours. I prepared a general plan that I followed throughout the duration of the workshop. Children were accompanied to the workshop by their parents; parents were not required but welcome to assist their children.

A few large, rectangular, foam covered tables were set up in a large makerspace where four other programs were being offered. Children freely ran to the waiting area at the center to talk to their family and to show them their work. On the tables, supplies stations and personal workstations were set up. Two laptops were positioned at either ends of the tables to record their activities. Two small digital cameras and two android phones were also available. Children were encouraged to take photographs of their creations and record short videos while describing them. Materials provided included: toys, circuit components of tech toys, LEDs, batteries, sticker Copper tape, Sparkfun e-textile LEDs, battery holder, conductive thread, felt pieces, glue, tape, other art and craft paraphernalia. The overall objective of the workshop was to tinker with materials and technologies like electronic components commonly found in toys. Such an objective would make children familiar with what makes their toys work so that they could repair and modify them and even make new ones. One broad design objective was set for each day (details can be found in Table 1) and the sessions began with a ten-minute hands-on lesson on how to create a circuit. The nature of activity was described as free-style tinkering. Children were free to work individually as well in groups and were encouraged to ask for additional supplies to take home to tinker with. All participants created projects at home and later shared pictures and descriptions.

Data Collection and Analysis. To demonstrate both the personal and social aspect of tinkering, I collected data in the form of group video recordings, field notes, and photographs of children's projects. Video recordings of sessions produced far more data than was relevant or even practical for use in analysis. I selected eighteen sections of video that were a broad and representative range of children's participation. Using these, I decomposed the complex events comprising each tinkering session and tracked the emergence and structure of artifacts and events (Lemke, 2000) for further examination. Based on my research questions and theoretical approach of constructionism, I adopted a deductive approach to create the data corpus comprising of tinkering projects and sampled from it to answer each of the sub questions.

I collected video recordings, one for each of the four sessions, each spanning two hours, of children's activity over the course of four days in June 2017. These recordings represent the most visible activities taking place at the tinkering station. All children and their parents gave their full consent to participate in research activities prior to data collection. Following data collection, I began data analysis by creating written summaries of the session, comparative qualities of the data (e.g. nature of project, independent versus collaborative work), and analytic memos (Miles & Huberman, 1994). As mentioned in the theoretical approach that I discussed, following both Habraken and Papert's observation, the goal was to trace the public and private, the social and the intellectual life of a tinkering project. I see the social interactions as manifested in the data sources as comments that children make about each other's projects, questions they ask, collaborations they invite, and gestures like a thumbs-up. I see the private, intellectual life of an artifact as manifested in children's actions, what and how they manipulate, the flow of their actions on a project or its parts, etc. These actions represent what children thought of but did not express in words.

The overall methodology, data collection methods and analytic strategies of this study are guided by a descriptive and interpretive approach (Denzin & Lincoln, 2000). The overall research design is that of a qualitative exploratory case study with embedded units facilitating exploration of a phenomenon within a context using a variety of data sources (Stake, 1995; Yin, 2003). I examine children's tinkering in the context of a library workshop using video data, field notes, and images and short video clips captured by children. Using another affordance of the case study methodology, I present my analysis as well as snippets of participants' unique experiences through their own perspectives (Crabtree & Miller, 1999). With an understanding of participants' views of the nature and design of tinkering projects their actions can be better understood. Both Stake (1995) and Yin (2003) agree that case studies are best suited to the study of subjective human creation of meaning while retaining a notion of objectivity. Pluralism of perspectives and interpretation of events is stressed with focus on both subject, participants, and object, tinkering artifacts (Miller & Crabtree, 1999, p. 10), in the premise of a social construction of reality (Searle, 1995). This is important because we need to develop a general idea of learning while tinkering despite the different methods tinkerers adopt and different design and learning outcomes that result.

The unit of analysis was each participant or participating team like a parent-child duo-project(s) unit within the social and material environment of a single session. I define the operational boundary of each case by participant's experience of tinkering in the space on a given day. For each participant, I tracked every project they worked on, including incomplete projects, and tracked the emergence of the social and personal-intellectual life of their projects in the social and material ecology of the library workshop.

Because of the setting of the study, the unstructured nature of activities, a lot more activity (like general conversation among children, running, stretching, etc.) was recorded than was relevant to answer the questions satisfactorily. Informed by broad framework of constructionism, I identified the ways in which three focal children participated in tinkering workshop while working on their projects. I began with identifying sections of video recordings that represented activity or talk related to tinkering projects. Using these sections and fieldnotes, I recreated children's participation, tracked the progress of each project, and wrote analytic memos about my observations. While tracking the progress of projects, I identified the project initiation (including children talking about an idea before beginning work on it), progress through tinkering, the emergence of problems (both what children identify and don't identify as problems), solving identified problems, and resolution of tinkering related work.

Next, I attached a priori codes representing key ideas representative of the theoretical framework (nature of tinkering activities, seeking help, offering help, collaboration, mediation using tinkering project, problem solving). Further, in a second round of coding, I aligned my findings to codes associated with the theoretical framing i.e. the social interactions mediated by the tinkering projects, learning through interacting with materials, and collaborative problem solving. A general description of this process can be found in Appendix 1 and Table 2. I present each child's participation as a full case (Stake, 2006) with embedded units representing each project they worked on that was inspired by the original case. For practical reasons, I present a maximum of three embedded units per case.

Findings

From among the numerous projects that were created during the session, I chose the following three:

1. A clever and popular project created by Henry (nine years old) who worked alone.
2. A joint project from Glenn (ten years old) and his mother; the child recruited his mother's help but both make important contributions to the project. This project, too, gained instant popularity.
3. A simple and cautious project created Emma (twelve years old).

These three projects cover a range of participation, intensity with respect to design, materials used, tinkering, and what children learnt from it. In the following sections, I first describe each project and its emergence and then discuss general findings as three broad overarching themes that address my research questions.

Glenn and Mom's snap-button circuit

Glenn prepared an initial circuit, then ran away because it was too difficult for him and called mom for help. He didn't show his mom how to complete project, and mom did not know about circuits, so she asked other kids, and then me. She was quick to learn. She sewed a basic circuit and declared that it was difficult, not for kids her son's age because most of them don't know how to sew. Henry and Emma got their circuit to work and helped Glenn's Mom. While Mom worked on the circuit, Glenn went through some of the other materials arranged on the table when he found a snap button set and thought that it could be used in the circuit. He wanted Mom to find out a way to insert the snap-button into the circuit. Unsure of the practical aspects of the idea, Mom asked Glenn to consider details such as where on the project would he like the button, and how would he like to use the button in the design. She asked the other children for ideas, but they had not seen such buttons, ever. At this point, I shared my experience with snap-buttons; I remember wearing dresses with Pony brand snap buttons on the back as a young girl. I remembered that once I had left a dress in the water for a long time and rust had formed on it; the buttons on my dress were probably made of a metal mix. We predicted that it would allow Current to pass through and Glenn said, "Well, sew the circuit *right through it*." Mom did just that, she sewed through each half of the snap-button into each half of the circuit. (The thread connecting the positive ends ran through one half, the thread connecting the negative ends ran through the other half) The buttons could still be snapped together and when Glenn did so, the lights switched off.

Figure 2.1 Glen and Mom's snap-button circuit

The children were stunned; Glenn had no explanation to offer, and neither did Mom. Henry offered an explanation - the Current flows through the buttons in a *circle* when they are snapped and the LEDs do not light up. When unsnapped, Current enters the LEDs and light them up. Ani who was working on her own project and listening in at the same time, explains, "You see, you have to *force* the Current to flow through the LED, if they find a shorter way, they will take it." Glenn likes this creation but runs away to play with something else, and he does not come back. Henry's sister Gillian was a participant in the sewing workshop at the next table, and Henry told her about the circuit that could be buttoned. They decided that they needed to make one for themselves and took some supplies home. Henry had first-hand experience of how much of a nuisance he thought the conductive thread to be, especially for beginners and people in a hurry. They replaced the thread with sticker Copper tape and replicated the design on the inside of a fabric tote bag. Emma gave them an idea and she too wanted to replicate the design for herself, but with an original idea that she saved for when the workshop was over.

Henry's toys that do things

Henry's projects are unique, each of them. The first one we describe here is a DIY Hexbug that went through some iterations to look like a remote-controlled toy. He initially made a Hexbug using a small vibration motor and colorful pipe-cleaners for the body and two LEDs as eyes of the bug. At one point, the bug had a lot of pipe cleaners and moved slowly; Henry tried to manage this problem to help it balance better and go faster. His next problem was that of making the bug move in a direction he wants to, like a remote controlled/robotic toy. There were no tools available to help him do this, so he attached two long Copper tape pieces to the Hexbug and inserted them into two straw Cu outs to keep the wires from touching. He held on to the battery unit to direct the movement of the bug. In another modification of the design, he connected the bug unit with pipe cleaners, this removed the possibility of the wires coming in contact.

Henry's second project used another vibration motor, a wooden clothespin, and straw cutouts to make a mini hand-held fan. The clothespin worked both as casing for the motor-battery unit as well as a switch. He later attached colored feathers to the blades to make a tickle machine+fan combination. His friends at the workshop wanted him to make these changes.

Figure 2.2 Henry’s projects (from left to right): The pretend remote-controlled car; the Hexbug; the clothespin and vibration motor fan.

Emma’s experiments with LEDs, glow, and materials.

Emma was making a circuit. Her father had taken her to STEM workshops where she had heard the word and thought it to be something complicated. Emma worried that she would not be able to make one, or at least get it to work properly to light the LED. Understandably, she was excited to design her first circuit. She requested Henry’s help to make a flashlight and a Hexbug before moving to two independent projects – an origami swan on an illuminated felt pond display for her work desk and an illuminated felt floral corsage. For both projects she used e-textile components. She was very particular about the effects she wanted in her projects – the pond had to look “magical, lit from deep under the water” and the flower had to look “glowing”. She seemed to have memorized the origami swan pattern and figured out a way to Cu petals for her flower corsage. Sewing the circuit, however, was at another level, Emma had no practice sewing. She knew how to sew using the basic ‘run’ but needed help threading the needle and planning a pattern that was need to secure the e-textile components in place. She faced the usual problems with using thread as wires, thread holds things together but also conducts electricity, dual function. Once the circuit works, she began to place felt petals around the light source, found the material too thick, says that she needs to use another material, looks around, but we don't have anything appropriate. She used milk carton cutouts for petals later, colored with acrylic paint, and shaded.

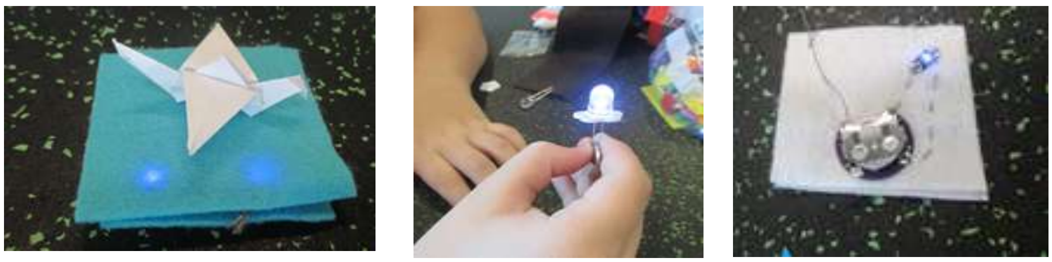

Figure 2.3 Emma's projects (from left to right): The swan swimming in a lake, an LED inserted into a flower-shaped button, the e-textile base for her corsage.

These three cases demonstrate the key elements of tinkering as an activity - these three children tried out a number of ideas, continuously made adjustments and refinements, played with possibilities through a messy process. Although they were required to use a circuit in their projects, their overall design goals were emergent in nature and were set only when they began playing with materials. Through inquiry that arose from the interactions with materials in a design situation, Emma constructed knowledge of materials that let light through in a certain way and the intensity with which LEDs glow, Henry constructed knowledge of circuits, Copper tape and conductive thread as wire replacements in circuits, and vibration motorheads; and Glenn constructed knowledge about one ingenious circuit. In each of these cases, what children came to know was not available as something that was ‘just there’ (Perkins, 1986), but was constructed actively. Each of these tinkering projects bridge ideas and knowledge that were in the head and in the world.

Having discussed children’s tinkering projects, I address my research questions: (1) What prompts the children’s ideas and choices? (2) How do they solve problems that arise? I also discuss the varied ways in which children progressed through their projects, which has important implications for how and what they learned through their tinkering experiences.

Tinkering project ideas and choice of design and materials. Glenn, Henry, and Emma’s projects indicate the *nature of choices* children make while tinkering in the temporary community that had come together during the workshop. While the use of materials like circuit components were dictated by the requirements of the workshop, use of other materials, like paper, felt, and buttons were dictated by children’s likes and dislikes, how they planned to use these materials, as well as the presence or absence of skills that would facilitate projects using these materials. Glenn, for example, had ideas about possible ways to use the snap buttons in a circuit, but lacked skills. However, he knew that his mother would be able to supplement his ideas with her sewing skills; neither of them were able to figure out how their design functioned. Henry had the skills to bring his tinkering plans to fruition while considering the relationship between design and function. Emma was unsure of her ability, did not want to ask for assistance, but was very happy to participate and appreciative of her peers’ achievements. All three of them negotiated their initial ideas and skills to think of plans that could be materialized as projects.

In this group of children, engaging with a co-participant’s project, figuring out how it works, solving problems and offering solutions was as important as working on one’s own projects. Henry helped other participants to make fans for themselves and himself recreated the snap-button circuit with his sister. When other participants faced problems with their circuits, he helped them identify and eliminate the source of the problem. As described previously, when Glenn's mother thought of the snap-button circuit idea and couldn't think of the way it worked, others thought of possible ways it worked. When Emma's flower didn't glow the way she wanted it to, children at the table suggested that she examine the faint glow in a darkened space. Meaning making and problem-solving in these cases were collaborative and mediated by the social existence of the designed artifact. Encouragement and requests with regards to projects were expressed as "Try this", "You can do it", "Here, let me do this for you", "Could you do this for me?" Overall, the ambience of sessions was one of playful tinkering with friendly collaboration and open problem-solving. While problems were identified by the creator, potential solutions were checked by more than one participant, and all designs, projects, and solutions were open for critique.

Nature of problem solving. Glenn, Henry, Emma faced numerous problems as they worked on their projects – problems that they identified and sought to solve. How they defined these problems is the focus of this section. Emma identified her problem in the general area of the corsage not glowing as desired and pursued a solution. The first time she faced the problem, she changed the project idea to one that would be able to accommodate the problematic situation. She came to her original project only later. Given her project and its design, she could have chosen solutions like adding a few more LEDs to the battery like some other children had to make the corsage glow more. Emma identified the problem to be with the flower, specifically the material she had constructed it with; this was the micro-context in which she solved the problem with her project. Once she identified the problem, Emma experimented with a few potential solutions for the petals in her corsage – paper and cotton fabric (lets enough light through but does not hold the shape for long) and finally, plastic from gallon jars (lets just enough light through). Attaching plastic petals to the felt band involved the use of a lot of hot glue and the flower finally came off. She learned about the affordances of felt and plastic, one allows relatively more light to pass through it, one melts in the heat and the other does not. We can see that Emma solved problems based on what she identified as problems, in a context she thought of as relevant.

While Glenn's LEDs did not light because the conductive thread touched at several locations, he associated the problem with his lack of sewing skills. He saw wires crossing as a problem in circuits only when his mother's sewing caused it. He was so caught up in the messiness of sewing as a process, his fabric had a sizeable blob of tangled conductive thread, that he might have felt overwhelmed. Henry, too, met with small problems initially, some connections were weak and the sticker tape stuck to itself a few times, but these problems were solved quickly. The improvements that Henry made to his vibrating motor fan project were not as a result of a problem as such and I conceptualize them as "a design experiment within a design experiment" using materials that were lying around in the same design. His construction of the clothespin-battery-vibration motor fan was an original design experiment the checked the usability of a design idea - could a clothespin secure the motor, the battery, and work as a switch? Once this experiment was successful, he continued to make small changes to the design to see how it would affect the design of the fan and the experience of using the fan as a toy. This necessitated the variations of the fan blade.

Research on constructionist learning describes how children's learning takes place in microworlds (Papert, 1980; 1993; Kafai & Resnick, 1996) and a design universe (Bamberger &, Schon, 1983) comprised of materials, design ideas, and the designer. Further, constructionist learning and problem solving have been described as bricolage, a trial and error method of problem-solving using solutions that are immediately available. Situated learning theory helps us understand the importance of microworlds by acknowledging that what we know of concepts depends on the activities and situations in which such knowledge is framed through interactions with the world (Brown, Collins, & Duguid, 1989). As we interact with one concept in different situations, we get to renegotiate and reframe knowledge in new light. Knowledge, hence, is always under construction; a part of it is always "inherited from the context of its use" (ibid, page 5). Witnessing the negotiation of meaning in the socio-cultural context of situations of learning are important as well. Such contexts teach us how to use tools of meaning-making, how to negotiate meaning in situations using these tools, and what to value in meaning. In doing so, activity, concept, and culture are understood as interdependent as opposed to independent of each other.

Decisions that emerged in Emma, Henry, and Glenn's microworlds projects demonstrate material interactions (involving materials and tools, and skills and ideas that these interactions represent) and social interactions. Their actions on materials demonstrate what they thought would work; their friends' actions on these projects, like the button circuit and the fan, shows how they engaged in intellectual activity with similar set of materials in a microworld. When one interaction did not work out as expected, they drew similar conclusions and thought of possible alternatives. Not all these children used metal snap-buttons, thread, felt, vibration motors, and clothespins in their projects, but they are valued as switches, conductive wires, and opaque fabric-like material. The microworld that each project was conceived in seems to have travelled across the table inviting more children to inhabit it for some time.

Progress through projects. Tracking the progress of projects through the duration of the session reveals that the projects were either planned within minutes, prototyped, and executed soon after, or project plans failed at a crucial step and the half-done project was abandoned for the time being. Some children came back to these failed projects later while others did not, and often children initially left the troublesome project to seek assistance. For example, Glenn abandoned several projects and never came back to them. One of them was a pom-pom cat with red LEDs for eyes; he abandoned the project because the cat did not look realistic enough and the glowing eyes made it look spooky. Emma, on the other hand, came back to one of her e-textile projects repeatedly but met with failure because the conductive thread was too entangled to be salvaged. She finally stopped working on the project and moved to a different one, but came back to work on it afresh more than a month later. This time she completed her project. Overall, *persistence* in problem-solving within the time frame of the workshop was not very common and projects were completed in the workshop only if the identified problem had a known solution that worked. A peer or an adult had to be aware of this potential solution.

Another aspect of children's participation in this tinkering workshop was *nonlinear*, *recursive* nature of their tinkering process. Rather than establishing one clear goal and pursuing it, the children often revised or abandoned their initial design as they experimented with tools. This process contrasts with popular conceptions of both the Design Thinking process (for example, Owen, 2007), engineering design thinking (Dym et al., 2005), and the Engineering Design Process (as described by, for example, National Research Council, 2012) that follow an ordered series of well-defined steps that culminate in the creation of an artefact. These models emphasize the importance of iterations as can be seen in the cases described above, but they are not influenced by the requirements of a planned, final design. Additionally, steps were reordered, some steps were completely skipped, while some steps took place over the period of hours, days, and probably even months and were not captured in this time-bound dataset. Instead of considering solutions to the problem in hand, like Emma's corsage and Henry's Hexbug, children often modified the design to avoid the problem. Such actions led to different problems. While children tinkering process at the workshop might not seem efficient, it did seem to allow the children to spend time on activities that interested them, that allowed them to experience success, and that kept them engaged.

Discussion and Implications

In the previous sections, I described what prompts aspects of children's tinkering projects and their progress through the design process. I found children to tinker with available materials and technologies to create artifacts, seek and offer help, and playfully engage in meaning making. Keeping these findings in mind, I now consider their implications.

It is well known that we design a number of artifacts, processes, and modifications, and solve problems in these contexts every day to purposefully use processes, materials, and tools to meet desired goals (Nickerson, 1994). As we can see, the ability to design is not restricted to a few highly intelligent people (Roberts, 1995), in fact, children playfully design in contexts such as tinkering and engage in related problem solving and designerly ways of knowing (Baynes, 1994). Emma, Glenn, and Henry's problem identification and solving might come across as too spontaneous to be of any educational value, but research indicates that design as an everyday activity is a spontaneous and intuitive activity (for example, Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), and that even adults engaged in problem solving in such ill-defined contexts are unaware of possible inadequacies and potential improvements. Paying closer attention to these “micro-design” situations can offer useful insight into opportunities for learning that might otherwise be overlooked. I found the educational value of this experience in two aspects: first, children were able to implement their own designs through tinkering and could see some of the outcomes of their actions, and second, they could do so with materials they were familiar with and could find in their everyday surroundings. The second aspect is important because it supported their explorations beyond the walls of the tinkering workshop. What if tinkering with circuits became a hobby like art and craft? The educational possibilities of such a fusion excites me.

While tinkering with a combination of materials, children got to see these materials in unusual and yet relevant contexts. For example, we do not usually experiment with gallon jars, but Emma’s experiments taught her that these jars are heat sensitive and semi-transparent. Inspired by the outcomes of this experiment, she might proceed to experiment with other kinds of plastics and glue and find out that although plastics are everywhere, they are classified into distinct chemical subgroups and some of them are not as sensitive to heat. Henry might be able to salvage components from a remote-controlled car and transplant them into an original creation. With practice, he might even be able to create components on his own. Glenn and Mom might be able to integrate other components into their circuits like switches and motion sensors. These additional technologies are available in the devices we use, in hardware stores, and through online vendors and can be acquired easily. What is not easily available, though, is the encouragement to take things apart and examine, to be aware of the possibilities that come with combining components from, for example, craft, toys, sewing, and electronics. Tinkering opens children's eyes to such possibilities, Emma, Glenn, and Henry's explorations are examples of this possibility.

Having discussed the key attributes of the process through which children tinkered with materials and tools to create projects of their own, I now consider the implications of such a learning experience. First, I would like to point to wide range of skills that children used to tinker. They already had some of these skills, for example Emma knew how to make a felt corsage and an origami swan, Henry was good at tinkering and seeing tinkering projects through completion, Glenn was good at creating numerous small projects and delegating more difficult tasks to friends and family. Together, they learnt to create a few projects and build on each other's ideas and as is evident, all three children had requisite social skills to work in a shared space. They worked while exchanging ideas and yet maintain focus on independent projects. These observations imply that tinkering and learning while tinkering in a collaborative setting draws from and contributes to knowledge and skills from other areas that are not concerned with school and not formally taught anywhere, and not just academic content. Similarly, what children from tinkering as an activity might enrich experience in other domains in which they participate. Knowing when to seek help, describing problems adequately, looking for trade-offs when ideas and plans don't work, and learning how to solve problems are some such skills I identified in this chapter.

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CHAPTER 3

MAKING SENSE OF THE MANGLE: AN EXPLORATION OF CHILDREN'S LEARNING WHILE TINKERING

To date, much of the interest in the Maker Movement, "a grassroots culture dedicated to hands-on making and technological innovation" (for example, Dougherty, 2012; Vossoughi, Hooper, Escude, 2016), concerns how excitement around making and tinkering can be leveraged to fuel STEM (science, technology, engineering, and mathematics) learning and innovation (Honey & Kanter, 2013). Such interest has ranged from Maker Faires (Kalil, 2010) to President Obama's Educate to Innovate campaign (Obama, 2009), countless workshops, and school, community, and museum makerspaces. Though this holds promise, we need to make a concerted effort to better understand making as a new domain unto itself, rather than in service of other learning outcomes. While connected to traditional disciplinary ways of understanding, making deserves to be understood and studied in its own right. Open exploration, intrinsic interest, and creative ideas are some of the commitments at the core of the educational Maker Movement (Halverson & Sheridan, 2014; Vossoughi & Bevan, 2014; Vossoughi, Hooper, & Escude, 2016). Encompassing platforms like MAKE magazine, Maker Faires, sharing enabled by YouTube videos, Pinterest boards, and Instructables.com, and a surge of interest in DIY and craft, the movement embodies material production and related practices in a host of domains like traditional crafts, sewing and woodworking, electronics and digital-physical systems (for example, Peppler & Bender, 2013). Across these domains, the movement and the projects it inspires and facilitates are propelled by (a) the introduction of new technologies, like 3D printers, laser cutters, and Arduino robotics, that allow for faster prototyping and new forms of digital fabrication; and

(b) the rise of social interaction and idea/skill-sharing via the internet, which allows for the sourcing of parts as well as the widespread sharing of ideas (Dougherty, 2012; 2013; Peppler, Halverson, Kafai, 2016).

As practices, making and tinkering are powerful means for engaging and exciting children around science, technology, engineering, and mathematics (STEM) learning (New York Hall of Science, 2013; Resnick & Rosenbaum, 2013). Even when watered down and transplanted into structured contexts, such activities provide a context for connecting children's everyday interests and practices, especially those around art and craft, in an interest-driven collaborative process of "(re)design, (re)production, reflection, and remixing" (Barron, 2006; Ito et al., 2010). Additionally, there are numerous opportunities to introduce introduce elements of fun, aesthetic, and playfulness through these activities that create an "invitational potential" that holds promise for easy, low-risk entry into STEM-oriented practices, such as projects that require circuit building or cardboard arcade game building (Vossoughi & Bevan, 2014). Because of the playful, imaginative nature of many such activities, the widely accepted notion that science is for scientists in lab-coats begins to dismantle, as children discover that they too can engage in scientific pursuits. Makerspace environments are known to not only engage children in STEM learning, such as figuring out what materials conduct electricity or how to create a circuit, but also for their ability to provide a reimagining of what learning can look like. Making and tinkering as hobbies or after school program areas can help develop a sustained engagement with learning processes (Resnick & Rosenbaum, 2013; Washor & Mojkowski, 2010), however, some of the bigger questions about the true learning potential of these activities in an everyday context are yet to be explored. This is important because, except for the use of typically 'maker' technologies, making and tinkering as activities are commonplace and so is learning while making and tinkering.

Supporting the emergence and development of expertise among learners (both experts learning a new skill and novices), has long been considered a productive direction for the design of learning environments (Lave & Wenger, 1991; Rogoff, 1994; Vygotsky, 1978). Through the context, the design, and the learning situation described in this chapter, I explore how knowledge and expertise gained through tinkering might lead elementary age children toward STEM learning. Drawing on sociocultural learning theories, I describe learning to be socially and relationally constituted, and consider children's tinkering projects as designs that emerge in a social and material context. Drawing on the conviction that valuable learning can take place through tinkering in playful, everyday, low-stakes environments that use a mixture of high and low-tech materials, I propose that such activities are a great way to promote equity in science learning. I draw on both sociocultural theories and the learning sciences to make my case.

Tinkerability facilitates exploration, fun, and learning

Through tinkering, children can pursue their own goals while learning when the design of the activity facilitates immediate feedback, open exploration, and fluid experimentation (Papert, 1980; 1986;1993; Resnick & Rosenbaum, 2013). Because of the "easy to start" and "easy to connect" (Vossoughi & Bevan, 2014) features of many tinkering projects, fluid experimentation, engagement, and movement is made possible. Tinkering activities draw attention to both the process and the result; "immediate feedback" from the physical activity that tinkering is facilitates meaningful and sustained learning (Resnick & Rosenbaum, 2013; Schoenfeld, 1998; Greeno, 1998). Testing patterns, designs, ideas to see the consequences of one's ideas during the process makes one's learning more visible (Bransford & Schwartz, 1999).

I focus on the aspect of immediate feedback that is central to learning in general but in the context of tinkering and demonstrate how social and material feedback can shape the course of exploration, and in turn, learning. Projects described in this chapter are the products of ongoing explorations and have a "live" quality that allows children to see how their actions related to a component of an artifact relate to its whole. These aspects of attention to process, feedback, and real-time feedback make it possible for children to engage with their projects for a long period of time (Resnick & Rosenbaum, 2013). In Papert's words, these projects gain the status of an object-to-think-with (1980), children keep returning to these projects, think about them, think with them, transition from one idea to another over a period of them, separating the boundary between what is imagined and what is concrete.

Theoretical Framework

The aim of this chapter is to examine the intellectual activities that children engage in with tools, materials, and designs in the context of tinkering with circuit components and craft materials to create projects. It is well accepted that the construction of knowledge is a socially and materially distributed phenomenon located not merely within the head but across systems of activity in communities of practice. A study of learning while tinkering, hence, requires attention to not only what children learn but also the full range of practices that are employed and made meaningful during tinkering. I view meaning making while tinkering as a *mangle* (Pickering, 1995) of human intention and agency, and agency of materials (affordances and constraints of processes, and designs. Mangles present possibilities to humans and sociocultural practices and norms develop around these. The idea of mangle is a metaphor for the development and revision of scientific practices and ideas through a dance of human intentionality and agency, and material agency. Such a dance is comprised of endless iterations of resistance and accommodation. As a framework, mangle makes visible the *real-time* understanding of actions and ultimately, practice.

Material puzzles. When humans act on materials they enact agency and intentionality. Materials, on the other hand, respond to human actions according to their properties, how they are naturally configured, and not through agency. Humans record the ways in which materials respond over time, become familiar with them, develop hypotheses, procedures, machines, and measures, and apply these, once more, to materials which respond in ways that are now familiar to humans. In the event of an unexpected and mysterious response from materials, humans re-engage in the process of accommodation to develop goals, practices, and understandings. Such an iterative process is akin to solving a puzzle (Pickering, 1995, page 144, 188), puzzles that *destabilize* ideas and practices in science and establish a need to "reconsider each in light of the other". Puzzles can appear at several stages of explorations, and it is up to humans to become aware of the presence of such a puzzle before trying to solve it.

The puzzle of material conversations. The mangle is not restricted to laboratories. In fact, Schoenfeld's (1998) description of material conversations while making pasta from scratch is a mangle as well. He sees making pasta from scratch as a learning process during which one becomes familiar with the process and materials. Making pasta from scratch is difficult; there are tools to help us with the process, but until we are well-versed in the process, know how the materials are supposed to look and feel like at different stages in the process, making pasta from scratch can be tedious as well. Schoenfeld presents his learning experience with making pasta as a progression of skills such as the awareness of affordances and constraints of materials and machines. Schon (1991) explains that such awareness is acquired when we try to make sense of the ways in which materials and tools "converse" with us through a reflective conversation. Through these conversations we are able to make sense of the puzzle of how a set of materials, like dough, water, and eggs, with the use of a tool, like the pasta maker, can be used successfully. When we try something new, like use a new brand or type of flour or a new machine, the process might respond differently to our actions, because the materials and tools have changed and so has the puzzle. The new puzzle is an opportunity for us to learn more about the materials and tools used to make pasta, a chance to have a similar and yet new conversation with materials and tools.

While materials respond to human actions in specific ways determined by their physical and chemical nature, humans can exercise intentionality; atoms and molecules that constitute materials cannot. Materials respond to human actions by virtue of how they are programmed in nature and such properties come to the fore during the reflective conversation with materials of a design situation. In this chapter, I use the ideas of mangle and reflective conversation to answer the following question: What do children's tinkering processes reveal about their understanding of the affordances of materials and technologies? I use the idea of mangle to record how children intentionally make changes to materials, tools, and designs, how materials, tools, and designs respond to such manipulations, and how children in turn react to these responses through their design stances. I use the idea of reflective conversation to describe this *process* of negotiation through which children arrive at the design of an artifact. While mangle represents the *nature of tinkering actions,* reflective conversations represent *what children think about the mangle, during the mangle, as well as before and after it* in the microenvironments of design situations. Although the focus in this chapter is on the mangle and reflective conversations around it, I would like to point out the broader socio-cultural approach of the chapters. The processes of mangle and reflective conversations unfold in a social space with the tinkering projects acting as mediators.

Methodology

The goal of this chapter is to locate and illustrate children's learning through tinkering while participating in a week-long tinkering workshop. Specifically, I examine what children's tinkering processes reveal about their understanding of the affordances of materials and technologies. I focus on both the artifact they tinker with as well their participation in the social space as mediated by the artifact. Overall, I adopt a qualitative ethnographic method to capture

events in a weeklong tinkering workshop for children between the ages of eight to twelve. The children whose projects I describe here are aged between ten and twelve. To enable comparison, I chose projects that have similar technological components.

Setting

I set up a tinkering workshop at a local public library makerspace. The space offers regular hourly sessions based on various aspects of making, tinkering, and art and crafts for eight school-age children. The workshop lasted for four days, and each session was two hours long. I arranged four large foam sheet covered tables and arranged mini-stations on them, these were our tinkering supplies stations. Children gathered around these stations and had individual workstations with tools and common supplies. I had placed two laptops at two ends of the tables to record children's activities. Two small digital cameras and two cell phones were available for children to record their projects as well as other projects that they find interesting.

Adults who accompanied children were not required to participate but were welcome to

if the child felt the need for assistance. All participants completed at least one project within the two hours of each workshop session and took home supplies to make something at home as well. I requested them to bring back projects during future sessions, but only one child did. Others shared images and descriptions through email and texts.

Data collection

I collected video data, photographs, and field notes during and after the sessions. A few participants donated their tinkering projects for my work and I collected these as well. I did not formally interview any of the participants, but instead I asked all participants questions during the process of tinkering. For example, when they added two batteries to their circuit instead of one, I asked them for the reason that motivated their choice. For projects that were completed at home, I asked them questions over telephonic conversations or during a meeting. In this chapter, I focus on tinkering projects created by Henry, Emma, and Ani. I include Gillian as well because she co-created the project described with her brother Henry. These children worked on versions of their original projectI met Henry and Gillian's family at their home a week after the workshop ended, Emma's mother texted me the photographs of her project and I spoke with Emma over the phone. I met Ani at Henry and Gillian's as well. I wrote notes to accompany the photographs for record. During the workshop as well as meetings that took place after it, I tried to maintain a casual atmosphere, I wanted the children to feel like they were meeting a friend's parent or a friend of their parent. Absence of regular data collection devices like audio recorders and video cameras (audio and video were recorded with the laptops) allowed me to do so. I let all participants and their parents know that I intended to study the process through which they created their projects and that photographs and knowledge of what they were thinking would help me achieve my goal. Children shared their thoughts and photographs based on this expectation. All parents consented to their child's participation and children provided assent and shared photographs of children's projects completed after the workshop through emails and texts. In such cases, I communicated with parents and children through Google Hangouts, Skype, and telephonic conversations. We talked about children's projects and project modifications in detail during these communications.

Data Analysis

Overall, I adopt a descriptive and interpretive approach (Denzin & Lincoln, 2000) and a research design of a qualitative exploratory case study with embedded units (Stake, 1995; Yin, 2003) using video recordings of sessions, field notes, and short video clips and images captured by children as data sources. In addition to my analysis of children's participation in tinkering, I present participants' unique experiences and perspectives (Crabtree & Miller, 1999). This helps me and readers understand the nature of their tinkering decisions and actions. Both Stake (1995) and Yin (2003) agree that such a combination of perspectives enables the creation of meaning while retaining a sense of objectivity. While we need to understand why and how participants in this study tinkered, it is equally important for us to know, based on findings I share in this chapter, that other children might make different choices, act in different ways, and make different tinkering projects. This might help us have a general idea of learning while tinkering while being open to differences. The use of embedded units within a case (Yin, 2014)

is important for this chapter because as we will see, tinkering takes many forms.

I reviewed all data sources (session wide video recordings of all four sessions, field notes, images and short clips recorded by children) and wrote analytic notes in response to the research questions (children's understanding of affordances and constraints of materials and technologies while tinkering). I selected three projects initiated during the workshop based on the varied *complexity* of the projects (for example, substantially modifying a design plan, supplementing an important component, supplementing ornamental components, supplementing project components to increase the fun quotient), nature of *collaboration* (friends, sibling, parents, and mentor), and the role of collaborators (source of ideas, problem solver, helper with additional skills but no intellectual inputs). These categories were necessary because of the sociocultural focus of the study in general. Using data sources, I constructed a timeline for each of the chosen projects keeping in mind the framework of mangle, making sense of puzzles, and reflective conversation. The initial interpretation of the data sources is a narrative with rich descriptions of the design process (Lavelli, Pantoja, Hsu, Messinger, & Fogel, 2004). Such a narrative of each project is the first level of finding (Polkinghorne, 1995).

For the next stage of data analysis, I used these narratives to identify the choices of materials and tools that children used and the nature of problems they identified and sought to solve. These two aspects are key to answering the research question (What do children's tinkering processes reveal about their understanding of the affordances of materials and technologies) based on the understanding of tinkerability (Resnick & Rosenbaum, 2013) of material. All aspects of choices of materials, tools, and design and problem solving that I identified are shared in the findings section. In subsequent levels of thematic coding, I identified factors that influenced their choices of designs and materials, and the nuances of the nature of problem solving they engaged in. As I share in the findings, in some cases children's choice of materials and design are related to problem solving. I categorized themes as complications in tinkering that arose due to process, due to design aspirations, and due to choice of materials. I examined these three themes to identify the basis of children's choices. The general process is described as a flow of events in Appendix 1. After coding all sessions, I developed full cases (Stake, 2008) of all three children with embedded units representing each project they worked on. For practical reasons, I present a maximum of three embedded units per case.

Findings

I present findings from the workshop in the form of three short cases; each of these cases has two embedded cases. The embedded cases are related to each other, in that they have their origin in the same inspiration but have been modified by the children in different ways. In each of the three cases, I provide an overview of the child's personal history and how s/he likes to tinker, discuss the "mangle," that is, the nature of tinkering actions associated with materials, tools, and designs, and what children think about the mangle, what I call their reflective conversations during the tinkering process.

Henry (nine years old) is an artist and tinkerer. He has two elder sisters and a little brother who are all passionate about "making things with hands" and working on projects that they decide among themselves. The children's hobbies include creating detailed constructions using play-dough, putting household castaways (like cardboard, paper, plastic bags, assorted cans, bottles, and lids, etc.) to good use, craft projects, and role-play. Henry's siblings value his ideas and suggestions when building things using Lego blocks and modifying toys. Ani is Gillian's playmate and their parents are friends; Ani communicated with me through Henry and Gillian's mother.

Glenn (ten years old) is a prolific crafter and artist. His mother is his craft partner, constant companion, and the only one who *gets* him. Glenn constantly works on projects and makes things from scratch but for very short durations of time. His mother has to seek his approval before sharing his projects with others. Glenn has an older brother in college who like music.

Emma (twelve years old) and her father are workshop enthusiasts. Together they keep track of and attend STEM workshops offered at public libraries and museums in the region. With her mother, Emma shares a passion for craft and takes on challenges. Emma's parents are not STEM content experts but are very enthusiastic co-learners. As a family, they come on board over weekends and holidays to make things and examine related processes.

In the following section, I describe the projects created by the children. Henry, Emma, and Glenn began working on these projects on the second (using a vibration motor in a circuit) and third day (using e-textile components in a circuit) of the workshop and extended them at home on their own time. They shared these projects with me later through informal communications. Gillian and Henry's mother emailed me with the details and we chatted over Google Hangouts about the details of the projects. Emma sent images of her projects through email as well and we had a telephonic conversation about the changes she made to her projects. Each case is divided into a brief description of the project and its modifications, and the mangle and reflective conversation that the project represents. As previously described, I think of the mangle as the dance of human intentionality and agency and material agency

(Pickering, 1995). While mangle is about agency, reflective conversation is about meaning making, making meaning of the mangle in the tinkering design universe and making judgements based on this. Snippets of such a conversation would include, what made me do this? What happened before my actions? What do I think will happen after? Is this how I want the project to progress? A collection of such questions would constitute the narrative the tinkerer has maintained with the materials.

Gillian and Henry use a modified snap-button circuit in a tote bag

The snap-button circuit was created by Glenn and his mother on the third day of the workshop. Children began called it the snap-button circuit because each half of a snap button was sewed into wire connecting one end of the battery to the corresponding end of the sewable LED. When the buttons were snapped together, the Currents flow to the LED was Cu off making the button function as a switch. Henry and Gillian decided to modify the circuit and use it in a project of their own. The following is a description of the two embedded units of this case, Gillian and Henry's modification of the snap-button circuit and Ani's modification of their project.

To Henry, people need to sew only to repair torn clothing. Sewing to build a circuit was a new idea for him and so were e-textile components. Having used regular cotton thread to sew buttons on his shirts, Henry felt disadvantaged while handling conductive thread. The thread broke easily when tugged, unraveled, and had to be wound several times around a loop in the sewable LED for the LED to light up. A long loop of thread was difficult for him to manage, since threads could not touch, and sewing through multiple layers of fabric caused the thread to break. While Henry was dealing with these frustrations, Glenn and his mother were working on their snap-button on a small piece of felt. Henry was inspired by their project, especially by the use of the snap buttons to manipulate the circuit.

(a) (b)

Figure 3.1 The snap-button circuit. (a) Glenn and his mother's snap-button circuit, (b) Henry and Gillian's tote bag with Copper tape and e-textile components snap-button circuit.

Gillian, Henry's older sister, was participating in a sewing workshop for children. Although Gillian knew the basics of sewing like threading a needle and sewing in a straight line in a run, the conductive thread brought a set of complications with it. Sewing a circuit is not the same as sewing in a straight line or even sewing in a Copperrve, since wires in a circuit need to head in a certain direction. Gillian was not used to Cuting off the thread when ending a line of runs, so she would bring the needle up where the next line began. She tried this with the conductive thread as well and the LEDs failed to light up. These teething troubles led Gillian to decide that simple, cotton thread needed to be used to structurally secure the design leaving the conductive thread only for the circuit. Once she began following this plan, she realized she did not have to use the conductive thread at all, because it was needed only to hide the fact that an artifact had a circuit. She replaced the conductive thread with Copper tape, something that she was already familiar with, that had an adhesive inner surface, and could be manipulated with a lot more ease. Together, Gillian and Henry used Copper tape, LED, and snap-button circuit along the opening of a tote bag. This worked with the tote except for times when the tape that formed the two ends of circuit touched and broke it. This made her cover the tape with a layer of felt glued on the fabric of the tote. She later said that she did not expect the felt to be non-conductive but the design worked because it is.

Ani, too, figured out that the conductive threads were to blame for most of the troubles with her circuit and replaced them with pipe cleaners. She used yarn covered length of two pipe cleaners to use as handles of a felt purse and the shaved and unwound length to wind around circuit components. Later, she created another version of the purpose using regular LEDs and a battery, but no snap button. These two modifications helped other children who could not sew carry the project forward and create some bags for themselves.

Figure 3.2 Ani's iteration of the bag with LEDs; instead of Copper tape she used pipe cleaners but without the snap-button switch.

The Mangle. Henry learnt from the manipulation of conductive thread. When he tried to thread the needle, the conductive thread unravelled; he tried to sew through three layers of felt, the thread broke. The special flat LEDs made for e-textiles were mounted on a board with conductive edges, and the thread had to cover the conductive edge for the LED to light up. Using the thread as a replacement for wire was difficult for someone who did not know how to sew. Ani drew inspiration from a damaged pipe cleaner with its ends unraveled; as she unraveled it further, the fuzzy yarn came off. She checked the wire for conductivity and it worked. As she continued to un-twist the pipe cleaner wire, she realized how difficult it was to reshape metal wires. At home, she asked her parents to help her untwist the wires. The wires were twisted around tiny pieces of yarn, she had to pinch these yarn pieces out. Ani noticed that while the wires conducted electricity, the yarn worked as an insulating material and prevented shocks.

Reflective Conversation. When faced with several problems with the use of conductive thread, Henry asked himself what other materials he could use to achieve the same function. He chose the Copper tape. Later, when inserting the Copper tape through the holes in the e-textile components, he could easily slide the tape to adjust its length. Ani's conversation was about replacing the conductive thread in the circuit, not because of the problems she faced, but because she saw that it could be replaced. Ani wanted to see if she could find something to replace the thread, just like Henry and Gillian had. She noticed that another participant was creating a project with pipe cleaners, she wondered if the wires in the pipe cleaners could be used with the e-textile components since they had metal wires in them. She left the pink yarn on the remaining length of the pipe cleaners "because I like pink and I don't like getting a shock." She did not feel the need to include the snap button in the circuit.

Emma's mixed-materials corsage

Emma's felt petal corsage let light was initially constructed as a series of pink felt petals arranged around a raised bed, also made of felt, with two e-textile LEDs connected to a battery unit. It dimly lit an area of half-inch around the base and the base of the petals; Emma wanted the petals to light up a lot more. She changed her project plan and used the circuit to light up a swatch of blue felt from underneath and placed an origami swan on it - this was her swan in a lake display piece, the first embedded case. Later, she chose plastic from a milk carton to create her corsage, this time it glowed more than it did during the workshop, but she couldn't color it. Finally, she used both felt and plastic petals on the flower and turned this into a pendant by punching a hole into one of the petals. This is the second embedded case.

(a) (b) (c)

Figure 3.3 Components of Emma's floral corsage - (a) the milk carton Cut-out petals, (b) the petals placed on an LED-battery unit with a pompom at the center, the band is made of blue felt, another iteration of the flower with felt petals inserted below the plastic petals, (c) the origami swan swimming in an illuminated lake.

The mangle. Emma tried to achieve an effect with felt and e-textile LEDs. She began her project with felt for petals which did not let enough light through. Failing to achieve the desired effect, she changed both the materials and finally, the design. She did not try to change the number of LEDs on her design or use a less densely packed fabric or paper. Instead, she chose to replace the felt with plastic and discovered a limitation of the design - the LEDs-battery-plastic petals unit was too big to be secured with glue on the felt band. She then turned the flower into a pendant which, owing to its placement on a wire, did not need to stay upright on a curved surface like a wrist. The materials in Emma's design pushed back in the initial iterations.

Reflective conversation. Emma began working on her project with inhibitions about building circuits and understandably, once she built a circuit to light the corsage, she avoided making changes to it. Instead, she tried to make changes to the material of the flower and when she couldn't achieve the effect she desired, she saved the project for later and creating the origami swimming in the illuminated lake during the workshop hours. At home, she placed a few materials on top of the battery-LED unit to test effects and finally chose the milk carton. Gluing things together and hiding the battery-LED, too, was a challenge. The construction kept falling apart. Finally, Emma changed her design, she chose to tinker with materials that let light through instead of circuits and conductive materials like Henry and Gillian.

Henry's clothespin and vibration-motor fan that evolved

Henry used a wooden clothespin to hold a vibration motor and battery unit. He attached a construction paper cut-out to the motor head using two-way tape, this way, when circuit was connected, the paper blade on the motor head moved. This was Henry's fan, a popular design at the workshop. Based on his friends' suggestions, he modified it to create what I describe as two embedded cases by replacing the construction paper with plastic straw cut-outs and a straw-feather combination blade.

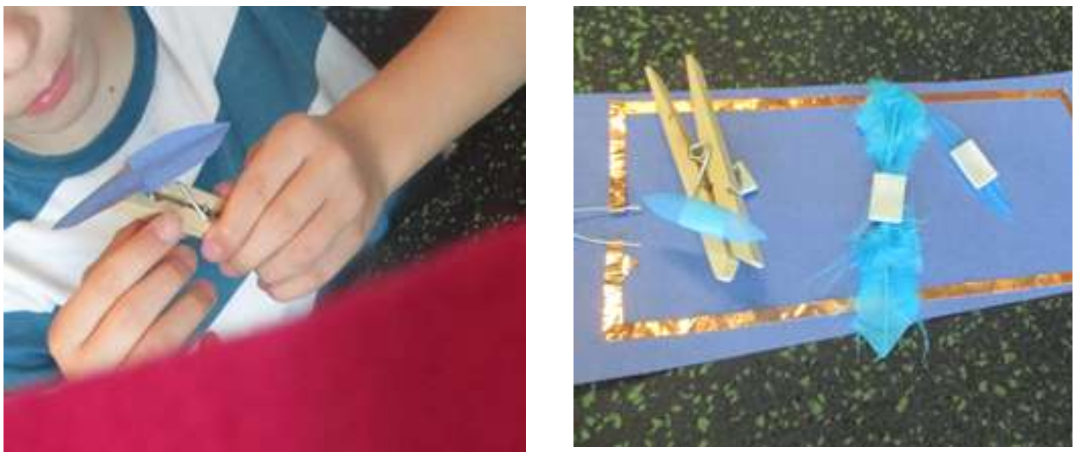

Figure 3.4 (a) Henry deep in thought while tinkering with the clothespin-vibration motor fan. At this point, the fan has a construction paper blade. (b) Later iterations of the fan, the feather and the straw blade can be seen.

The mangle. Henry began by tinkering with the vibration motor and soon realised that the motor head was a crucial component. He first made a Hexbug (a popular toy that has a very small but powerful vibration motor inside a silicone mold in the shape of an insect) using the motor and pipe cleaners. While working on this project, he saw that the bug moved around on a flat surface because of the regular motion of the motor head. He decided to test the motor stuck to a clothespin that also worked as a switch to see if it still moved and it did. Encouraged by the positive outcomes of his experiments, he decided to add a blade to the motor head and called it a hand-held fan. He was satisfied by the breeze created by the plastic blade and added the feather at his friend's insistence, they wanted to use the fan to tickle other people.

Reflective conversation. Henry examines his environment for inspiration and considers replacing parts and alternate uses. He sees wooden clothespins for what they are - two interlocked pieces of wood with a small spring wedged between. The wood can stick to two-way tape, the wood will not let current through, and the small indent on the inner surface can be a great place to hold the motor. When his friends offer suggestions, he asks questions and considers the potential value of these suggestions - What would they add to the project? Why do they like it so much? Although he sees no great value in making a fan that tickles people, he does it anyway. His friends have been admiring his projects throughout the workshop. Having described the children's projects, and the mangle and reflective conversations involved in the process, I now move on to more specific details of what they learnt about the affordances of materials and technologies.

Solving material puzzles through tinkering

Having noted the nature of three children's tinkering projects, I now move on to findings related to the affordances and constraints of the materials that each of the participants noticed through each of the cases. I focus on three sets of materials: (a) the wires, (b) felt, plastic and glue, and (c) paper, plastic and feathers.

The wires. Henry, Gillian and Ani's puzzles were with the process of sewing as well as the materials they were using. Henry knew thread to be of use for certain purposes only, like to hold pieces of fabric together, to secure buttons. When presented with the conductive thread, he felt baffled, but continued to use it in a hybrid way. His initial project did not need anything other than the LED and battery unit to be secured, and yet his way of using the thread showed that he felt the need to use thread in a certain way. When his LEDs failed to light up, he first cut the thread in places to prevent a continuous loop of thread connecting two ends of a battery, and then, he wound the thread around the metallic edge of the LED. By this time, the conductive thread had begun to unravel, baffling Henry. He asked, “How can I make it stay there and make the LED light up if it is not strong enough?” At this point, he knew he would keep the e-textile LEDs but replace the conductive thread with the Copper tape. He learnt that Copper tape conducts electricity in the same way that conductive thread does. Similarly precautions that need to be taken while working with conductive thread, had to be considered while working with Copper tape as well. Ani learnt that exposed metal wires in pipe cleaners could conduct electricity, but the polyester yarn on them insulated the remaining length of the pipe cleaner. Because of this insulation, she did not need to prevent two wires from touching.

Troubles with felt, plastic, and glue. Emma took time to solve the shape-material-transparency puzzle. By substituting the felt for lack of transparency, she gave herself the opportunity to manipulate and explore another new material - milk carton plastic which she found to be translucent, but also fell into another puzzle. The hot glue that she used to hold components together could no longer hold the flower and the LED-battery unit to the base. At this moment, her puzzle changed to one of the design, the trade-off between what she wants and what the components of her current design would allow.

Paper, plastic, and feathers. Henry’s clothespin and motor fan was a project that amazed every participant. The vibrating motor-head inspired the idea of creating a fan, all he had to do was to find something to hold the body of the motor in place and a material to fashion blades from. His first choice, ruled paper torn off a notebook, was a proof-of-concept. Henry made a tiny puncture at the center of the paper into which he inserted the motor-head, when the circuit closed, the motor vibrated, the paper whirred around the motor as the axis creating a whirr and a light breeze that he could feel on his cheeks. The light-weight of the paper made it floppy, the blades of his fan needed to be "better" and "stronger so it would not fly away" and he used milkshake straw cut out as an improvement. A friend suggested that he attach two purple feathers to the plastic to make it tickle the face when held close. Both ideas worked well.

What necessitated these observations and decisions. While the projects are fascinating and implement materials in clever ways, it is important for us to note what facilitated these observations about materials and processes. We consider three such observations in this section.

Process related complications. As mentioned earlier, sewing was complicated enough for this group of children, and the nature of conductive thread made the process so complicated that children decided to get rid of both sewing and the need for thread altogether. Gillian chose to work on a tote bag that was store-bought, and the need to sew was thus eliminated. The Copper tape was much easier for her to use because it did not fray and she did not need to take care of knots. She made these observations because she took on the challenge of trying to sew the circuit and decided to go through the difficult process even though it was far beyond her abilities. Emma, our cautious tinkerer, avoided sewing altogether, she requested the facilitator to sew the circuit for her while she looked on and wondered how difficult the process might really be. No circuit related material or design innovation was seen in her floral corsage.

***Design related aspirations and effects*.** The floral corsage lit from below and the fan are examples of design decisions that were motivated by the effects that children imagined. Emma's felt and e-textile project created a pleasing visual effect as well, but the idea of a floral corsage lit from underneath appealed more to her senses and she decided to work on it further. Similarly, Henry's paper blade fun was good enough but he imagined his tiny fan to have a cooling effect when held close to the face. These aspirations helped them move their projects further, consider alternate options about materials and designs are played a crucial role in their noticing the affordances and constraints.

Complications that arise due to the choice of material and designs. Although felt, pipe cleaners, paper, and plastics are a part of children's craft projects they had not been tested on these designs and this context. Only when Emma tried to use the light and the felt pieces in one project did she notice that felt was a relatively thick and opaque material. The interaction between felt and the circuit facilitated this observation and Emma facilitated the interaction. Similarly, Gillian's decision to persist with her sewing project and her commitment to the snap circuit design facilitated the range of interactions between materials in her project. Only when the wires of the circuit around the edge of the tote bag touched did she notice that "electricity finds the easiest way inside a circuit. . . When wires touch, it (electrons) is no longer forced to enter the LED and make it on."

Beyond puzzles, affordances, and constraints: The way children think

Henry and Gillian enjoyed digging deep into their design problem. Their effort and explanation revealed so much of the design and the process to their peers that they all ended up learning about the circuit components, the materials of the bag, thread, and Copper tape, and the design as such, but most importantly about developing an idea as such.

Emma's approach was about finding a solution, an immediate solution to her design problem. After the summer was over, she still treasured her corsage but did not work further on it; she liked it for the effect of pink light emanating from underneath the floral corsage. Henry and Gillian, on the other hand, liked the bag for the fun they had building it, how they could show it to their friends and family and they would look at it with an expression of awe. These two examples reveal that they tinkered for different reasons. Children in general probably tinker and craft for different reasons as well, they are all good reasons and lead to learning in different ways and about different things.

Henry evaluated the clothespin-vibration motor fan developed during the workshop every step of the way. His comments reveal questions such as, is this what I want? What if I did this other thing that my friend is suggesting? What would happen? Would that be something I want? Both Henry and Emma spent time both thinking and doing. While Henry was aware of the clear advantage of knowing a little more about how the fan works every time he embarks on a modification of the design, Emma felt the need to be cautious in her approach to any design modification. While working on his projects, Henry saw the connection between the design situations in both the fan and the snap tote bag concerning not just the materials, but the role of the material in the design of the project sub-part and the project as a whole. He could navigate the process easily; Emma, on the other hand, was inhibited by fear. What if further changes created more problems in her project?

Emma's tinkering is for a different reason. She likes cute, pretty things; she considers the process a task, a very difficult one and proceeds with a lot of caution. When looking for ideas, Emma's approach is to look for the easiest process and what is available. The children are both aware of the affordances of materials, tools, designs, and processes, but use their awareness in different ways. Emma avoided the route of hard labor, the essence of inquiry was not appealing to her. Once the outcome was in front of her, like Gillian's project, she identified why it worked so well but never made a copy of it because she could not sew.

Discussion and Implications

In this section, I discuss why these tinkering projects and activities related to them are important for STEM learning. Through this discussion, I point to the aspects of learning STEM, and doing so in an unstructured and everyday context, that have largely been ignored in existing research in learning while making and tinkering.

Learning to Learn

While coding notes, videos, and images of artifacts, I noticed that the largest and the most diverse group of codes belonged in the category that I can only describe as learning to learn. While there has been some discussion on what kind of content knowledge can be expected to be nurtured through tinkering, two huge gaps in science learning have been left open. First, following critics of discovery and inquiry based learning (for example, Klahr & Nigam, 2004; Kirschner, Sweller, & Clark, 2006; Eberbach & Crowley, 2009), one might point out that personally meaningful learning through tinkering alone does not lead to children acquiring any content knowledge that is even worth testing, and rightly so. However, in trying to address this issue, it might be useful to note that in direct instruction based lessons, attention is called directly to facts and formulae that help us in solving scientific problems using content. Although this remains the easiest and the most effective way to impart science education to children around the world, solving scientific problems in the real world is important as well. As has been mentioned by experts (for example, Hill, 1998; McDermott & Webber, 1998; Fortus et al., 2005), in the real world, problems cannot be labelled as belonging to one domain of scientific exploration, solutions based on just definitions and formulae often fail, and is known to be an immensely frustrating endeavor to non-experts. Tinkering, along with craft, gardening, sewing, and making pasta, take place in the real world and through participation in such activities, children learn to identify aspects of a problem that could be relevant to them, frame questions to ask and answer them, keep mental record of this iterative process, and teach themselves to make sense of and solve a problem. These metacognitive abilities are indispensable to the ongoing effort to nurture STEM literacy and expertise for present and future learning.

Learning with familiar materials

McDermott and Webber (1998) note, among other things, how in our rush to impart STEM literacy, we forget that scientific discovery is but an iterative, frustrating, and serendipitous process. Like Schoenfeld (1998) they emphasize that with increasing familiarity with materials, processes, and awareness of affordances and constraints related to the problem or design situation, we get better at solving the puzzle, making meaning of the mangle. Like McDermott, Webber, and Schoenfeld, I would like to draw attention to the need for familiarity in a learning situation and point to how in the cases I shared, learning was facilitated by, in part, the familiarity with materials like paper and fabric, and skills like gluing hard and soft surfaces together and basic sewing. Such familiarity with materials around us is indispensable to the ongoing discussion on equitable STEM learning opportunities. When children tinker with glue and paper, they become aware of at least a few manifestations of the interactions between these two materials. As educators, we can draw on these experiences to teach concepts like cohesion, adhesion between like and unlike molecules of materials around us and how they relate to the behaviour of these materials. I find these observations to be in support of Cajas' (2001) recommendation that technological literacy be tracked to design content for core science literacy. Observations of different kinds of glue being used for different purposes because of their unique affordances can definitely lead to engaging chemistry lessons and these lessons can be delivered through tinkering and craft. In fact, K12 benchmarks state that elementary age students should know that some kinds of materials are better than others for a purpose. Materials that are suited for some functions maybe be unsuitable for some others, even related functions, for example better in some ways (such as stronger or cheaper) may be worse in other ways (heavier or harder to Copper)" (AAAS, 1993, p. 188, as cited in Cajas, 2001). Additionally, elementary age children should also be able to distinguish the properties of an object from the properties of the materials it is made of (Russell, Longden, & McGuigan, 1991). Learning about materials, hence, is a goal of science education. Tinkering with materials can be the context in which children explore and learn the different properties of the materials they select and how these properties affect their manipulations of materials, and hence, their projects. To enable this, science educators need to understand how children come to understand functional properties of materials and perhaps more importantly, what kind of tinkering projects interest them. In the following paragraphs, I consider a few implications of such learning while tinkering with materials.

Teaching science through everyday technologies. Science and technology integration comes with some problems. The focus of this integration is mostly on factual and conceptual science and not on technology. Further is mostly used as a way to deliver content or to teach kids how to use computers. Instead, technology can be used as the context for science education, especially technology that children, most children have access to. Tinkering can be a good context. Technology is how we have manipulated, and how kids can manipulate materials around them to meet needs. The mangle of human intentionality and material agency becomes evident in these interactions. Beside science education, this might help kids see knowledge of the world, materials, natural elements and forces, as produced from an assemblage of ordinary actions and understandings. This takes science beyond facts and positions it as “science, any science, anywhere, under whatever circumstance” (Mc Dermott & Weber, 1998).

The right time for the mentor to step in. The social nature of the development of these tinkering projects foregrounds the situated aspect of learning with friends with shared resources. These activities organized collective attention, children organized attention on their own terms, and identified problems and potential solutions. When questions and concerns are raised at this point, mentors can explain the science behind he mangle, make sense of the puzzle, and begin unravelling the mangle while modelling or reflecting the tinkerers reflective conversation.

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CHAPTER 4

TAKING TINKERING HOME: DESCRIBING CHILDREN'S TINKERING ACTIVITIES FOLLOWING PARTICIPATION IN A WORKSHOP

Renzo built a horse using plastic straws. His mother, sitting at a distance, keeping track of his progress, wondered what he was learning. It was the second time this month that Renzo had been here, playing with random stuff like plastic bottles and glue. The library promoted the workshop as one that was a part of its STEM learning outreach, but she had her doubts. At home, she worked hard to keep Renzo focused on math and reading homework, and his school had coding lessons once a week.

It took Ms. D's students four weeks' worth of the once-a-week class period to sew a pillow for themselves. She had chosen this particular activity from a list of potential maker projects that was handed out to her and her colleagues because of its simplicity and the ease with which materials could be found. The PTA had donated soft felt, washed cotton, plastic needles, yarn, and synthetic foam. Her students, an enthusiastic team of third to fifth graders, had decided to donate the pillows to the kindergarten. They decided how big, how fluffy the pillows needed to be and learned to sew. The maker sessions were full of chatter and sharing over discussion of how difficult it was to sew, but Ms. D wondered what STEM skills her students had acquired while making a pillow. She had used the suggested lesson plan, but what other than the measurements they had taken this week would the kids learn?

As the Maker Movement continues to march onwards, enthralling us with tools that promise endless possibilities, smart projects shared at Maker Faires, and children using 3D printing technology to print out toys they have designed themselves, parents and educators are faced with challenges. These challenges include deciding what counts as making and tinkering, how children can be taught to make and tinker, and how children can learn STEM while making and tinkering. The two big questions at this moment are it looks like fun but what are they learning, and more importantly, how are they learning? In our rush to adopt making and tinkering to teach and learn the use and application of some select technologies, we seem to have forgotten that children like to mess around with things around them, taking things apart, often mixing and interchanging parts. Some children even take to making and tinkering as hobbies in domains such as crafts like sewing, paper-craft, play with clay, buildings things, digital arts, etc.

Lee, King, & Cain (2015), describing the coming together of a Makerspace and a community in Utah, rightly pointing out that although the movement is described as a grassroots movement, it gained popularity because it brings us back to our roots. Indeed, humans make and tinker with materials, tools, and objects, children make stuff out of stuff and the Maker Movement, and the enthusiasm about making and tinkering that has come with it, has made it possible for us to re-examine how people, in this case, children, are learning while making and tinkering. Gabrielson (2015) shares the story of Robert Noyce and children growing in the American Middle West who, as adults, “dominated the engineering frontiers” situating their experience of learning and tinkering in the geographic, social, and material context. The importance of such contexts and how they shape experience and learning that emerges from it is important even in 2018 in the Middle-West and everywhere else. In this chapter, adopting a sociocultural view, I describe two boys’ experience of tinkering over the period of ten weeks and connect it to their social and material context. This helps me contribute to the Current understanding of children’s learning while tinkering by describing how children engage in tinkering after attending a tinkering workshop at a library. I describe how their tinkering practices and understanding of materials and design develop over time. In doing so, I provide a glimpse into two young boys' tinkering worlds, the materials they tinker with, who and what supports their activities, and what encourages them to tinker.

Theoretical framework: Framing learning while tinkering

To develop my arguments conceptually and to build a basis for the analytical approach, first, I elaborate a socio-cultural theoretical framework that can capture tinkering as a learning activity.

What does it mean to learn while tinkering? This question becomes relevant when we acknowledge that tinkering is an activity that is situated in the history of humans, as well as communities and persons. Individuals tinker with materials, tools, and objects around them to modify them to meet a need, to salvage components, to create something entirely new, or out of curiosity. Human interactions with materials have been described as a mangle (Pickering, 1995) of agency and intentionality. Humans enact their agency by intentionally acting on materials (tools and objects are made of materials) and materials enact agency according to how they are configured by nature, their physical and chemical properties and ambient forces of nature, but lack intentionality. Over time, humans make sense of the response of materials, but occasionally materials respond in unexpected ways and resists its capture by human agency. These new ways of responding to human agency could be because of new actions by humans or familiar actions in a new material context, and count as new interactions. These new interactions arise in response to the demands of tasks and environments, competing demands of children's simultaneous activities (Goodwin, 2011), as well as negotiation with materials and tools (Schon, 1992; Pickering, 1995). These are some of the factors that influence tinkering as an activity that children engage in and can be captured through a broad activity theory framework and interactionist perspective (Greeno & Engeström, 2014; Jordan & Henderson, 1995; Vygotsky, 1978) at any point in time and social situation (for example, a tinkering workshop and home).

Transactions within an experience. I think of learning while tinkering as an experience (Dewey, 1938; Roth & Jornet, 2014), one that manifests itself in and as passions, and integrates over space and time. An experience captures activities of tinkerers, their material and social environment, their transactional relations (mutual effects on each other), and how they feel about their work. An experience of learning while tinkering, like any other experience, is not sealed off from the general stream of experiences and extends in space and time, for example, an individual's general experiences with the world, materials, tools, and artifacts. Knowledge construction within an experience is recursive and takes place through transactions, the process of making sense of the world by interacting with it in ways that change the object of study as well as the mind. Meanings made through transactions become relevant and are tested as and when the situation warrants it, and as a result, both transactions as well as their outcomes evolve with time (Biesta & Burbules, 2003, as cited in Jornet, Roth, & Krange, 2014).

One activity among many others. As mentioned before, children's activities like tinkering arise in, and are related to the context of all other activities they engage in. The many dimensions in which other activities have their bases in, for example, material, social, cultural, psychological, physical, and others, have a bearing on each other (Azevedo, 2018), and are inseparable from one another (e.g., Saxe, 1996). Any activity in one's repertoire is situated in the moment (Jordan & Henderson, 1995; Stevens, 2010) as well in a history that accounts for how it is produced at a time (for example, Greeno & Engeström, 2014; Rogoff, 1995; Cole, 1998). Personal histories of participation studied in the context of hobbies such as amateur astronomy and rocket building (Azevedo 2011; 2013; 2018) have been framed as an individual's "historical patterns of practice participation, within and beyond the immediate context of action" (Azevedo, 2018). I look into the personal histories of two boys in the domain of tinkering and trace their participation on a project-to-project fashion, the connections they establish with other elements of their lives, and seek to find how these interact in the development of their personal tinkering practice.

The boys' fabric of activities. diSessa describes an individual's range of activities as a fabric woven with individual thread stands of single, specific activity within a larger repertoire (diSessa, 2000). A new interest, like tinkering with technological tools, following this metaphor, is a part of the weave of the fabric and understanding the activity means understanding both the fabric and the thread - seen in the characteristic weave that the emergent activity creates with the fabric. An implication of this metaphor is that all threads are connected, that any single thread may extend through the fabric, the many domains in which one participates, and somehow connects them. Studying the weave of children's activities tells us how interest-based activities such as tinkering are integrated with all other activities they engage in. I specifically look into learning while tinkering, how the thread of tinkering-related activities is integrated with the threads of the boys' other interest in the unique context of their family. I define learning as an increasing awareness of affordances and constraints (Greeno, 1998) of a system that emerge in a microworld through constant negotiations and conversation (Pickering, 1995; Schon, 1992). Negotiations with materials of a design situation have been described as reflective conversation that are a part of larger sense making process, a mangle (Pickering, 1995). Humans make changes to materials and objects in their surroundings based on what they know or expect, and every once in a while, materials and objects surprise us with unexpected responses that pique our curiosity and challenge us to delve deep into how things work.

Using this framework, I answer two questions:

A. How do the boys' understanding of materials and design develop over time?

B. How do the boys' tinkering practices develop over time?

In the following sections, I describe the design of the study exploring tinkering activities of two boys, the nature of their activities, how I captured and analysed their activities, and finally, present findings**.**

Methodology

Context of the study

Matthew (12 years old) and Gabriel (8 years old) are brothers, home-schooled. Their father runs a construction-related business from home and travels a lot and their mother is a former healthcare practitioner who now stays at home to home-school the boys. The parents take turn to accompany the boys to programs and workshops at libraries across the city. They were participating in a coding workshop when a week-long tinkering workshop was scheduled at a library and asked to be accommodated on another day. Since their mother began home-schooling them, their educational activities have been divided into categories like online coding games that the boys play by themselves, science and math content through worksheets, apps like Brainpop, books, and experiments that their mother identifies from searching the world wide web. Both boys are avid gamers, but neither parent believes in learning through games. They are both "good at school stuff" like math, spelling, and reading.

After participation at Toy Lab, a week-long tinkering workshop at a public library makerspace, they joined me for eight more sessions, some remotely, and some face-to-face. AT the workshop, children aged eight to twelve tinkered with circuit components (sticker Copper tape, 3V 2032 batteries, LEDs, and vibration motors), art and craft resources, and discarded toys to create projects to take home. The following timeline presents their progress over the eight weeks following ToyLab. Like some other children who participated in the workshop, Matthew and Gabriel are workshop veterans. Since their mother began homeschooling them, they have been to almost every STEM workshop offered by community libraries in the metropolitan area. Some of these workshops are about STEM-based crafts, like making pinhole cameras out of shoeboxes, others are about robotics. The boys think the robotics workshops are cool because the components can be coded to make robots do things. They have but one complaint, that participants are not allowed to take these components home after the workshop. Matthew and Gabriel have other hobbies too; for example, they are allowed to play Minecraft for an hour every day. Other than Minecraft, they both play Terraria, Gabriel plays Poptropica, and they both play Mario. Surpassing their interest in everything else is their passion for Legos; the boys are builders, and since their father is in a field of work related to construction, he encourages their interest. The boys were overjoyed to participate in the study and to have someone to help them make their own toys, in Gabriel's words "like real Lego stuff. . . The real stuff, like the men in factories make."

Collection of data. Because of extreme summer weather conditions, time constraints, and the nature of their hobby-based activity, the boys' tinkering activity could not be captured in a uniform manner. In the first three weeks, the boys and I connected through Google Hangouts; I had mailed a tinkering tools package to them in the previous week before each session. In the next three weeks, we met at public libraries, at a university campus work-space, and a restaurant and their activity was captured on video. After these six weeks, the boys began to work on a project a day and their mother emailed the pictures to me; the boys and I talked about the projects during our weekly telephone conversations. They were able to answer a lot of questions about their work and influences. We continued to meet once a month to chat about projects and exchange ideas, materials, and tools.

Finding the right depth for analysis

Resnick and Rosenbaum (2013) use the term tinkerability as a feature of "many materials-such as wooden blocks and modelling clay—support and encourage tinkering, enabling people to create houses, castles, bridges, sculptures, and other structures." I set out to capture how Matthew and Gabriel exploit the tinkerability of materials around them. To be able to capture these moments, I use the method of interaction analysis (Jordan & Henderson, 1995) to study their experience of tinkering within the span of the tinkering workshop. To capture how their knowledge of tinkerability changes over time, I adopt a transactional lens (Jornet, Roth, & Krange, 2016) that allows me to capture transactions (two mutually influencing events) within the boys' experience of tinkering. An experience of tinkering would include several transactions between materials, tools, and objects and the boys, situated in the socio-cultural and material environment, rooted in history, and yet constantly evolving.

In line with the framing of the study, I documented Matthew and Gabriel's activities as the naturally occurring activities (Hall & Stevens, 2016; Jordan & Henderson,1995) in a place set up for playful tinkering (their home and a university office space modified temporarily). In keeping with the requirements of both interaction and transactional analysis, I recorded knowledge in use, in actions, and in practice in the boys' tinkering activities and talk in ways that are adequate for practical purposes. To enable close, repeated analysis and accountability that allows alternative interpretations of the boys' activity, I captured their interactions with each other and materials on video (Saxe, 1996; Atkinson & Heritage, 1984) and on photographs. I interpreted the video recordings as evidence of the boys' conceptual practices (Hall & Stevens, 1995; Stevens & Hall, 1998) to conceive, plan, and implement tinkering projects to their own satisfaction and requirement as well as learning while tinkering as an activity shaped by what the boys take to be relevant for their practical activity (Stevens, 2010). At this level, I also set my focus on what influences their projects, what they say influences their projects, how and what kind of importance their parents place on these projects and tinkering as an activity, and how the boys engage with these projects in the near future.

Analysis of data. Anticipating a massive volume of data, I began an initial pass through the data soon after recording it, tracked the progress of the boys' projects and looked for their engagement in tinkering activity and mention of influences both intentionally and unintentionally. Because of the high number of projects (twenty-seven in all) the boys worked on, I chose four that are representative of all project types for closer analyses. I identified "hot spots" (durations of video that captured the boys' activity in ways that were relevant to the analysis) in the videos and analysed them for interactions and transactions, as described in the next section. I also noted their parents' talk for mentions of what kind of activities s/he encourages the boys to engage in, the general nature of their projects, and how they are valued. I began looking for influences of the wider socio-Copperltural context after the initial ten weeks were over; this includes instances of their sudden interest in soldering, professional quality toys, and the modified Ozobot.

Next, I reviewed all field notes, images, and video recordings to familiarize yourself with the data, writing up analytic memos about what I observed in the data and created a chronological order of their activities. In the first level of exploratory, non-specific coding, I looked for the boys' tinkering activities, boys talking of other activities, and things they like to do. At this stage, their ideas become data for analysis, data about their tinkering activities. I now had a general view of their participation in tinkering over eight weeks with rich, explanatory stories (Polkinghorne, 1995) that are shared as findings. I coded these stories for affordances and constraints of materials, tools, and designs that the boys noticed and instances of problem solving during tinkering. Once again, I created a chronological order that presented an idea, that the boys tinkering activity was evolving, and details of this idea from the data. In the final round of analysis, I examined how their participation in one tinkering project connected to aspects of their life. A colleague and I went through these codes as they had been applied to situations till we reached agreement on all codes.

Case study with embedded units. I present my findings as a case study (Stake, 1995) with embedded units bound by time and activity (Stake, 1995). The case is descriptive in nature (Yin, 2003) and captures activity in a near-natural setting. I use the embedded units to describe the boys' projects and activities related to the creation of these projects; while the holistic case helps me describe their tinkering activities in general. The embedded units can be seen as sub-units of a functional macromolecule with individual functions that contribute to the whole. I build a cross-case analysis, present it as a summary, and connect it to the holistic case. I shared my analysis of the tinkering projects with Matthew and Gabriel and another boy their age, and my analysis of the influences of the social context with the parents as well as the boys. Such a method of sharing analysis with participants has been suggested as a way to clarify interpretation.

Findings

In this section, I first provide a general overview of my findings and then provide specific details divided in categories. I begin with the general overview. Two specific aspects of the boys' activities are worth mentioning because they bear directly on the upcoming analysis. First, workshop activities were highly open-ended, which allowed the boys to explore a wide variety of circuit designs, and design-material-circuit combinations. Once the basics of circuitry were explained and the boys could construct a basic circuit, they were free to make their own project and consult facilitators only when they needed to. Second, work on any single project continued beyond the duration of the workshop, and the boys worked on some projects for several hours on their own. Once the workshop was over, the boys continued to work on the projects at home with their parents and two friends who occasionally joined them on workshops. This allowed them enough time to try out their own emergent interests in ways they saw fit.

Analysis of retrospective reflection from the boys shows that both boys had been working on several other projects along with the maker projects, trying to stay entertained while learning new concepts. They had to convince their parents that their tinkering was learning, specifically, learning content about circuits. Both boys had been participating in

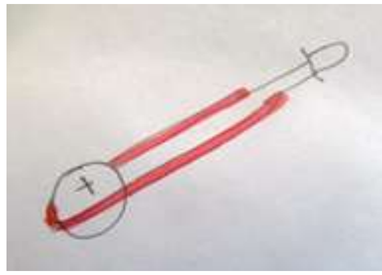
Lego workshops for a while and had occasional access to the electronic components that come with the high-end sets. These components are rare, at least considered so, and workshops are expensive, but the boys' parents consider these an investment into their future and insist that their kids participate in every such workshop offered in the area. Matthew and Gabriel describe their participation in these workshops as extremely guided; facilitators carefully regulate their design moves and methods because the projects are taken apart and components taken back after the workshop. Getting to build projects, their sub-components and taking them home was a big motivation to the boys. Some of their tinkering projects, for example, building Lego electronic components, therefore, represent an uptake of a preexisting interest and activity.

I share Matthew and Gabriel's tinkering activities over the eight-week period as three phases, each represented by projects they worked on during the time. After describing the phases, I discuss their learning relevant to each phase.

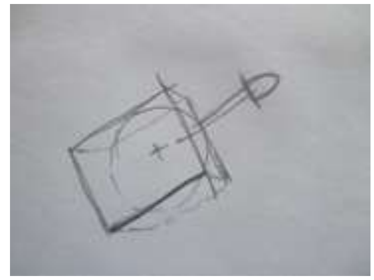
Phase 1

During the workshop and for some time following the workshop, the boys had trouble creating functional circuits independently. The boys say that their projects just would not work; their circuit arrangements reveal that they were having problems attaching the wire to the right leg of the LED. They began with a basic paper covered battery and LED inserted on it as a flashlight. One of the legs of the LED would not touch the battery without pressing on the outer paper packaging, they used this as a switch to turn the flashlight on and off.

(a)



(b)



(c)

(d)

Figure 4.1 Matthew's sketches of (a, b) wrong ways in which he and Gabriel connected the battery to the LED, and (c) the design of the flashlight with the battery in a paper encasing. (d) A photograph showing one of the boys' wrong circuit orientations with the Copper tape wound all the way around the battery.

The boys later created a switch-operated flashlight encased in Lego blocks: Created right after the workshop, this project has a very simple structure with a few Lego blocks, tape, a battery case, an LED, and a switch that snaps in place. This flashlight was structurally sturdy.

During this phase, the boys also worked on a pair of noise-making tins with vibrating motors inside – comprising of a vibration motor-battery unit taped together and inserted into a mint tin, it was a project that was not planned but conceived in desperation. It had no switch and the battery had to be removed from the motor manually to save battery life or to stop the noise. Distraught at how “like nothing” their project seemed in comparison to the other projects at the workshop, they went to work on the noise making tin. They needed to think why and in which specific way was their project unique – it’s a rattling tin box, but how would they sell the idea to their friends? Friends wanting to replicate one of their projects was a sign of their appreciation, and they had “copied” some of their friends’ projects, but would their friends replicate the rattling tin box?

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Figure 4.2 (a-h): Three projects created by the boys; a, b, and c: The Lego flashlight. d, e, and f: Another flashlight created using a toothbrush case - three double-sided tape dots have been used as space fillers; g and h: The vibrating mint tin.

Phase 2. The boys and I had talked about making the now famous Doodle-Bot when this idea struck them - a helicopter with a vibrating motor-head and a light attached to its propeller. When the motor makes the propeller spin, the light attached to the propeller spins with it. They already had the special Lego parts required to make a helicopter and knew how to work with them; the spinning light idea and moving propeller, however, was thought of only when they realized that these additions would be possible.

Figure 4.3 The boys' collection of helicopters, the one on the right is seen with a vibration motor attached to it. The motor originally was attached to a battery.

The boys had a codable toy that could read color as code and respond with an output of colored light. Inspired by an idea on Pinterest, they already had a table with a washi tape path on the top, and the toy follows its path according to its code. Using their new tools, they added a non-codable vibrating carry-on to the robot; both the robot and the carry-on were covered with transparent plastic cups with optical fibers glued on them (salvaged from a toy), when the toy was set in motion, it created a disco-light like pattern on the ceiling.

Phase 4. As avid Lego fans, the boys had been wishing for Lego electronic components. Earlier this year, they had been gifted Lego technic sets by their parents, and now they wished for bigger, better parts like motors and batteries in Lego encasing that could be integrated into projects with ease. Inspired by these components, they created a block encasing a battery that powers a motor. The rotating head of the motor is attached to a gear and their plan was to attach a range of things to the gear to create effects. For these two projects, they needed their father to solder connections and cut off bits of the Lego blocks.

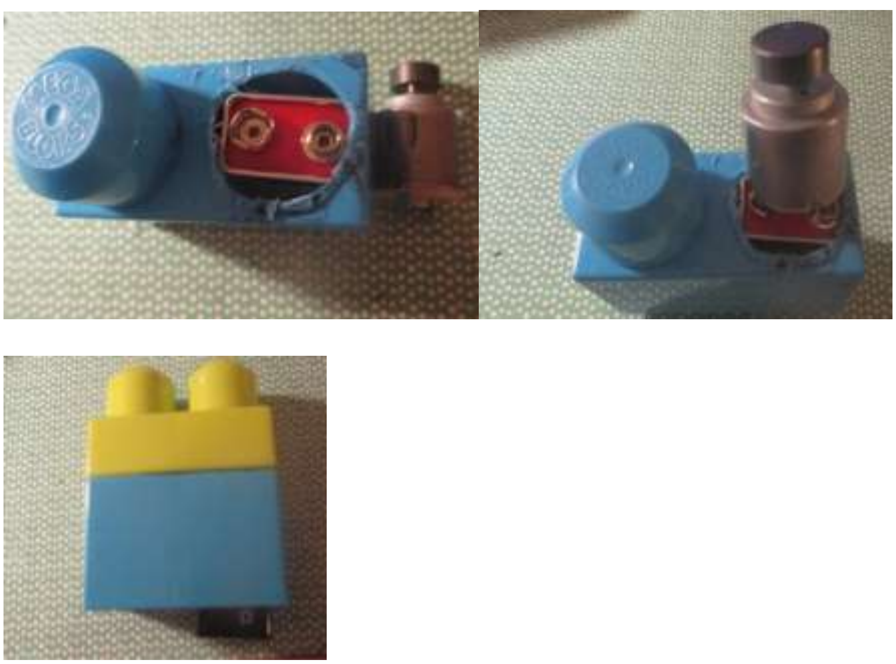


Figure 4.4 A test arrangement of the Lego vibration motor with a powerful motor and battery.

The boys worked on a number of other projects, but for practical reasons, I am not sharing these projects or details regarding them in this chapter. In the following sections, I will discuss findings in relation to the focus of my two research questions: (1) changes in the boys' understanding of materials and design over time, and (2) the development of the boys' tinkering practices over time.

Understanding of Materials and Design

I have organized findings related to the boys' developing understanding of materials and design into two broad categories. First, I will discuss their learning in relation to the affordances and constraints of circuit-related projects. Second, I will discuss changes in how the boys sought ideas, resources, and assistance, reflecting their growing understanding of specific aspects of the tools and materials they recruited for their projects.

Affordances and constraints of circuit-related projects. Matthew and Gabriel began their work on circuit-based components with some trouble. Although Matthew had learnt about circuits in school, "like a line going around things like batteries and lights and stuff," both boys had trouble building a circuit. Their projects show that, initially, they thought that as long as the LED and the battery were in contact, + to +, - to -, with or without a wire, the LED would light up. The Copper tape was tightly wrapped around the battery, the LED was glued to the Copper tape without cutting the tape off in the middle, and a bit of tape leftover after the circuit was completed, was wound halfway around the battery. When these arrangements did not work, they struggled to make sense of the failure. Finally, they learned that circuits work only when the "Current is forced to go through the LED and light it." In Gabriel's words, "Although it is simple. . . Rules have to be kept in mind. . . (It is) not like bringing the wires and stuff together and things work." Their next challenge was finding something to make with a circuit.

While creating the flashlights, the boys found out the simplest form of switch - preventing any one leg of the LED from touching the battery. For the Lego flashlight, they used components from a finger light. This allowed them to study the components of the finger light, take it apart, and reuse the components in their own design. The Lego flashlight had a switch and could be operated like a real flashlight. Because it was built with Lego blocks, it could be attached to larger Lego projects and was much sturdier. "No other DIY flashlight has a switch that works so well, " according to ? Drilling holes into materials is another skill Matthew and Gabriel had to learn. Soft plastics and wooden blocks were vulnerable to a metallic drill, and brittle plastics needed to be secured with fabric or insulated tape before drilling into it to prevent the plastic from cracking. Taking bits off Lego bricks was more difficult because of the construction and the quality of plastic. On such occasions, they used heated drills and knives to cut off parts.

For future tinkering projects, while they did not feel the need to go beyond the simple circuit design, they found out that even when the current travels a very short distance, the connections between circuit components need to be robust. Since the circuit is a part of a toy, the set-up cannot disintegrate with continued or even rough play; tape can only survive so long or so much. To construct circuits that could survive play, Matthew and Gabriel moved on to learning to solder connections from their father. To make room for circuits and switches, they learnt to Cu Lego blocks with hot knives; to keep arrangements compact, they used insulated materials as space fillers. To upgrade circuits in their tinkering projects, they had to find ways to modify other project-related materials to accommodate these upgrades.

As is evident, both affordances and constraints of materials and designs were noticed and used.

More importantly, they learnt that materials and tools, as well as designs have both affordances and constraints. On one occasion, they took apart a toy that was purchased at two for a dollar and found that the wire connecting the circuit was too fragile to be tinkered with. While transplanting components of the finger-light into the Lego flashlight, they found the circuit components and arrangement to be simple, but everything was held together in a way that was very sensitive to physical disturbances. Manipulating factory made toys, making new ones from scratch, and transplanting components requires understanding both affordances and constraints of design, and materials. Additionally, their projects included some degree of negotiation between their choice of materials, design aspirations, and what was possible in a situation.

As Matthew and Gabriel’s projects increased in number as well as complexity, their combined repertoire of skills expanded. Examination of their projects makes it evident that their skills regarding circuit design did not extend much, since they never used academic vocabulary or drew circuit diagrams as would be expected of them in the future. However, their skills regarding modifying the simple circuit, using it in new material environments, and adding novel upgrades received a major boost. Tinkering with circuits, in the case of these two boys, taught them how to construct basic circuits well and how to use circuits to enhance a pre-existing skill, for example, building with Legos and making their own toys to play with.

The material resources around them inspired immediate solutions and alternatives to all problems except for times when skill upgrades were required. When Matthew and Gabriel realised they needed to learn to solder, they described it as glue for circuits. Just like working on paper crafts is impossible without learning to use glue, soldering is an indispensable skill.

Seeking ideas, resources, and assistance. The boys sought ideas and resources in increasingly sophisticated ways as the weeks passed. As mentioned before, when the boys began working on the circuit craft and tinkering sessions, they were beginning to learn about circuits. Although they were aware of circuits in toys and other objects around them that had circuits built into them (for example, table lamps), their exact design and more importantly, how to put one together, baffled them. In the weeks that followed, instead of asking for ideas, the boys sought ideas and resources for projects independently, occasionally asking specific questions instead of general ones. I share two examples here: the first concerns the attachment of the appendage to the Ozobot in week 5, and the second concerns the repair of a damaged headphone, in week 9, after they learned to solder under their father's tutelage.

When the boys worked on their Ozobot-disco light project, they were disappointed to find out that they could not modify the toy's code (making it respond to something other than the four colors), the circuitry, or the structure. This was their first attempt at making the toy do something different from what it was supposed to - function as a disco light in a darkened room. With the hope of making the vibration motor a part of the PCB inside the Ozobot, they took apart its outer casing by themselves and realized how daunting the task would be. Their next plan to tape a motor and light unit and a battery onto the casing did not leave room for dual disco light effect. At this time, the boys requested a "thin but sturdy piece of material" to be cut off and folded to "link the two units of their design" and "have a nest" for the battery-motor-LED unit. They considered the thickness of the material, the places it would need to be folded, how it would need to be folded, and the dimensions of the nest that would be appropriate for the unit to stay put, the motor head to move freely, but not fall of at the same time.

A headphone that belonged to Matthew had suffered some damage; the wire had come of the headgear, and the boys wanted to fix it. By this time, they had learned of soldering to "glue" circuits", seen different kinds of wires (Copper tape, thin Copper wires encased in plastic in toys, and conductive thread), and seen that each of them, depending on how efficiently they conduct electricity, are used in specific ways in projects. Although they would see thin strips of Copper wires exposed at the edge of the wire, the boys set out to fix their headphone with conductive thread. They were confident in their choice and sought help only to solder the conductive thread to the metal wires and then seal the encasing. When trying to use the headphone they saw that while the soldering worked on the conductive thread, the wire-thread mixture did not "fix" it; no sound could be heard through the headphone. A little more than a week later, they salvaged wire from a discarded lamp and soldered it to the headphone's wire; the headphones worked and their project was a success. There were no questions about the conductive thread and why it did not fix the circuit, but the boys were confident in their problem-solving ability and begun to work independently.

A lot of their Lego+circuit project ideas were inspired by one YouTube contributor but they freely modified the projects to suit their skills and need. They used Pinterest to catalog ideas, often not looking into techniques and details but focusing on the general idea, and even critiquing projects for being too simple, or making comments such as "where's the fun in making this?" Often, they set out on a project, looked for required Lego pieces in their tub of assorted pieces, found something that interested them, and made modifications to their original plan. I discuss such cases later as personal excursions. Changes in the boys' utterances from "What do I do?", "How do I make something out of this?", "Could you see what's going on?" to "I need you to hot glue this for me", "Cu the block along these lines", "Solder the wire here" are testimony to their growing independence in tinkering and related problem-solving process, and in some cases, better recognition of affordances and constraints of materials, tools, and designs.

Development of tinkering practices over time

In this section, I discuss several findings related to how the boys' tinkering practices developed over time. I start by discussing the trajectories of their projects, followed by their personal excursions out of circuitry, and how skills were acquired to complement ideas. Lastly, I discuss how the boys situated circuit-craft in the overall fabric of their activities.

Project trajectory. After I initiated construction of circuits using Copper tape, batteries, and LEDs, the boys faced failure for two weeks and made several copies of the basic flashlight. As the weeks progressed, their use of circuits progressed, so did the boys' projects, and although the projects appear in a linear fashion in the timeline, the ideation and excursion were anything but. During their work on the projects, they switched frequently between a private, deep in thought mode and a social, idea-sharing, feedback accepting mode. Some projects, like the helicopter with moving lights was created almost on-the-go with short breaks in between while others like the Ozobot-Disco lights combination were created in steps and in pieces with days and even weeks between them. During these intervals, they talked about how good their Current project was going to be and possible alternatives to challenging tasks, added to their Minecraft worlds, won challenges on games, played basketball, attended camps at libraries and enrichment school, watched TV, and shared their achievements with their friends.

The nature of personal excursions out of circuitry. Such episodic detours have been conceptualized as personal excursions - deeply personal, recurring self-initiated activities which align to the goals of the original activity and often result in the collection of resources that feed back into both subsequent and Current activities (Azevedo, 2006). While personal excursions may last for varying periods of time before people come back to their pursuits sporadically or because of a more conscious effort to return to their work, their nature and duration depend on one's longstanding and emergent goals, and the relationship between those goals and the goals of the activity-as-framed. In the video recorded sessions, the boys can be seen taking personal excursions to talk to each other or friends about games, play a favorite game, work on another construction, and talk about some recent incidents before coming back to their project with new ideas and changing it. While working on a Lego-vibration motor powered fan, the boys followed a path of activity that lead to the goal, but while planning further modifications, Gabriel had the idea of using the motor to power a moving light on a Lego crane, one of his side-projects. In doing so, however, he switched to an activity, the Lego helicopter, that related to some of the tasks in the activity-as-framed, the clothespin-motor powered fan, but which did not fully align with the goals of that activity. Gabriel did not come back to the modifications of the fan, but Matthew did and he remained invested in it. On another occasion, while working on the LED-crane device, the boys began talking of the lead character in Minecraft, began constructing a Lego version of the character, and did not come back to the project at all during the session. Their conversation during this exCopperrsion was entirely about games, and the comparison between Minecraft and Terraria, the two games all participants avidly participated in and followed on some YouTube channels. They came back to their project weeks later at home.

Gabriel described subsequent personal excursions as involving performing magic tricks learned on YouTube, watching some more YouTube, and performing a few backflips to "clear the mind" while Matthew described them as intense Minecraft and Lego time. Both boys said that during personal excursions they did not think about the tinkering project at all but always returned to the project with a new-found interest and fresh ideas, like a "car with a new engine. . . pushed the project in a new direction." The "push", as we can see, comes from the general area of their personal, everyday interests, and who they are as children; it seems to be a very specific combination for an individual.

Skills to complement ideas. As their ideas expanded and metamorphosed, Matthew and Gabriel felt the need to learn some advanced skills that would facilitate the creation of better projects. These projects would be unique and allow and withstand various manipulations and hours of play without falling apart. Their wish was not limited to the context of tinkering; for example, while working on the Hour of Code challenge, Matthew wanted to make a Gumball character do a somersault but the program accommodate it. On another occasion, Gabriel wanted to make the Makey-Makey respond to a clothespin made entirely out of plastic and realized that the device responded to electrons passing through conductive materials. To make it respond to touch, through a non-conductive material, they would need a touch sensor to be incorporated into the device and that required a different "skill-set". Both boys had trouble holding their creations together with rolls of tape and hot glue and circuit components frequently detached from the toy; their father offered to secure circuit components with solder. Their father recalled the soldering session as quite an event, describing how his boys watched as he soldered connections in place, Cu blocks after measuring things exactly, and showed them a few "tricks of the trade". Watching him work, the Matthew and Gabriel realized that they knew about half of what was required. They had ideas and knew how to put together a circuit, while Dad knew how to solder and measure, and make plans that actually worked. Dad, however, did not know "school stuff" like terms for circuit components, the flow of electrons through different materials, and problem-solving with code. Their craft, therefore, constituted of "two parts", one they knew and one they didn't. In Matthew's words, "You need to know what to glue *and* how to glue. You *just gotta* be really good at gluing things."

Situating circuit-craft in the fabric of activities. When asked to describe their project ideas, inspirations, and generally, what inspires them to tinker with Lego pieces, toy parts, and circuits, Matthew and Gabriel pointed to both the nature of tinkering as an activity and its alignment with the general fabric of activities they were involved in. Lego, games like Minecraft and Terraria, popular crafts like slime making, playing with tech-toys, building models from kits, and workshops at libraries are non-sports activities they engage in on a regular basis. They keep each other and friends updated about their achievements in virtual game-worlds, they keep their parents aware of projects they pursue inspired by the many workshops and YouTube channels. They seek new ideas from friends and resources and encouragement from parents. Hearing them describe their passion for their hobbies, seeing how these hobbies influenced their tinkering and their projects, it is difficult to separate them as a unique activity among many others. Yet, the boys find time to tinker when they get bored of playing videogames, and they turn to making slime when they get bored of tinkering with Lego and circuits; their choice of activities depend on what they are able to accomplish while engaging in it.

Discussion and Implications

I had set out to answer two questions, first, how children's tinkering practices develop over time after participation in a tinkering program, and second, how their awareness of materials and design progresses. In this final section, I situate the boys' learning in the broad context of their everyday life and STEM learning, and then discuss what their activities mean for STEM education through making and tinkering.

What children draw on while tinkering. The broad activity theoretical and interactionist perspective (Greeno & Engeström, 2014; Jordan & Henderson, 1995; Vygotsky, 1978) that I adopted captured how children draw from and rely on the wide and rich fabric of activities while tinkering with materials and tools. Their activities were further influenced by factors like parental expectations and profession, personal aspirations, lifestyle, and the materials and social arrangements around them (specifically, Cole, 1998; Rogoff, 1995, 1997). New technological components, like circuit components in this case, when introduced, were quickly adopted for use in other domains, like games, favorite toys, and aspirations were designed around it. Aspirations functioned as drivers/motivations for new projects and eventually practice. Matthew and Gabriel's case demonstrates how learners integrate new ideas, meaning, and experiences into existing ones while tinkering. However, such a phenomenon of a new activity blending into their lives is probably not exclusive to the context of tinkering; the boys talked of their game-related building and tinkering in the same way, talking of negotiating similar affordances and constraints to find trade-offs.

What's old is new again. The boys had little conceptual knowledge of electricity and circuit design. When the concept of electric Current flow through a circuit and circuit design, and technologies like copper tape, motors, different batteries were presented to them, they were recast as "things" that power toys and can be found in them, an impression that allowed them to explore designs to power toys through concepts that were previously inaccessible to them and opened up a new domain for exploration. Such freedom to mess around, create, and implement their design through trial and error that is typical of tinkering created a unique environment for the boys in two ways. First, a lot their work took place in a social and yet personal space in the presence of friends, inspired by content on YouTube, but in the absence of teachers and mentors. No one was present in these situations to point to design problems, potential solutions, the right concepts and assist with problem solving, but since the projects and the ideas were relevant and meaningful to children's personal lives, they proceeded further and ended up learning. One might question their learning given the complete absence of circuitry related learning in the boys' projects and this indicates the need to examine their learning in a different sub-context, for example, one that includes Lego pieces and the toys they modified, the skills they learned, and the questions they learned to ask. Second, we see that making and tinkering, and teaching and learning unfold in a context where the design of the activity, learning to use circuits, enables the use of ideas from everyday life to enrich children's intellectual life in areas they can relate to. This situation in which the boys use circuit components on their old Lego parts, parts they have played with for a long time, enables the creation of a new context in which ideas using both Lego and circuit components can be tried out enabling experimentation. Making and tinkering, hence, is not just a medium for teaching; they are a set of powerful ideas for children to explore and learn to learn in a familiar context that can be tied to the broad fabric of activities they are a part of.

The benefits of excursions of the personal kind. In considering the trajectory of the boys' projects, I find a pattern - their tinkering projects are rarely initiated and completed at one go, they take personal excursions to pursue other projects, to play, and to share ideas with friends and family. The ways in which the boys relate to each project, and the timing and nature of the excursions are hard to predict, but the excursions, as Azevedo, too, noted, function as "energy generators", problem solvers, and idea generators for the projects. Through these solutions and ideas, they extended their projects and generate possibilities for future pursuits. The implications of such excursions are important. As children participate in several domains through these excursions, they engage with different materials, practices, and even epistemologies (for example, scrapbooking versus designing and printing stickers for use in scrapbooking). These experiences demonstrate to children that a number of skills and knowledge in various different content areas are involved in being a good tinkerer and a professional one in the future. Continued engagement in tinkering might be akin to a push in related but different disciplinary areas.

A transformative experience for a father. The boys' father, as mentioned before, runs a construction related business from home. He operates out of a van and a storage, and helps his boys with math and drives them to workshops and soccer practice, considers his work to be far away from the world of STEM. Offering help to his boys on one of their building projects was a transformative experience (Wong, Pugh, & The Dewey Ideas Group at Michigan State University, 2001) for him - soldering, a skill that he uses solely in the context of his profession, was the skill that saw the projects to completion. These experiences are defined by characteristics such as motivated use, expansion of perception, and experiential value and have been linked to important learning outcomes in children. This implies that the role of parent, too, needs to be nurtured; parents can be motivators, supporters, as well as co-learners. Their familiarity with a child's fabric of activities and social circles might enable parents to put together materials from their surroundings to engage in tinkering and design solutions for problems. The use of technology in such cases need not be new, but it might bring out unnoticed affordances in familiar materials, suggest uses for familiar practices in new activities. Seeing making and tinkering in this light makes us realize greater possibilities for STEM education than we have realized yet.

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CHAPTER 5

CONCLUSION

The chapters that comprise this dissertation investigate children's tinkering activities while participating in a workshop and for eight weeks after participating in the workshop. In doing so, this dissertation makes scholarly contributions to our understandings of children's loosely structured tinkering while working with craft and technological resources and working by themselves, with peers, and with adults. In the arena of making, tinkering, and learning, this study calls attention to the many types of tinkering projects that interest children, how they solve problems, how they make sense of what they see (for example, scientific phenomena manifested in their projects), and how their interest in tinkering is combined with other interests they might have. With regards to the Maker Movement in education, this dissertation identifies opportunities for teaching and learning in simple craft and tinkering projects and offers examples of failures encountered by children that can be problematized to teach scientific concepts. In addition to these, this dissertation describes an important aspect of children's engagement in out-of-school activities. While the children who participated in the workshop did so because they already had an interest in tinkering, this dissertation documents their activities related to tinkering after workshop. Joining other studies examining the connection between making, tinkering, and learning (Bevan, Gutwill, Petrich, & Wilkinson, 2015; Litts, 2015; Brahms, 2014; Calabrese Barton, Tan, & Greenberg, 2016) this research contributes conceptualizations of learning while tinkering with everyday resources and technological components and children's participation in such activities.

To fully understand the ways in which children, through participation in interest based activities like tinkering, contribute to their own learning, it is useful to conceptualize how activities mediate repeated participation and learning in the long term within and across contexts.

For instance, in chapter one, I highlighted the kind of collaborations that children engage in when they find ideas that interest them or challenge them to think. In chapter two, I described the way children make meaning of material puzzles that emerge while tinkering with both materials and tools. Both these chapters add to the sociocultural and ecological conceptualization of the interacting roles of practices, and resources in human development, specifically, how children contribute to their own learning by intentionally appropriating and adapting the resources available around them.

The learning ecology supporting and enabling learning through tinkering would require an understanding of both resources available in the environment and how interest-based tinkering self-initiated learning plays a role in development. Although what initiated an interest in tinkering was beyond the scope of this dissertation, it would suffice to say that there were "ideational resources that are available in diverse facets of a learning ecology" (Barron, 2006). We see that once interest in tinkering is sparked children utilized various strategies to further their skills and understanding of materials, tools, the social support required for tinkering, and to seek and develop new ideas. As we can see in the third chapter, interest-based tinkering that can be supported using resources readily available to families can enable both parents and children to be knowledge brokers and may enable boundary crossing into other areas of interest. The learning ecology in such cases can only be imagined as a dynamic entity characterized by the diversity and depth of learning resources and activities.

By drawing upon both craft and technological resources, this dissertation demonstrates that they are both rich resources for learning. In fact, because of the familiarity and comfort with everyday materials and skills, both children and parents might be able to explore the material and aesthetic attributes better. Combining everyday and unique technological resources like e-textile components, too, makes for rich learning opportunities. Had it not been for the sewable e-textile components, children might never had the opportunity to explore the conductivity of felt and other fabrics. While children's progress through their projects and learning that results from it is important, how parents supported their activities is impressive too. Dougherty (2014) mentions how at Maker Faires parents who themselves were engineers and scientists often ask how children can be groomed to be engineers and scientists as well. Dougherty insists that these parents clearly see the value of making and tinkering activities and the value of playing with technological kits and toys, but the connection to learning, and more specifically, STEM learning isn't apparent to them. One way to address to address such a gap in understanding might be to encourage parents, not just parents who are engineers and scientists, but all parents, to see these connections while tinkering with their children. Everyday materials and technologies makes this a possibility. Rather than equating technology use with learning, tinkering and sewing can reveal the richness and negotiation that is inherent in building and tinkering with artifacts.

This dissertation also contributes to the scholarly literature on science education by beginning to reinforce what it means for children to use newly learnt information in ideas of their own and to make them a part of their lives. Too often, we are tempted to teach content to children. From museum and library workshops to school lessons, educators and learning and technology enthusiasts constantly endeavor to teach children advanced STEM content, formulae, and complex tool usage, without considering how such knowledge would bear upon their lives. This study demonstrates some instances when children use new knowledge to create something for themselves, something that they would like to engage with on their own time. Such kind of engagement beyond the duration of a workshop elevates the status of tinkering projects from just artifacts to Objects-to-think-with (Papert, 1980). As we see in the projects that children created, the advantages of having an object-to-think-with are several. Children devote time and intellectual resources to these objects, these objects mediate social interactions with peers and mentors, and by wanting to improve these objects, learn to use existing skills in new ways and even learn new ones.

Finally, this dissertation contributes to the literature on informal STEM education by providing an example of how learning experiences like tinkering lead to life-long, life-deep, and life-wide engagement (NRC, 2009). Such integration presents an opportunity to recognize the contributions of peers and parents, mentors like workshop leaders, and the power of idea-sharing through platforms like Pinterest and YouTube.

Directions for Future Research

The contributions made to the arenas of making, science education, and informal STEM education can be expanded in a number of ways. First, tinkering and making could be examined across a range of communities, activities, and settings. I see new technology infused craft, sewing, knitting, painting, pottery etc. as a few promising avenues among many others. Second, the role of family and friends can definitely be explored to include parents in the role of mentors for learning popular and/or traditional skills. Third, the role of children's preferred social media can hardly be ignored. From game play to tinkering and craft, YouTube and Pinterest are full of inspirational shares and tutorials that children access with their friends and family to enhance their projects. The role and power of such a network and a constant source of support can hardly be ignored.

Implications for Maker Education

Educational researchers have long suggested that while teaching and learning with technological and material tools, the focus should be on how children use tools and not the tool as such (for example, Papert, 1983; Resnick, 2002; Resnick, Myers, Nakakoji, Shneiderman, Pausch, Selker, & Eisenberg, 2005; Blikstein & Krannich, 2013). 3D printing objects without knowing how 3D printers work, how 3D objects can be designed, might not be very beneficial for children. The problem is not just with 3D printing, but with circuits as well. When children learn about circuits, they should be able to use circuits to make them do things for them, like add circuits to purses and notebooks. Such maker projects initiated and developed by children with assistance from mentors, parents, or experts hold promise.

Often as parents and educators, our goal is to educate children and do engage them in productive ways and we often define productivity in very restricted ways. Although the idea of legitimate peripheral participation has been around for long, messing around is not counted as learning. Maker education might enable us to see the value of messing around with materials and tools. Making sense of mangles is difficult and requires practice, but with time, children might develop their own ways of meaning making and problem solving, and modify existing solutions to personalize them for unique situations. Situativity of problem solving and knowing is well developed area of research and its benefits are clearly known.

Finally, since messing around, tinkering, and making stuff-out-of-stuff is a lot of fun, it promotes social interactions not just between children, but between children and enthusiastic adults as well. The opportunities for collaborations, mentorship, apprenticeships, and skill development are rich. Through tinkering children might be able to consider alternate viewpoints, empathise with others, and act as social and technological brokers to enrich their own as well as others' lives.

Limitations

The first limitation of this study is the small number of participants involved. Secondly, I studied tinkering activities of children who have a passion for tinkering and craft. Not all children might want to tinker, learn while they tinker, or learn through tinkering. As can be seen in the chapters, I did not teach or test kids for conceptual knowledge. Additionally, findings from this study cannot be extrapolated to scenarios like choice of courses later in the lives of these children because they are dependent on a number of factors that cannot be predicted at this time. Based on their interests and inquiry, what children notice and learn, how they connect personal aspirations, identity, and Cultural capital to tinkering would be important to determining its value as an activity.

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APPENDIX A

OVERVIEW OF GENERAL DATA REDUCTION AND ANALYTIC STRATEGY

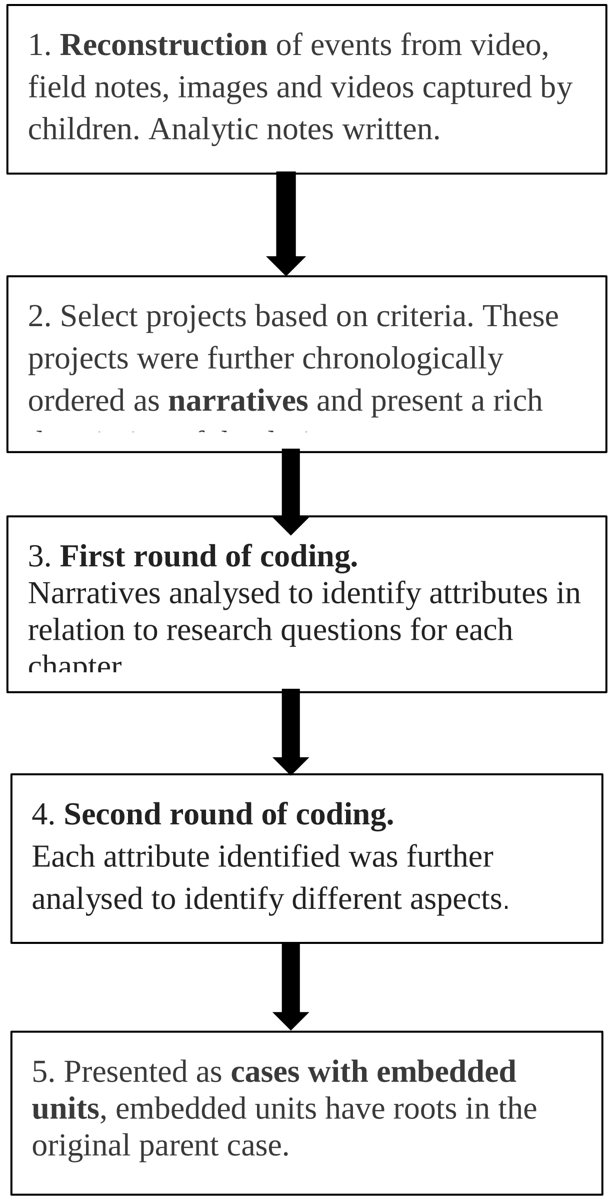
1. **Reconstruction** of events from video, field notes, images and videos captured by children. Analytic notes written.
2. Select projects based on criteria. These projects were further chronologically ordered as **narratives** and present a rich
3. **First round of coding.**
Narratives analysed to identify attributes in relation to research questions for each chapter
4. **Second round of coding.**
Each attribute identified was further analysed to identify different aspects.
5. Presented as **cases with embedded units**, embedded units have roots in the original parent case.

Table 1
Plan for the Workshop

Day	Goal	Materials
1	Introduction to LEDs, batteries, circuits, and using toy parts/whole toys to make a new toy or repair an old one.	Discarded toys, circuit components, LEDs, toolbox, construction paper
2	Using a vibration motor to modify an old toy or make a new one. A Hex bug is an example of a toy that uses a vibration motor.	Discarded toys, circuit components, LEDs, vibration motors, toolbox, construction paper, craft supplies like pipe cleaners, and pompoms.
3	Exploring circuit components that look different - sewable LEDs, things that can be used as wires in a design.	Discarded toys, circuit components, e-textile components, LEDs, vibration motors, toolbox, construction paper, craft supplies like pipe cleaners, pompoms, sewing supplies, fabric, and felt.
4	Free choice tinkering using different toy parts, motors, circuit components to create anything you want.	Discarded toys, circuit components, e-textile components, LEDs, vibration

		motors, toolbox, construction paper, craft supplies like pipe cleaners, pompoms, sewing supplies, fabric, and felt.

Table 2.
An Example of Reconstructed Data

Events, questions/comments Reconstructed	**Source of information**
Copper tape circuit session, Day 2	
Henry likes the vibration motors, especially because the motor head spins and he can see it. He says that if the head is blocked in some, the motor won't work (vibrate). He connects to a battery with two-sided tape, the unit vibrates and spins around the table. Henry wants to make Hexbugs. He covers the unit with pipe cleaners, Adds to LEDs onto the same motor-battery unit as the bug's eyes. Bug moves slowly and Henry finds this to be problematic. He takes a few layers off, now it does not look as realistic. Henry removes the battery, he says he thinks it is the making the unit heavy. He uses Copper tape to connect the motor to the battery. This works well.	video field notes

New problem: tapes sticking together, disconnecting battery and motor, also where to attach the LEDs? Inserts Copper tape into milk shake straws, keeps the tape pieces from sticking to each other. Holds the battery in his hand. This no longer looks like a bug. “This is a remote-controlled car without a remote control. The battery is the control in my hands, see how it moves? Just like a control car.”	video field notes
Makayla, Makenzie, Henry working on circuits built into wooden clothespins. Henry uses clothespin to fit a vibration motor in it. Makayla and Makenzie use their phone to access Pinterest and find clothespin projects, choose a clothespin butterfly. Henry likes their clothespin butterfly and wants to make something like it, takes a clothespin and looks among other supplies. Wants to use a vibration motor. Clothespin has a small depression in each half, uses this depression to hold vibration motor, inserts construction paper Cuoff onto motor head to make a fan.	video field notes
E textile session, Day 3	
Elements introduced, I show how things work and begin sewing using conductive thread, tell them it is just like making a copper tape circuit.	video field notes

Glenn with a threaded needle in his hand, where does this go? I show them how to sew, very confused looks. Henry tries it out first. Makayla and Makenzie follow. Emma calls mom for help, she has left the table to learn how to sew from mom. Glenn calls his mom too.	video field notes
Conductive thread disintegrates in Henry's hands, twice. Emma is confused, This is so difficult, Priyanka, could you help me, please? What do you need help with? How do you sew? P shows her, walks over to other participant, Emma walks over to mom, she helps her. Mom sews the whole think with cond. Thread. Nothing works. Emma says nothing works, asks when to use thread, when not to? Will it go through many layers?	video field notes
Henry gets the circuit working, shows it. All kids move to his place at the table. Henry shows them. Emma compares her project to his, Henry talking to her. Emma walks over to P's place, looks I used this for sewing everything, everything got connected, that's why it is not working. Sits with it, looking at it. P, please help me. What do you want me to do with it? Fix it.	video field notes

P begins to take the stitches apart.	
Glenn's mother is at the table, kids don't know how to sew, you know that, right? Begins sewing for Glenn. What do toy want me to sew? The wires of a circuit. Okay, show me how to make one. Glenn calls Henry, asks him to teach mom, goes away to play. Comes back, add buttons to this, where are the big buttons? P, where are the big buttons? I want big buttons in my circuit. Emma hands him the big buttons. Mom, I had in my doll's clothes when I was little, laughter, small ones, though. How?? Actions. Glenn points, right here, somewhere, one in one half, and one here. Runs away to play area, mom keeps working on circuit. Very quiet.	video field notes
P continues to work on Emma's circuit, Emma, this is very tightly sewn together. I know. This will take me some time to take apart, may I take this home? You can go ahead and make another one just take another bag of supplies.	video field notes

Emma wants to make a corsage and has already measured and Cu pieces of felt for the band and pink felt pieces for petals. She arranges them around an LED popped onto a battery to see how it looks. Okay, can he help me? Points to Henry. He comes over to help, spring in his step □	
Workshop next to ours, J leading, sewing for beginners, has a scheduled break. Librarian D Walks all kids to "potty break". P gives kids a break as well. Gillian walks over she is Henry's sister, shows her sewing project to Henry, tic-tac-toe on a felt swatch. Henry shows her his circuit sewed onto the felt patch. Gillian, I like your workshop, do you have some for me to take home? Will you show me what you made? Sure!	video field notes
Post break: Emma sewing simple circuit on felt, a turquoise blue swatch she likes. She gets it right. I had to wind the wire several times around the hoop, just like Henry said. Now I need something to make with this. . .	video field notes

Glenn's circuit works! Henry's questions, what does the button do? Glenn, nothing, it is just there. Henry, may I see it, please? Emma lets out a gasp, how did you do it? Henry, this is actually a switch. All heads together at table. Ani, you know why? There's no way for the Current to flow through the LED and so it does not light up. Snapping the buttons is like turning off a switch. I will make one too.	video field notes
Ani's project is a tiny blue felt purse. Two bright pink pipe cleaners have been inserted into holes Cu into the felt to make handles. Base of purse has circuit sewn into it. She has also made a pink wristband, bright pink, two layers, bottom layer has circuit sewn into it, light glow can be seen. She has stapled the two edges of the wrist band together. Ani asks for something to pull the pink thread off the pipe cleaners. P, ask the gentleman at the desk for a suitable tool. Ani came back with a tweezer, a plastic one. Too much work, went back to the gentleman again, came back with the ends exposed.	video field notes

Arranges for snap-button circuit, falls short of pipe cleaners, goes to desk again. Winds exposed wires around hoops on LEDs, battery holder, and snap-button. Too much looping, wires are difficult to bend and wind around hoops. Changes plan, lets go of snap-button, I mean it is still good, right? Has poked her finger in a few places, band-aids.	
Emma needs ideas, has stopped working on her project for some time, folding paper to make origami swans. Asking for ideas. Makayla and Makenzie admire her origami, suggest that she make these a part of her project. Emma asks me, is this a good idea? Do you think it would be possible? P: Yes, you can add circuits to paper. Emma, but I still want to make the fabric circuit. Pause	video field notes
Ani's purse is ready. She says that she is done for the day. She asks for some supplies to take home. She wants to make a tie with lights in it. Harry Potter style.	video field notes

Henry has a swatch with a snap-button fabric for practice. The thread has broken several times. He decided to take a break. Two hours are almost up.	video field notes
Emma decides to place origami swan on blue felt patch with circuit sewn onto it and covered with another blue patch. Is this good enough. Priyanka? It is very pretty, Emma. What do want to call it? A swan in a lake, swimming. Will you try to fix my circuit? I would like to make a corsage with it.	video field notes
Project updates post-workshop	
Henry and Gillian worked on their snap-button circuit on a tote bag. Gillian learnt to sew, Henry wouldn't have it. Sewing with this thread is different, not like the usual stuff. Gillian agreed (Henry had samples). All e-textile components had holes in them and Henry and Gillian used the them to insert copper tapes through them, like Ani had inserted pipe cleaners. Once they saw that their idea of using copper thread instead of conductive thread worked, they began arranging components on the tote. All components of the circuit, including the snap-buttons, were hot glued onto the tote.	conversation/email exchange with parents conversation with child

Emma began work on her corsage months later. She learnt to sew the basic run in the time between the workshop and returning to work on her corsage. Her mother helped her. She showed her mother how a circuit works, following her directions, mom sewed the circuit. They needed a few attempts to get it right. Emma wanted the flower to glow from underneath, two layers of felt petals in fuchsia and pink did not let enough light through. She replaced them with plastic pieces Cu out from a milk gallon jar. This could not be sewed to the base. Finally, she chose all three layers to make the flower and glued everything onto the base. This didn't work either, the flower kept coming off. She then punctured two holes into the plastic and sewed it onto the piece of felt with the circuit components sewed into it.	conversation/email exchange with parents conversation with child