Moving Beyond Making: Towards the Development of ThinkerSpaces

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Abstract
In this paper, we argue for the need to support cognitive development alongside maker experiences. We then present a new form of maker space, called ThinkerSpaces, specialized maker spaces where facilitators and mentors are dedicated to four core learning principles. We explain our rationale for these principles and provide examples in the side bar.

Author Keywords
Maker Spaces; Fabrication; Learning; Design; Cognitive Development; Broadening Participation; Metacognition.

ACM Classification Keywords
K.3.2. Computer and Information Science Education

Introduction
There has been a growing interest around fabrication, the maker movement, and the creation of maker spaces. In this paper, we focus on considerations for the design of maker spaces for young learners. Building on constructivist theory and constructionist pedagogies, proponents of the maker movement argue that fabrication labs can provide opportunities for young people to learn about design and engineering by doing and through this process, develop meaningful interest and proficiency in these domains [1]. However, to accomplish this important aim, makers may need added cognitive support due to lacking metacognitive abilities [16], a form of guided making. Without such support, makers may not be able to use their experiences to refine processes associated with good design [2, 7, 8, 11]; this is why we argue for the need to support cognitive development as part of the maker experience.

The Afterschool Club

We developed an afterschool design club for learners, ages 9-12. We created a series of short one-minute design videos to introduce core design concepts and techniques, associated with different phases of the design cycle (see figures 1 and 2). Fun, collaborative design challenges require users to apply concepts from videos to find design solutions.

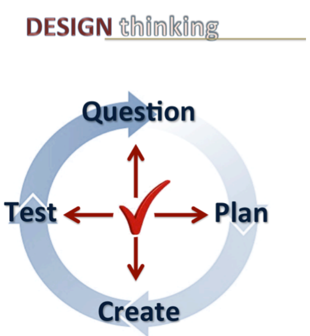

Figure 1: Our representation of the design cycle: question (establishing requirements), plan (evaluating design alternatives), create (prototype development), test (evaluating prototype), and back to question.

WHY THE DEVELOPMENT OF THINKING PROCESSES IS ESSENTIAL FOR DESIGN

A large part of human-centered design processes requires aspects of metacognition, the monitoring and regulation of thinking processes [11]. Human-centered designers are taught to unpack a design problem in order to reflect on user and system requirements; to use their assessments of the problem space to inform design decisions and plan out the best design path; and to test their existing assumptions by monitoring their designs in action [11]. Designers also use new information to iteratively revise artifacts to better align them to the contexts in which it will be used [11]. Many design errors can occur from a lack of this type of metacognitive awareness and regulation:

"A solution-first approach to design is energizing, effective, and efficient; it explains the popularity of contemporary system development approaches like rapid prototyping (Wasserman & Shewmake, 1982) and extreme programming (Beck, 1999). But this general strategy also entrains well-known hazards (Cross, 2001): Designers tend to generate solutions too quickly, before they analyze what is already known about the problem and possible moves. Once an approach is envisioned, they may have trouble abandoning it when it is no longer appropriate. Designers may too readily reuse pieces of a solution they have used earlier, one that is familiar and accessible, but perhaps not appropriate. They may not analyze their own solutions very well, or they may consider too few alternatives when exploring the problem space." [11, pg. 6-7]

Such examples support the claim that metacognition and reflective practice is an integral part of good design.

The problem is that not all people have equal opportunities to develop these types of abilities [15]. The development of metacognitive abilities requires either (1) a rich cognitive environment where students can internalize higher-order thinking processes from parents, peers, or teachers or (2) metacognitive training [15]. Many students do not get such opportunities, as high metacognitive ability is often dependent on Socioeconomic Status (SES) [15].

There are also many problems that can interfere with metacognitive activity. Learners often misjudge their own abilities and demonstrate sub-optimal self-regulatory behaviors [3, 16], [3]. Many learners also lack models of competence to compare existing activity to desired actions [16]. However, domain specific metacognitive training has shown to improve performance across differing contexts [2, 15] and is particularly beneficial to those from low socio-economic backgrounds [15].

THE DEVELOPMENT OF THINKERSPACES

Given the known problems that arise when making is not paired with sophisticated metacognitive processes and known deficiencies among learners with regard to metacognition, we propose the development of ThinkerSpaces. These are guided maker spaces where facilitators and mentors are dedicated to four core principles: (1) developing design thinking processes through strategic making and reflecting, (2) creating meaningful emotional experiences, (3) embracing the

Figure 2. Screen shot of a short video that introduces concepts of human-centered using language and examples appropriate for young learners.

Teams complete design challenges using art, building toys, or gaming technology (see figure 3). One challenge focused on understanding user requirements: design a garden for "Lego Fred". Students could ask questions about Fred and we would answer from a user profile. Students modified plans based on new requirements.

Figure 3. Team of learners designing a garden for a client called Lego Fred.

importance of failure, and (4) working towards solving real problems.

Developing Thinking Processes Through Strategic Making and Reflecting

In order for young learners to make sense of something they need an "object to think with" [10]. Shared design experiences provide learners with anchors for reflection. Learner control can be prioritized during making, to allow learners the space to be creative and team the opportunity to try out design processes. After a period of making, activity should be constrained to promote targeted reflection. Observations of the making experience can be used to push makers to think about targeted processes so as to modify future activity and improve how they go about creating innovations (see figures 1 and 2). Specific design learning goals would help facilitators identify points of reflection in a similar manner as design studio courses.

Creating Meaningful Emotional Experiences

Emotional experiences have the potential to affect important thinking and learning processes [9]. When we create something, we can experience a variety of emotions stemming from visceral, behavioral, or reflective responses to experiences [9]. These emotions can encourage learners to put forth more cognitive effort, ignore difficulty, and as a result learn more [12]. Negative experiences can also serve as markers for information that can enhance or impair memory encoding [6]. Thus emotions have the potential to make events and specific information around those events more or less readily accessible to learners during reflection. Moreover, the embodied, pleasurable experiences promote open-mindedness, deep connections to new experiences, and resilience in the face of failure [9]. This is why it is important to design meaningful emotional experiences, to balance pleasurable experiences with just enough frustration to promote sense making. In our work we try to identify potential difficulties, frustrations associated with an design for two purposes: (1) to pair with positive, fun emotional experiences so as to balance emotional responses (see figure 3 and 4) and (2) to use as fodder for reflection to understand what went wrong. We also, reflect on positive experiences to understand them, encourage teams, and strengthen activity.

Embracing Failure

Making errors and experiencing failures are as valuable to learning as is success [5]. When innovators believe that failure is a bad thing, they avoid taking risks, or pushing their own boundaries of learning and creativity, and may inadvertently make errors that lead to more failures [7]. Innovation is facilitated by the creation of a culture that promotes risk-taking and values the sharing of positive and negative learning experiences [7, 13]. Helping innovators deal with failure through the development of better reasoning processes may help them realize the importance of failure and the opportunities that failure presents for learning [7]. One of the benefits of combining making and reflecting is the ability to help learners recognize that failing is a common and important part of innovation that provides opportunities to learn from error and make iterative refinements.

Using Previous Experiences to Solve Real Problems

During reflection, it is important to be able to draw on existing mental models of systems, the internalized representations, analogies, artifacts, and experiences as a means to facilitate complex learning and reduce

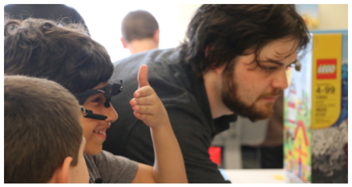

Figure 4. Learners playing with eye-tracking technology during evaluation phase.

Design challenges require real design processes and techniques (figure 4). In between work sessions, students discuss team problems, joys and frustrations, and helpful strategies to mitigate problems. We encourage learners to take pride in their learning processes (figure 5). Over time, students move from solving imaginary challenges to real problems.

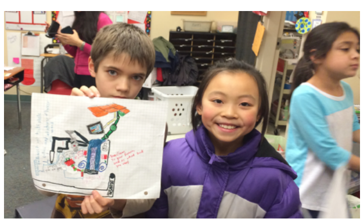

Figure 5. Students, showing their plans for a tool that included details of how they met client needs.

cognitive load [8, 14]. Moreover, working to solve real problems is what designers actually do. Providing opportunities to solve design problems learners have personally experienced as part of the club or elsewhere provides a strong foundation to introduce important design considerations as part of guided reflection.

Conclusion

If the democratization of innovation subsumes a goal to make STEM more accessible and meaningful to a broader population, then we need to move beyond simply providing access to maker experiences and start supporting the development of higher-order cognitive processes during making. Such cognitively rich experiences may help to develop a more diverse and capable generation of designers.

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