The Learning Practices of Making: An Evolving Framework for Design

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Making as Learning

Making is characterized by interest-driven engagement in creative production at the crossroads and fringes of disciplines such as science, technology, engineering, art, and math, and has developed into a recognized social, technological and economic movement. (Honey & Kanter, 2013; Sheridan et al., in press). Making has emerged as an engaging entry point and activity for STEM education (Making Meaning Report, 2013; Peppler & Bender 2013), workforce development (Executive Office of the President, 2014) and the development of innovative and entrepreneurial skills (Benton, Mullins, Shelley & Dempsey, 2013). As an emerging phenomenon of education reform, making is becoming an established feature of many environments and experiences designed for informal learning. Cultural institutions, such as museums, science centers, and libraries are expressing growing interest and investing in the integration of making into exhibits and programs. Amidst this overwhelming wave of programmatic adoption, designers, funders, and policy makers are seeking evidence of learning in order to rally public support and substantiate their investments.

MAKESHOP at Children's Museum of Pittsburgh

Opening on October 23rd, 2011, *MAKESHOP* at Children's Museum of Pittsburgh is a rich and supportive informal learning environment for children and families to engage in authentic making experiences with "real stuff." A partnership of the Museum, the University of Pittsburgh Center for Learning in Out of School Environments (UPCLOSE), and the Entertainment Technology Center (ETC) at Carnegie Mellon University, *MAKESHOP* embodies the Museum's dedication to nurturing and furthering informal learning opportunities and research-based understanding at the intersection of the digital and the physical. *MAKESHOP* provides Museum visitors open-access to digital media resources and physical materials to produce a robust place for curiosity, exploration, creativity, and innovation. A dedicated facilitation team comprised of skilled makers, artists, and educators with specialties in the areas of digital media, sewing and flexible materials, electronics, woodworking, and informal learning introduce visitors to the diverse materials and processes of making as they help visitors translate their visions into tangible products. The presence of facilitators skilled in both the domains of making, and in the facilitation of visitor experiences is a central component of the *MAKESHOP's* design and practice.

At the Children's Museum, we are currently engaged in the process of developing and defining a learning framework for making. In this report, we will describe the recursive process of developing this learning framework and illustrate the ways in which the framework is applied to families' making experiences in *MAKESHOP*. Through our collaborative design-based approach to research, practice, and analyses, we have identified key factors of design that influence and support children and families in making as a learning process.

What Do We Mean by Learning Practices?

In this report, we apply a *practice-based* approach to learning and making in the context of a museum makerspace. This perspective draws upon theories of cultural and social learning, which assert an understanding of learning as fundamentally tied to the social and cultural contexts in which it occurs and focuses on the "practices" that define learning communities (Brown, Collins, & Dugid, 1989; Lave & Wenger 1991; Wenger, 1998; Gutierrez and Rogoff 2003; Greeno, 1997). By practice, we mean the "…more or less coordinated, patterned, and meaningful interactions of people at work" (Spillane, 2012).

The practices identified in this report are observable and/or reportable evidence of learners' engagement in making as a learning process. Below we will provide examples of what we mean by the learning practices. In considering these learning practices, we acknowledge that the tools and materials of making help learners actually engage in the practices and they can be seen or reported both in the moment and possibly across many visits to *MAKESHOP* (Engestrom, 2000; Haapasaari, Engestrom & Kerosuo, 2014).

Why Learning Practices?

By identifying definitional *learning practices* in which learners engage through participation in *MAKESHOP*, as well as the elements of design that are responsive to and support learners' participation in these practices, we are attempting to develop a common language around making that is practice-based (Brown, Collins, & Dugid, 1989; Lave & Wenger 1991; Wenger, 1998). This common language is intended to guide discussions across settings about making as a learning process by identifying ways to conceptualize, support, and assess such forms of learning through design. Ultimately, this work will enable us to make empirical claims about making based on the actions, interactions, and work of making as it is being carried out in informal and formal learning contexts.

Over the past year, the staff of *MAKESHOP* have engaged in an ongoing, iterative process of articulating and refining the *Principles of Practice* which guide design, development, and facilitation of making as a learning process within our space and through our programming. By focusing on *Principles of Practice*, we are attempting to define a framework that serves as a tool for identifying, describing, and ultimately designing for making as a learning process within *MAKESHOP*.

Our first step in developing a framework for learning practices of making was to identify core practices at the center of the making community (Brahms & Crowley, in press). Through a content analysis of *Make Magazine*, the most popular and nationally recognized textual source of maker community participation in the United States, we identified seven central learning practices of making as they are understood and translated by the community of makers themselves. Using this initial set of practices as a baseline, we looked to see whether and how such core making practices might be enacted and studied as part of family activity in *MAKESHOP*. Through microanalysis of participant interaction in 20 video-based observational episodes of family participation (Erickson, 1992), we were able to locate and trace children's participation in maker practices through an afternoon of making in the museum (Brahms & Crowley, under review).

Next, we sought to understand how these practices resonate as a framework for learning in context. *MAKESHOP* Teaching Artists and museum researchers engaged in a collaborative process of testing and refining the practices. We participated in weekly critical discussions to consider the conceptual space that existed within each of the learning practices, and whether and how such learning practices were core to the experiences the teaching artists as designers and facilitators of making. Through these efforts, various practices were collapsed and modified and language was changed to reflect the realities of the context.

In addition, our research-practice team at the Museum has identified missing links between the learning practices we consider to be central to making in our space and our ability to comprehensively support such forms of participation. In response, each teaching artist has identified aspects of activity, program, space, and/or facilitation design that may be modified and tested through small design experiments to better support learner's engagement in the practices. Through regular iterative testing, data collection, reflection, and discussion, teaching artists have presented their evolving designs and observations of visitor experience to the team for feedback. Together, the team has generated new understanding as we have considered the ways in which the iterative designs align with or challenge our assumptions and aspirations as designers of rich learning experiences. Importantly, this messy and rich design process has offered concrete examples for our practices, surfaced counter-examples, and generated new categories that help shape the core of what we consider ambitious making experiences.

This work has enabled the team to close gaps between desired learning behavior and current museum practice, to further reveal observable and reportable evidence of children's engagement in the contextual learning practices, and to point towards elements of design that support children's engagement in these practices. Through this work, we have established a common and contextual language for learning that is shared across research and practice.

MAKESHOP Learning Practices

MAKESHOP Learning Practice	Practice Description
Inquire	Learners' openness and curious approach to the possibilities of the context through exploration and questioning of its material properties.
Tinker	Learners' purposeful play, testing, risk taking, and evaluation of the properties of materials, tools, and processes.
Seek & Share Resources	Learners' identification, pursuit/recruitment, and sharing of expertise with others; includes collaboration and recognition of one's own not-knowing and desire to learn.
Hack & Repurpose	Learners harnessing and salvaging of materials, tools and processes to modify, enhance, or create a new product or process; includes disassociating object property from familiar use.
Express Intention	Learners' discovery, evolution, and refinement of personal identity and interest areas through determination of short and long term goals; includes learners' responsive choice, negotiation, and pursuit of goals alone and with others.
Develop Fluency	Learners' development of comfort and competence with diverse tools, materials, and processes; developing craft.
Simplify to Complexify	Learners' demonstration of understanding of materials and processes by connecting and combining component elements to make new meaning.

Designing to Support Learning

Children's Museum of Pittsburgh's mission is to provide innovative museum experiences that inspire joy, creativity and curiosity. The Museum's guiding design philosophy is "play with real stuff," which promotes an organizational commitment to the use of authentic materials and processes in all exhibits and programming. This philosophy is manifest through all aspects of the Museum's planning and practices, from the composition of our staff to the design choices we make. Intrinsic to this approach is a deep respect for the Museum's visitors, and the belief that a well-designed and beautiful environment that uses sustainable and quality materials, affords visitors — children and adults alike — a comfortable and empowering museum experience.

The following *principles of design* reflect our current understanding of the ways in which we are designing to best support learners' engagement in *MAKESHOP* learning practices. As we continue this important work, we anticipate these principles to evolve in scope, alignment and language with respect to the learning practices.

Design of Space

Exposed Construction: Elements such as furniture, fixtures, and exhibit components, are fashioned in ways that reveal the contents and methods of their construction.

Flexibility: Elements such as activities, furniture, materials and tools are constructed and positioned in ways that allow for flexible and varied use, reconfiguration, repurposing, and social exchange of resources.

Productive Proximity: Elements such as activities, tools and materials, are arranged in ways that elicit productive associations and invite inquiry.

Access: A variety of real tools, materials, processes and learning resources are visible and physically accessible.

Minimal Instruction: Instructional signage is kept to a minimum to enable varied experiences and undetermined outcomes.

Design of Activity

Personal Pathways: Making experiences are learner-driven, choice-based and empower leaners' development and refinement of interest, identity and personal learning pathways.

Scaffolding: Making experiences develop comfort and competence with diverse tools, materials and processes by providing material and social resources that are approachable, accessible and supportive.

Process-Orientation: Making experiences are process-oriented, have undetermined outcomes, and provide opportunities for extended purposeful play, testing, risk-taking, and evaluation of material properties.

Repurposing: Making experiences inspire learners to identify and use familiar tools, materials, processes, and ideas in new or unexpected ways.

Productive Proximity: Components of the making experience, such as mechanisms, tools and materials are arranged in ways that elicit productive associations and invite inquiry.

Design of Facilitation

Expertise: Facilitators bring domain-specific expertise and a passion for possibility to the learning context.

Inquiry: Facilitation supports and invites learners' choice as well as development of intention, interest, and personal learning pathways through inquiry.

Scaffolding: Facilitators support learners' development of comfort and confidence with diverse tools, materials, and processes.

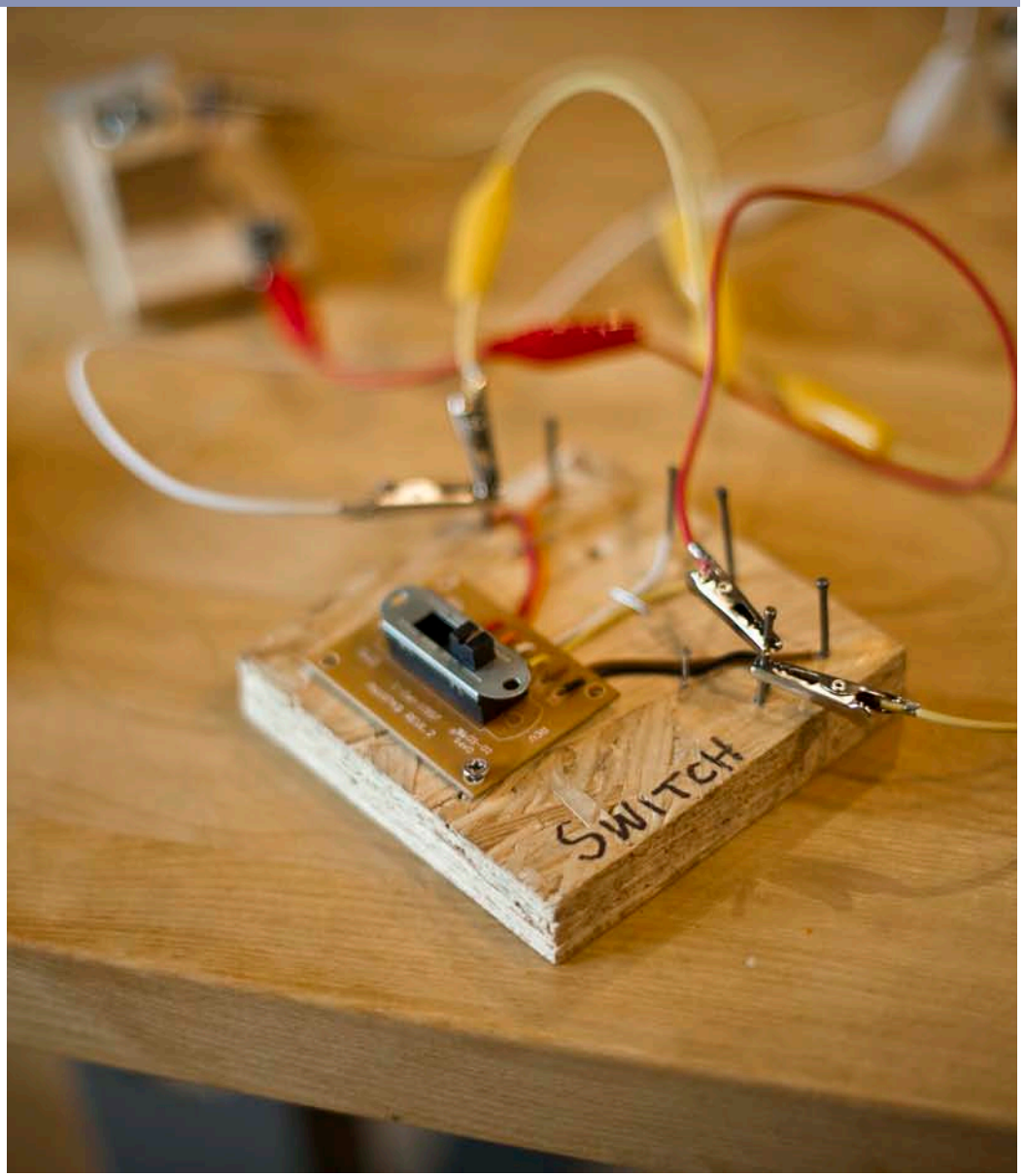
Co-Learning: Facilitators are co-learners (of visitors and fellow educators) in all making pursuits.

Leveraging Learning Partners: Facilitators leverage children's adult learning-partners (parents, grandparents, etc.) in best supporting familiar learning habits and extending learning pathways.

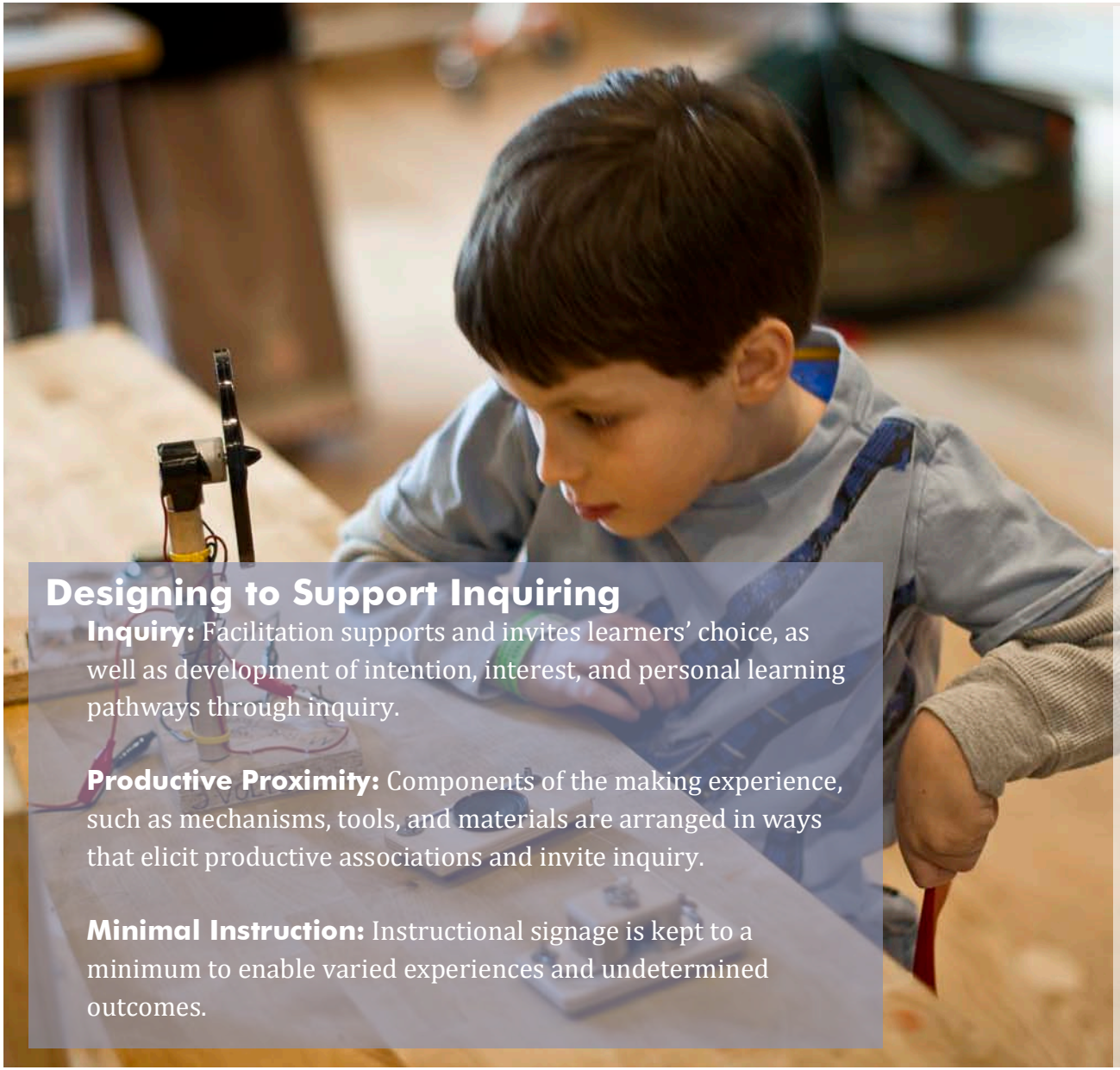
Circuit Blocks: An Illustrative Example

The Circuit Blocks are a collection of wooden blocks with different components and power sources affixed to them. These blocks are made of a variety of materials, such as small motors, buzzers, speakers, propellers, and wheels, most of which are harvested from electronic toys or appliances. Each of these components is fastened to a separate wooden block, with its wire leads exposed and attached to conductive nails. Blocks can be connected to one another using wires with alligator clips on the ends. A number of power sources are available, such as battery packs and cranks, as well as diverse forms of switches, including traditional light switches such as those found in a home, binder clips, paperclips and even conductive hair pins. Visitors may connect and reconnect the various components and switches to a power source with the loose wire leads.

Below we describe and briefly illustrate each practice as it relates to learners' participation with the Circuit Blocks. In addition, we highlight certain principles of design used to support visitor engagement in the learning practice. The examples depicted come from data collected with visitors' consent to participate in research activities, through researcher observation using video and field notes.



Inquire



Designing to Support Inquiring

Inquiry: Facilitation supports and invites learners' choice, as well as development of intention, interest, and personal learning pathways through inquiry.

Productive Proximity: Components of the making experience, such as mechanisms, tools, and materials are arranged in ways that elicit productive associations and invite inquiry.

Minimal Instruction: Instructional signage is kept to a minimum to enable varied experiences and undetermined outcomes.

Inquiring as a learning practice means that the learner is open and curious about the possibilities of the context. This context is the making activity that may include tools, materials, processes, and other makers. The curiosity and openness that the maker exhibits can be seen in the exploration and questioning of the properties of the tools and materials available for the making activity.

Learners often engage in the practice of inquiring as an initial phase in their making process. When approaching the Circuit Blocks, children's inquiry is often heard through a the questioning of the materials before them or of the function of the mechanism, such as when a child picks up a circuit block and asks, "What is this?" or "What does this one do?" Often times, these simple questions provide robust points of entry for deep exploration of process.

Tinker

Tinkering as a learning practice relates to the learner evaluating the various properties of the tools and materials available to them in the making experience. This evaluation might be seen as purposeful play, testing or risk-taking.

For example, there is a small fan on the Circuit Block table. Children often spin the fan with their fingers if it is not moving, and if the fan *is* moving, children often obstruct it with their hand or a piece of wood to see it stop and then start again. The tinkering we see with the Circuit Blocks includes learners swapping power sources, testing different wires or configurations of wires among circuit blocks, flipping switches on and off, and gently striking an alligator clip connected to a power source against different parts of other blocks, such as the nails, wire tails, or holes within a component itself. Children often begin their exploration of the circuit blocks with phrases such as, "Let's see what happens when I try this," or "What if I do this?" As learners are connecting blocks, some connect and reconnect them in ways that complete the circuit as well as ways that do not complete a circuit but exhaust the possible combinations of connecting the wires. We also see tinkering when children work at repeatedly opening and closing the alligator clips or connecting the alligator clips to various surfaces.

Designing to Support Tinkering

Process-Orientation: Making experiences are process-oriented, have undetermined outcomes, and provide opportunities for extended purposeful play, testing, risk-taking, and evaluation of material properties.

Co-Learning: Facilitators are co-learners (of visitors and fellow educators) in all making pursuits.

Seek & Share Resources

As a learner engages in a making experience, they openly rely on the resources available to them to understand how to use a particular tool, what the affordances of certain materials are, and how specific processes may be used to pursue their goals. Seeking and sharing resources means that learners may identify, pursue, and/or recruit the expertise of another in order to carry out their making activity. As participants in the making activity, these learners also share their own expertise with others who are participating. Ultimately, seeking and sharing resources as a learning practice acknowledges, on the learner's part, that he or she does not know some things related to the making activity and there is a desire to learn more.

As learners engage with the Circuit Blocks, we have seen them seek and share resources in several ways. Children observe and show off what they have done to family members or nearby visitors. A child might say to friends or someone sitting near them, "Hey, look at this" when they have made a working connection between a power source and component, such as a light or motor. Once they have made the connection, children often offer an explanation of their process to a parent or Teaching Artist, as a way to processes their developing understanding, as well as to simply express their accomplishment. A child might seek out information, or ask of another child, parent, or Teaching Artist, "How did you make the fan move?"

As children's adult learning partners, Teaching Artists and parents serve as learning resources in important ways. Teaching Artists ask guiding questions and guide children in answering their own questions, as well as model appropriate language use and assist children in getting over conceptual hurdles. Parents assist children by making applied connections between the Circuit Blocks in *MAKESHOP* and familiar elements at home or school, such as holiday tree lights, an electronic toy, or a common household appliance. Parents will often provide technical support to their child by opening and attaching the alligator clips to the conductive nails on the Circuit Blocks, a necessary, but difficult task of using the "real stuff" of electronics for small hands.

Designing to Support Seeking and Sharing Resources

Co-Learning: Facilitators are co-learners (of visitors and fellow educators) in all making pursuits.

Scaffolding: Making experiences develop comfort and competence with diverse tools, materials, and processes by providing material and social resources that are approachable, accessible, and supportive.

Scaffolding: Facilitators support learners' development of comfort and confidence with diverse tools, materials, and processes.

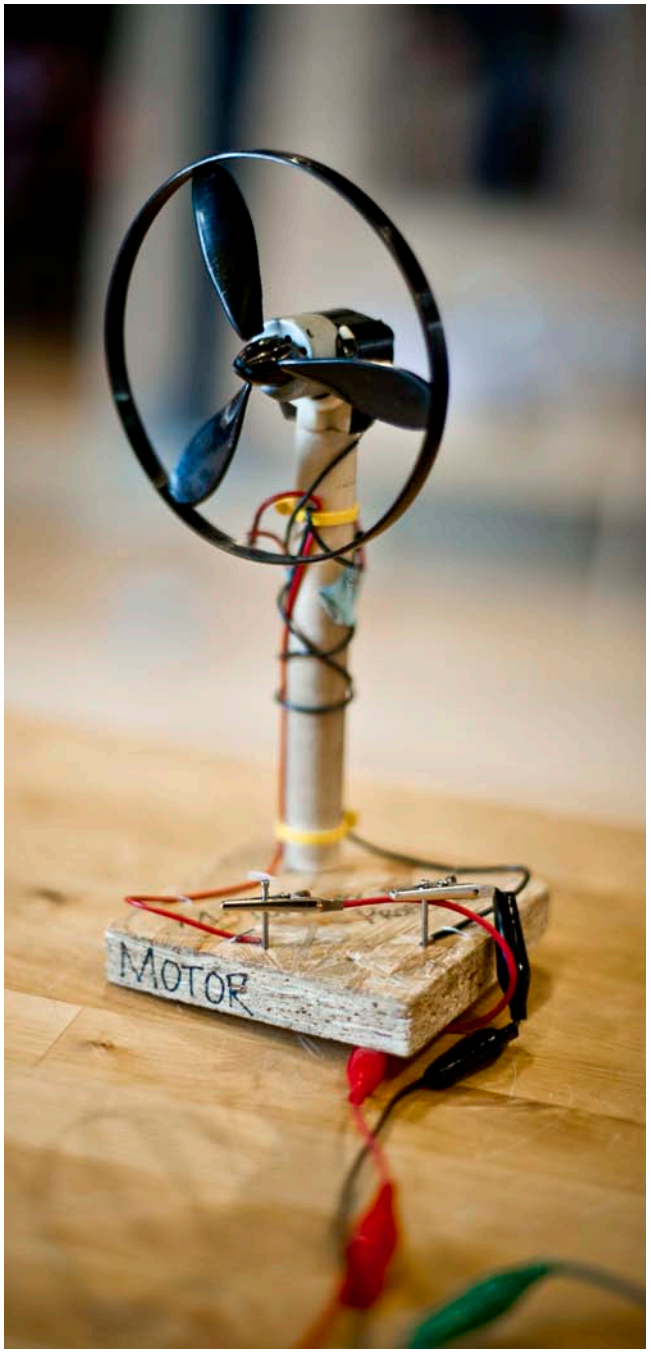
Leveraging Learning Partners: Facilitators leverage children's adult learning partners (parents, grandparents, etc.) in best supporting familiar learning habits and extending learning pathways.

Hack & Repurpose

Learners that hack and repurpose while they engage in making activities demonstrate the potential of materials, tools, and processes beyond their intended use. When learners hack and repurpose, they modify, enhance, and/or create a new product or process by salvaging or harnessing old ones. Hacking and repurposing disassociates the properties of an object from its most familiar use.

With Circuit Blocks, children's engagement in hacking and repurposing as a learning practice includes recognizing and using everyday materials in useful or new ways for creating complete circuits. The Circuit Blocks themselves are made primarily of repurposed electronic components (motors, lights, buzzers, switches, etc.) that have been harvested from old electronic toys, appliances, and devices. This act of deconstruction happens in *MAKESHOP*, as a "take apart" activity, situated near the table of Circuit Blocks, allowing for direct connections to be made between the whole toys and appliances and the repurposed elements of the blocks.

We have seen children suddenly discern that the motor that opens and closes a sliding tray is from a compact disc player, the battery pack attached to the Circuit Block is the same found in their favorite toy, or that they are using a familiar binder clip to serve as a switch that completes a circuit to turns a light on and off. Children will even "hack" the circuit blocks themselves, using an existing combination of power source, component and switch to teach themselves how a connection is made, swapping out different blocks to test variables. We have even seen some children repurpose a motor to generate power for another component, such as a light or buzzer. In workshop formats, children are able to build their own circuit blocks, choosing among a collection of repurposed parts, soldering the elements and wires together and affixing them to wooden blocks.



Designing to Support Hacking & Repurposing

Repurposing: Making experiences inspire learners to identify and use familiar tools, materials, processes, and ideas in new or unexpected ways.

Productive Proximity: Components of the making experience—such as mechanisms, tools and materials—are arranged in ways that elicit productive associations and invite inquiry.

Express Intention

As learners are involved in making, fundamental to the process is the learners' ability to express intention. By this we mean more than the learner following their own path: Expressing intention involves the discovery, evolution, and refinement of the learners' areas of interest through the determination of short- and long-term goals. These goals are pursued independently and collectively through responsive choices and negotiation of the making experience. Ultimately, this process of goal pursuit and interest development serves to foster the learner's personal identity.

Through engagement with the Circuit Blocks, learners exhibit intentionality from the moment they decide to work with the Circuit Blocks and not with some other activity in *MAKESHOP*. Learners express intention by articulating a goal or goal path, such as, "First, let's connect these wires together," "I'm going to get all of lights to turn on at the same time," or "I'm going to make the fan spin faster." Children will make explicit choices about which components they will use and explain their rationale for such choices, as one child swapped out a hand-powered generator for a batter pack and said, "Now I'm going to use the wheel [generator] to make the propeller go faster and faster." Some children will express interest in applying the concepts exhibited through the Circuit Blocks to a larger personalized project, such as building a set of Circuit Blocks to take home, or imagined creations such as a "working robot" or a "weed whacker" with an electronic motor and on/off switch to cause the blades to spin.

Designing to Support Expressing Intention

Personal Pathways: Making experiences are learner-driven, choice-based and empower leaners' development and refinement of interest, identity, and personal learning pathways.

Leveraging Learning Partners: Facilitators leverage children's adult learning partners (parents, grandparents, etc.) in best supporting familiar learning habits and extending learning pathways.

Minimal Instruction: Instructional signage is kept to a minimum to enable varied experiences and undetermined outcomes.

Develop Fluency

As learners engage in making, they may become more fluent in different components of the making activity. This includes the development of the learners' comfort and competence with a variety of tools, materials, and processes. Ultimately, this fluency development might be seen as the cultivation of a learner's craft within a domain.

When making activities are shorter or less sustained over time, it can be difficult to observe fluency development. However, there is a range of ways in which we see children developing craft, especially with circuits. Children will often repeatedly connect and complete a circuit, demonstrating an understanding of how they work. Similarly, adding switches, dimmers, or other additional elements further demonstrates this understanding of circuits. Children may exhibit fluency by using accurate vocabulary and by identifying the right tool for the job, such as knowing the property of a switch. We will often hear children apply understanding by making accurate predictions or extrapolations, or by trouble-shooting, such as testing batteries or checking polarity when a connection does not work as it should.

Designing to Support Developing Fluency

Expertise: Facilitators bring domain specific expertise and a passion for possibility to the learning context.

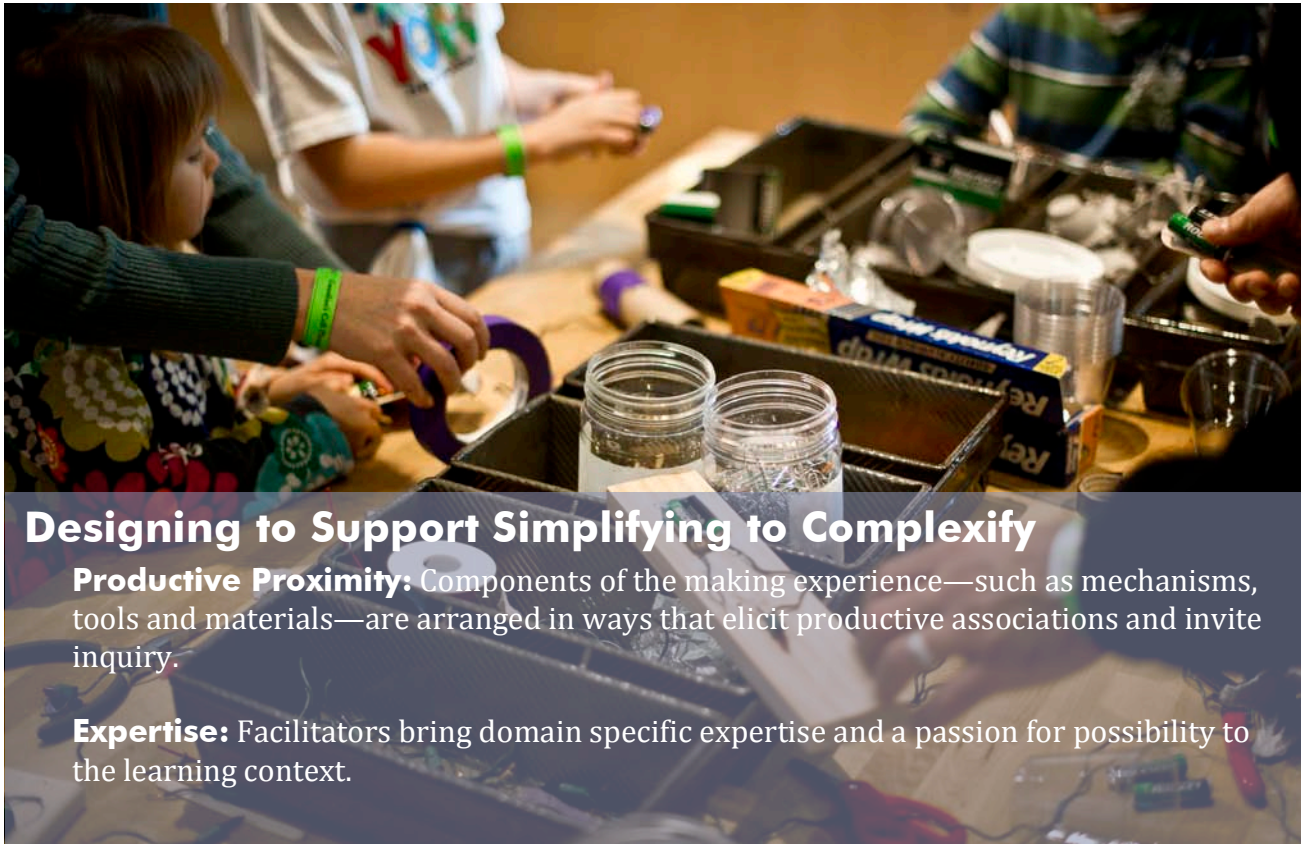
Scaffolding: Making experiences develop comfort and competence with diverse tools, materials, and processes by providing material and social resources that are approachable, accessible, and supportive.

Scaffolding: Facilitators support learners' development of comfort and confidence with diverse tools, materials, and processes.

Simplify to Complexify

In many cases, making enables learners to build and create using a variety of base materials. By simplifying to complexify, we mean learners combining and connecting unique elements to make new meaning of those elements. This serves to demonstrate a learner's understanding of materials and/or processes, and to enable learners to expand and deepen their understanding in limitless ways.

With Circuit Blocks, this practice is basic to building complete circuits. For example, when a child completes a circuit, they are connecting a power source to some sort of output, like a light or a fan with wires. Each of these components is given meaning through their relationship to the others. To a simple circuit (power source and output), the learner can add a switch. The Circuit Block table enables a learner to combine different components in nearly infinite ways, such as building parallel circuits or testing the limits of outputs relative to different power sources. Outputs, power sources, and switches can be exchanged or added to explore possibilities and make new meaning. In addition, visitors have the opportunity to extend or complexify their making experience by applying their understanding of circuits to the construction of an artifact to take home or add to the Museum's collection.



Designing to Support Simplifying to Complexify

Productive Proximity: Components of the making experience—such as mechanisms, tools and materials—are arranged in ways that elicit productive associations and invite inquiry.

Expertise: Facilitators bring domain specific expertise and a passion for possibility to the learning context.

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