Flexibility to Learn: Material Artifacts in Makerspaces

Anna Keune
Indiana University
1900 E. 10th St.
Bloomington, IN 47401
+1-510-277-2289
akeune@indiana.edu

Andrea Gomoll
Indiana University
1900 E. 10th St.
Bloomington, IN 47401
+1-414-531-4901
agomoll@indiana.edu

Kylie Peppler
Indiana University
1900 E. 10th St. Office 528
Bloomington, IN 47401
+1-310-497-8921
kpeppler@indiana.edu

ABSTRACT
Youth-centered makerspaces, applauded for their development of intrinsic motivation and interdisciplinary skills through project creation, come in many forms. This paper explores how material artifacts support learning through their representation of time, projects, and tools for making in three makerspaces. The socio-cultural constructs of boundary-crossing and distributed cognition are used as a lens to explore selected artifacts' flexibility for co-constructed learning in the spaces. Our analysis of boundary crossing focuses on perceived boundaries between adults and youths, insiders and outsiders of makerspaces, and accessible practices, as well as how material artifacts communicate crossing these boundaries. Characterizing the flexibility of artifacts in relation to pliability, accessibility, and mobility, we found that material artifacts can promote co-constructive learning, for example by distributing workflows across artifacts, and that the study of material artifacts might inform the design of makerspaces based on educational theory.

Categories and Subject Descriptors
K.3.1 **[Computers and Education]:** Computer Uses in Education –*Collaborative Learning.*

General Terms
Theory, Documentation, Design.

Keywords
Makerspaces, material artifacts, boundary crossing, co-constructed learning.

1. INTRODUCTION
Entering a youth-centered makerspace, visitors may find tools scattered across tables, cardboard boxes artfully plastered with masking tape, or rows of 3D printers nestled beside colorful reels of filament. From an outside perspective, some makerspaces may appear messy and disorganized—a mix of materials and tools. Others are highly organized—tools and resources divided into boxes with color-coded labels. Makerspaces, primarily informal and out-of-school spaces, have been explored in terms of location, agency, content and projects, pedagogy, and assessment [10], as well as in terms of community and identity. [8] With the continued expansion of making into educational spaces, students are provided with the opportunity to recognize and follow their personal interests. [9] Opening doors to diverse projects and experiences, makerspaces provide learners with time to tinker and set self-directed goals. Learning goals of makerspaces often revolve around interdisciplinary learning and the development of personal identity, community, and collaboration skills through the co-construction of the space. [3]

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While these learning goals guide the development of future makerspaces, it is less clear how the artifacts in makerspaces support learning. As material lists and suggestions for future makerspaces are devised [6], it is important to consider the stories that artifacts tell about the culture of a space. To support those interested in designing youth makerspaces, we asked:

- How do physical artifacts and materials in youth-serving makerspaces communicate access to (a) time, (b) projects, and (c) tools for making?
- How can makerspaces support co-constructive learning through the arrangement of artifacts?

This paper is a study of the material artifacts of three makerspaces: a library space, a museum workshop, and an after-school community program. Taking a sociocultural perspective, we examined artifacts from the three spaces and their representation of salient characteristics of making in order to develop hypotheses about how the physical artifacts in makerspaces afford co-constructive learning. In doing so, we explored how artifacts within the spaces communicate *flexibility to learn*—a term used by our team to refer to the potential that artifacts hold for co-construction—in relation to time, project, and tools for making. This analysis privileged the researcher perspective, as it was driven by the physical set up of existing spaces and drew upon photographic data and field notes. We sought to draw attention to design details that may inform the development and learning cultures of makerspaces.

2. BACKGROUND & GUIDING THEORY
Acknowledging that learning and cognition must be studied in context, we unpacked learning in makerspaces through the examination of physical artifacts. Taking a sociocultural perspective, which connects knowledge to the "social and material history" of a person's culture [7], we studied the discourse, history, and beliefs embedded in the practices of the spaces, as seen through material artifacts.

Understanding that learning is inseparable from context and community, we considered how knowledge was distributed in makerspaces that are co-constructed by their members. A distributed cognitive perspective sees knowledge as within the individual and the surrounding physical and social environment, and explores the relationship between individuals and artifacts [7].

In the fledgling world of makerspaces, what counts as "expert" making is not clearly defined, nor is how a spatial set up can encourage accomplished making. This lack of definition provides a valuable opportunity for participation. Youth makers must have a significant voice in shaping the culture of making through their projects and collaboration—constructing what it means to be an expert as they go. Over time, a cognitive system can be constructed, in which knowledge is situated within the individual and the surrounding physical and social environment. Beyond human interaction, the distributed cognition of youth-centered makerspaces includes the knowledge translated by physical artifacts in the space as they communicate how they are to be used. Thus, we focus on the ways in which materials afford the co-evolution of cognition and culture. Additionally, as young makers learn from and with adults in a makerspace, they develop practice-linked identities, through which they see the work they do and the artifacts they create as an important part of who they are.

The complex relationship between the members of a space and the surrounding environment can be navigated through boundary crossing—the movement between and negotiation of tools, rules, language, and the artifacts that make this movement possible.[2][5][1] Beyond the dialogical boundary crossing between humans, artifacts can help participants to overcome discontinuities and elicit discussion about norms of the space. Focusing on perceived boundaries between adults and youths, insiders and outsiders of makerspaces, and accessible practices, we work to understand how artifacts influence and support communities of learners.

3 CONTEXT: THREE MAKERSPACES

Three makerspaces were selected from the 10 field sites of the Maker Ed Open Portfolio project [4], which identifies salient documentation practices of making. The three sites represent nuanced out-of-school settings, and they included distinct differences in their organization of artifacts.

The Millvale Community Library in Pittsburgh, PA is a former storefront that was transformed by the Millvale community into a drop-in space for youths and adults. The majority of the library's maker programming occurrs at the Makeshop, a cozy back room with a rectangular table at its center. The Makeshop's shelves and closets are filled with books, circuitry blocks, bicycle pumps, yarn, impromptu workspaces, and projects in-progress.

The Chevron Maker Annex is tucked into a glass-doored corner that is located on the lower level of the Children's Museum of Houston, TX. The drop-in space is open for scheduled demonstrations and step-by-step workshops for visitors to explore state-of-the-art tools and materials, including a 3D printer, laser cutter, and electronic hand tools. Featured projects include light-up robots and laser-cut wooden boxes.

The Digital Harbor Foundation (DHF) Tech Center in Baltimore, MD is a former recreational space and is open to youth members to work on personal projects with just-in-time support from educators and workshops revolving around topics like 3D printing and modeling. Roughly sectioned into multiple work stations, the space includes a long wall of 3D printers, a soldering station, a communal lounge area, a haphazard pile of cardboard boxes, and storage closets stocked with consumables that are open to youth.

4. DATA & ANALYTICAL TECHNIQUES

Our study drew upon field notes and photographs of workstations, projects, and tools that were collected during site visits. To understand how interdisciplinary learning and co-construction were communicated through artifacts in our selected makerspaces, we drew upon socio-cultural literature related to boundary crossing [2][5][1], and theories of distributed cognition [7] to guide the identification of artifacts. Our analytic practice used discovery to define important aspects of a research topic and to ground theory in reality [11], aiming toward understanding the flexibility of artifacts to support boundary crossing and distributed cognition. We reviewed all photographs and compiled an emergent coding scheme that could unpack "flexibility" in relation to the potential for youths to physically change artifacts and co-construct the physical setting of the learning environment (by distributing workflows across artifacts.) This coding scheme addressed the ways that artifacts in a space supported co-constructed learning through flexibility. Our three codes represented the meaning of flexibility in relation to artifacts:

Pliability: invitation to change and shape artifacts
Accessibility: transparency and availability of artifacts to all
Mobility: potential to physically move artifacts in a space

To analyze the flexibility of artifacts in relation to pliability, accessibility, and mobility, we carefully examined artifacts in the selected spaces, to identify (a) key aspects of making, and (b) what artifacts could communicate these key aspects. Through discursive analysis we identified time, projects, and tools as key elements for making that could communicate flexibility to cross perceived boundaries and co-constructive learning. We agreed to explore three key artifacts that corresponded to the key elements of making: *(1) Schedule artifacts* to demonstrate the youths' time for making. *(2) Youth projects,* finished and in-progress, to reveal workflow in the space and what kinds of projects are possible. *(3) Tools for making* to present the resources available to youth. These categories were the framework for initial analysis of how artifacts can support co-constructive learning in youth-serving makerspaces.

5. FLEXIBILTY OF ARTIFACTS

Next, we examine physical artifacts of schedules, projects, and tools in each space in relation to the flexibility of these artifacts (i.e., pliability, accessibility, and mobility) to communicate co-construction.

5.1 Time for Making

To explore how the flexibility of artifacts communicates the time provided to youth for making, we analyzed makerspace schedules. Understanding the flexibility of schedules led us to understand how time and learning were mediated by the materiality of the scheduled access to space.

Dangling from the doorway at one makerspace, hung a handwritten community schedule, made of cardboard and suspended from a thumbtack. Accompanied by illustrations, the colorful lettering listed specific times of community-derived activities. Maker educators developed the schedule based on their experiences with youth participants. The schedule was physically and conceptually pliable—made by the community from temporary materials. It suggested that anyone could make a schedule. The artifact was accessible, visible, and open-ended, allowing youth to actively engage in the construction of time for making.

Another schedule was a laser-cut glowing acrylic sign that listed demonstrations and workshop times in two-hour increments. Demonstrations included introduction to high-tech experiences, such as 3D printing, while workshops offered the opportunity to

use these technologies. The hard plastic material of the acrylic schedule was cut into shape with a laser cutter, an adult tool in this space, and was augmented with electronics. This construction implied that changing the content and shape of the schedule involved particular skills. The schedule was not easily changed by youth, but structured visits to serve many visitors.

Unlike the tangible schedules, the third schedule was invisible—existing primarily as a concept. Without a material artifact to guide access to the space, members may have communicated verbally about when making could happen. The absence of a physical schedule artifact to communicate time for making may mean that it was negotiated through social interactions and open to co-construction for youth participants, while drop-in visitors may not have known what kind of making happens and when.

5.2 Projects for Making

The projects created within the three makerspaces showcased the work that was possible in each space, having been pointed out to us during field site visits. Examining youth projects, we understood more about how pliability (invitation to change artifacts), accessibility (transparency and availability of artifacts), and mobility (potential to move artifacts) were communicated through projects. This helped us to understand co-construction and boundary crossing possibilities.

Inspired by an early shoe-box prototype created by maker educators and a group of 4- 5-year-old children, a life-size foosball table was built in one makerspace. Supported by educators and organized by youth, this visible artifact told a story about collaborative creation. As a work in-progress, the foosball table was pliable—its construction timeline and process changed by youth. During the first author's visit, the floors of the foosball table had not yet been installed, and some of the handlebars were too short for play. While highly visible, the heavy foosball table could not be moved easily.

Another project that was assembled during the first author's field visit was the step-by-step creation of laser-cut wooden boxes that could be taken home by participants—tangible tokens of their making experience. The educators who designed the workshop provided verbal prompts, introduced tools, and prepared pre-cut pieces for assembly. The predetermined nature of the project in may imply less pliability than some of the others. However, this may have afforded smooth management of the space, and the ability to serve a large number of youth.

An *interactive LED sign* created by youth crowned a high shelf. The letters of the sign were made of poster board and semi-transparent paper, encasing a color-changing LED strip. The sign was connected to the Internet, allowing it to read Twitter feeds and to change color with hashtagged tweets. The sign was advertised as a collaborative project, and all youth makers were invited to create something new using the materials of the sign. The inexpensive cardboard material and the prototypical technical construction added to this pliability. The lightweight materials made this pliable artifact mobile, and invited members of the space to refine and relocate it at will.

5.3 Tools for Making

The capacity for young makers to create projects using both high- and low-tech tools contributed to the culture of each makerspace. Next, we explore how access to tools was communicated in relation to pliability, accessibility, and mobility to examine artifact flexibility in relation to co-constructive learning and crossing of perceived boundaries. In all spaces, most high- and low-tech tools were visible to youth, placed inside unlocked cabinets. Yet the flexibility communicated by materials differed.

A hand-illustrated wooden tool board, depicting the outline of tools, solicited group participation from its position leaning against a bookshelf. Illustrations included pegs on which to hang screwdrivers, wrenches, scissors, and measurement materials. A pair of scissors was placed to match its illustration, while all other pegs remained vacant. The inexpensive materials and prototypical position of the tool board made the artifact pliable in form and conception. The pairing of tool illustrations with tool names and pegs for positioning suggested that the board played a dual role—acting as spatial organizer and as an introduction to tool vocabulary. The accessibility of the board was further underscored by its makeshift placement, and the vacancy of the pegs suggested mobility of tools.

A professionally printed and mounted sign in another space showed the colors found on tools throughout the makerspace, and paired these colors with rules for tool access. Green tools, including hot-glue guns and googly eyes, could be used freely. Red tools such as electronic toolkits and micro-controllers could only be used after a youth passed a proficiency test. The professional finish and design of this signage communicated clear expectations about safe and expert-like tool use. The sign was visible to all, and extended through the space with ubiquitous color-coding—making it highly accessible.

An excellent example of open access to high- and low-tech tools for youth was a row of 3D printers. Once a model was ready for printing, youth copied their models to the laptop paired with a printer. Educators were available for support. The set up of each printer included a laptop, a laminated cheat-sheet of printer materials, and rolls of filament on shelves above. The complicated technical setup and multiple cables used by 3D printers was a deterrent to moving them, which limited their mobility. However, the set-up offered high accessibility of high-tech tools to youth. The way materials were positioned surrounding the printers presented a transparent workflow. Young makers could easily reach printer filaments. Anyone could add a file to the queue, and the wall of printers invited social engagement as makers waited for their prints to be made.

6. SUMMARY OF RESULTS

The analysis of material artifacts communicating time, workflow, and tools for making in makerspaces offers insight about how the flexibility of artifacts can support co-constructed learning in makerspaces and boundary crossing between adults and youths, insiders and outsiders, and practices in makerspaces.

6.1 Summary of Time for Making

The cardboard schedule, inexpensive and handmade, was flexible in relation to pliability, accessibility, and mobility. It could be seen, replaced, and remade—possibly supporting collaboration between youths and adults. The acrylic schedule, created with state-of-the-art technology, communicated clear coordination and management of the space. While communicating less flexibility in time for making, the sign's communicated emphasis on boundaries and structure seemed to present opportunities for a large number of youths to engage with exciting materials in an organized way. It supported an engagement that may be valuable for short-term drop-in activities for large populations. The invisible schedule offered flexible access to the space and the

negotiation of perceived boundaries. However, details about the flexibility of the schedule require additional data to consider how youths and adults may take advantage of the schedule's affordance to socially negotiate time for making.

6.2 Summary of Projects for Making

The in-progress foosball table project communicated a flexible workflow. While not easily moveable, the project seemed to support boundary crossing between disciplines (integrating engineering, art, and communication skills,) and age groups. Collaborative ownership, appropriation of personal and community materials, and the in-progress state of the project potentially presented the chance to distribute understanding across the space, co-constructing it one project at a time. The step-by-step, laser-cut wooden box project, while highly structured in terms of pliability and mobility, presented ways for anyone to engage and have access to hand-tools. Anyone participating in the making of this project had something to take home and remember their engagement by, leaving the space clean for the next group of youths to enter and start making without being influenced by prior users. The community-shared and pliable LED cardboard project held the potential to aid youth in crossing physical and social boundaries. It may have sparked conversation about longer-term members and the history of the space. The sign also seemed to represent an example of distributed cognition and co-construction–adjusted over time by youths and educators.

6.3 Summary of Tools for Making

Access to tools, as communicated by the example of the pegged tool board, was pliable, accessible, and mobile. It may have furthered co-construction of the space by young makers. Its makeshift placements communicated much flexibility to move the sign, if youth were to take the initiative. The tool board also offered language to name tools, providing youth with a way to communicate with adults and new visitors using a shared artifact and practice. The professionally printed sign accessibly extended the organization of the tools for making throughout the space using ubiquitous color codes. It communicated access to tools in a way that seemed to support child-adult collaboration for the use of increasingly complex tools. The access to tools, showcased by the row of 3D printers, left room for member input and co-construction of the space's organization. Though it had a high-tech and complex set-up, the row of printers communicated pliability, accessibility, and mobility in relation to tools for making. For example, the set-up along a wall may have encouraged purposeful debate about workflows for 3D printing, giving youth a voice in the construction of the space.

7. DISCUSSION

Unpacking the flexibility of key artifacts of making in three makerspaces, we gained understanding about how material artifacts may support the crossing of perceived boundaries and co-construction of space. Considering the flexibility of these artifacts allowed us to make inferences about the specific spaces we examined, and to generate conjectures about the connection of artifact flexibility to the shaping of learning communities. First, we believe that flexible material artifacts foster co-construction of spaces, potentially weaving a tightknit community, and that less flexible materials may support more structured settings for making for larger numbers. Second, we hypothesize that the three key material artifacts selected speak to the affordances of makerspaces for boundary crossing and co-construction. The analysis of the flexibility of several key artifacts in one space can present characteristics of the learning culture of a space. Additional data collection and analysis is necessary to validate our hypotheses, to identify how youths use the selected artifacts, and to understand whether additional artifacts representative of time, projects, and tools for making may present a more differentiated understanding of the culture of makerspaces and flexibility to learn. In future research, we would also like to investigate youth perspectives and interpretations of the flexibility of artifacts. We see this work as relevant for the design of makerspaces across contexts–encouraging designers to consider how detailed aspects of their designs can encourage flexibility to learn.

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