Design, Reflect, Explore: Encouraging Children's Reflections with Mechanix

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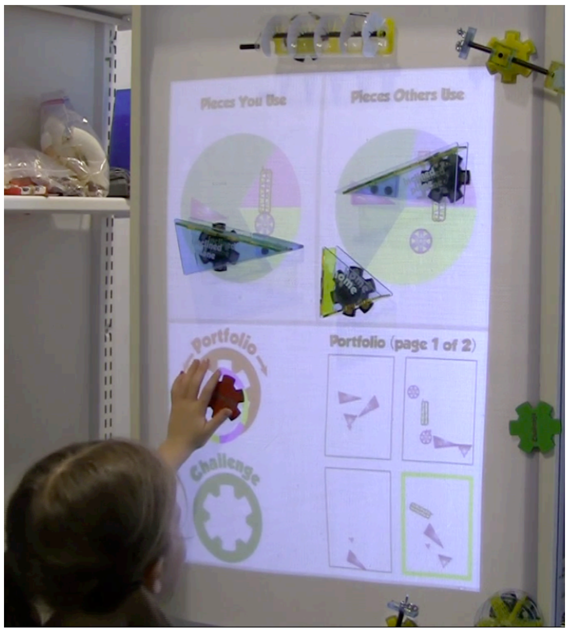

Figure 1. Child reflecting on her designs using Mechanix.

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Abstract

The integration of meaningful and effective reflection interfaces with learning technologies remains an open yet important challenge. In this paper, we describe the incorporation of several interfaces for reflection into Mechanix, an interactive system for creating tangible simple machine designs. We also discuss the results of early user studies that demonstrate the potential of these interfaces to engage children in reflection and facilitate transformative shifts in understanding.

Author Keywords

Reflection; design; children

ACM Classification Keywords

H.5.m. Information interfaces: Miscellaneous.

Introduction

While reflection is widely acknowledged as a critical component of learning, effective integration of reflection into interactive systems for children, particularly tangible user interfaces, remains a challenge [1, 2, 3]. Existing interfaces commonly isolate reflection from the design process or merely utilize reflection for assessment rather than a tool for fostering new understanding. In this paper, we explore alternatives for integrating reflection into Mechanix (Figure 1), an interactive system with which children create and record designs with tangible simple machine components [7]. Prior work on Mechanix has explored ways in which integrated design examples can serve as inspiration, references for troubleshooting, and a review of one's work [7]. However, despite these benefits, the original interface did not effectively motivate children to explore examples on their own. We extend Mechanix to use reflection as a motivator for exploring examples in new ways and discuss results of our user study with children using these interfaces for the first time.

Background & Related Work

The process of learning through discovery is dependent on reflection, the act of stepping back to evaluate and internalize successful processes and outcomes, points of failure, and alternative approaches [1, 5]. Reflections can be classified according to a hierarchy extending from *result-based* (what is done), to *procedural* (how something is done), to *critical* (what assumptions and approaches inform what was done), to *metacognitive* (why assumptions and approaches were acted upon). These reflective acts contribute to transformative shifts in *knowledge*, *strategies*, and *perspectives* [1, 4].

In their seminal work *The Computer as a Tool for Learning through Reflection*, Collins and Brown suggest several categories of computer-mediated interfaces that might promote powerful reflective experiences [1]. These include *replay*, a depiction of process that retains physical fidelity, such as a video recording; *abstracted replay*, a depiction of a process that highlights select elements; and *reification*, a static representation of a process unfolding over time. A final mode for reflection is the *juxtaposition* of one's work against another's, facilitating learning through comparison and contrast.

A major challenge in computer-mediated interaction is designing interfaces that motivate reflection and meaningfully incorporate reflective output. Lamberty and Kolodner explored how introducing a video camera to a classroom environment can encourage reflection [4]. However, children's recordings could not be self-reviewed, thus only facilitating reflection in-the-moment. In designing tabletop interactions for children, Kharrufa et al. introduced opportunities for children to analyze alternative designs and review their design process [3]. However, children's reflections were not saved into the system for the benefit of others. Furthermore, Hornecker argues that tangible user interfaces are not particularly good at supporting "reflection on prior action" as the movement of tangible components are transient, making it difficult to review actions over time [2]. In several ways, prior work on Mechanix has addressed concerns about capturing children's interactions with tangible components and making them available for subsequent review [7]. However, despite evidence that children learned new design strategies from reviewing examples, they did not elect to review examples on their own [7]. As such, we saw an opportunity to integrate reflection into the Mechanix interface to enhance learning and better engage children in designing and reviewing examples.

Mechanix Reflection Interface

The Mechanix interaction flow is outlined in Figure 2. The goal of Mechanix is to guide a physical marble "home" using different arrangements and combinations of tangible simple machines. Each design commences with a *Challenge*, a projection of mandatory start and end pieces, and culminates when a completed design is saved into the *Library of Examples*, a compilation of all designs created with the system. This interface was

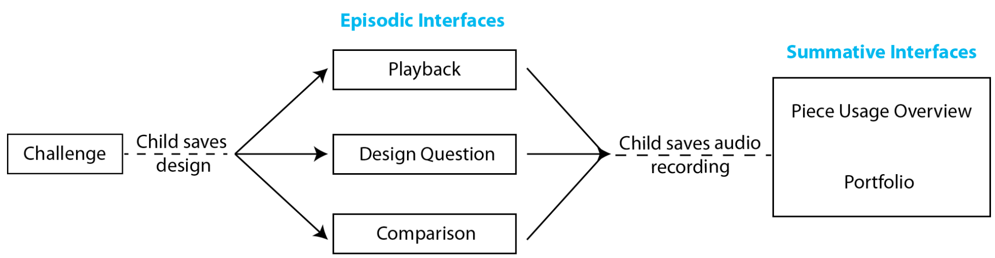

Figure 2. Mechanix design cycle.

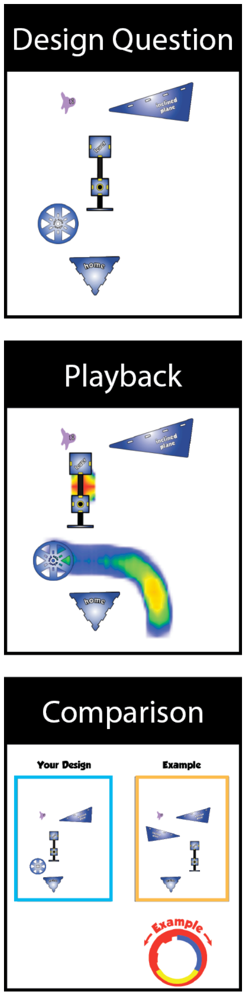

Figure 3. *Design Question*, *Playback*, and *Comparison* episodic interfaces.

augmented with *episodic* and *summative* reflection experiences at key points in the design cycle (Figure 2). *Episodic* reflection interfaces, which occur after a design is saved, ask children to reflect on various aspects of their design. An audio recording of the child's reflection is saved with their design into the *Library of Examples*. Audio was chosen as the medium for reflection to avoid overloading the visual and tangible interface elements of Mechanix and to enable pseudo-anonymous personalization. At the end of each design cycle, the child is presented with *summative* reflection interfaces that showcase various aspects of the designs they have created thus far.

Mechanix provides three distinct *episodic* interfaces: *Design Question*, *Playback*, and *Comparison* (Figure 3). In the *Design Question* interface, children are prompted to critically analyze their design while exploring engineering principles such as uncertainty and optimization (e.g., "Does your design work every time? Why or why not?"). In the *Playback* interface, the child is shown an abstracted *replay* of their design process backed by a residual heat map of accumulated piece locations (an abstraction of the child's design process). As in the *Design Question* mode, the child is presented with a prompt for reflection (e.g. "Can you tell me how you got your design to work?"). The *Comparison* interface *juxtaposes* the user's design with those from the *Library of Examples,* prompting the child to select one for comparison with her own.

In the *summative* interfaces (Figure 4), the *Piece Usage* overview depicts the types of pieces the child has used and their frequency of use in a graphical pie chart. A second *juxtaposed* pie chart depicts the usage of pieces by all Mechanix users. With the *Portfolio*, children can review each of their designs and listen to their corresponding audio reflections. These interfaces provide an abstracted *reification* of designs and preferences as they evolve over time.

Study Design

To evaluate the effectiveness of the new Mechanix interfaces, we performed a qualitative user study with children engaging with Mechanix over hour-long sessions. Six first-time users (50% female) between the ages of 6 and 10 were recruited through local mailing lists (Table 1). This age range is consistent with prior research with Mechanix and generally aligned with the Piagetian Concrete Operational stage of development [1, 6]. The sample size was chosen to reduce ordering effects (each child was introduced to

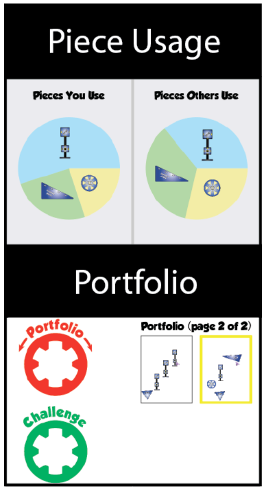

Figure 4. *Piece Usage* and *Portfolio* summative interfaces.

Child	Age	Gender	Mode Preference
A	6	F	Design Question
B	6	M	Playback
C	7	F	Comparison
D	7	M	Comparison
E	8	M	Comparison
F	10	F	Design Question

Table 1. User study participants.

the three episodic reflection modes through one of six distinct permutations).

Each session commenced with an introductory challenge and reflection interface followed by three controlled challenges (one for each episodic reflection mode). Children were then prompted to choose a reflection interface for each subsequent challenge. At the end of the session, each child was asked which interface they preferred and interviewed about their experience using a semi-structured protocol; sessions took place in a research lab and were video recorded, transcribed, and analyzed by two independent researchers using open-coding to identify emergent behaviors. Finally, recorded reflection episodes were organized into categories based on the literature.

Results & Discussion

On average, children completed 7 challenges (SD: 1.4), devoting 15 minutes (SD: 7) to the 3 initial challenges and 13 minutes (SD: 7) to remaining challenges. All children fully, and in some cases, enthusiastically, participated in the reflection episodes and demonstrated varying levels of reflective depth.

Depth of Reflection

Of the 32 recorded reflection episodes, 18 were *result-based*, 7 were *procedural*, 6 were *critical*, and 1 was *metacognitive*. *Result-based* reflections consisted of piece descriptions, steps taken in creating a design, and component-level comparisons: "(Pointing to his design) This has a lever and (pointing to comparison design) this has a wheel" (E). The preponderance of *result-based* reflections is consistent with the hierarchy of reflective depth in the literature [1, 4]. Still, the combined number of *procedural*, *critical*, and *metacognitive* episodes, where children justified their design choices or reassessed their assumptions, nearly equaled those of *result-based* reflection.

An example of *procedural* reflection can be seen in the description given by the oldest child: "I knew the lever needed to be where it was to get [the marble] into home, but if I didn't have the inclined plane there (points between the start piece and the lever), [the marble] would have just fallen" (F). In this case, the child demonstrated not only what pieces were used but why they were arranged in a particular way. The same child, when later asked if her design worked every time, gave this thoughtful, *critical* response: "It might work every time…(long pause)…but it might not work every time because you can't really tell if the marble is going to land in the black spot (points to the entry point of the screw piece)" (F). Her response reflects a growing realization and, potentially, a transformation in understanding regarding the inherent uncertainty of the physical system. Finally, child C uttered this *metacognitive* realization in which she evaluated her capacity for understanding and explaining her actions: "It's kind of hard to explain the [designs] I do. You have to explain something that you made, and how you did it, but you don't really know how you did it. And so, it's hard for someone to answer the question of how you made it [and] why you made it."

Overall, the depth of reflection appeared to be independent of the reflection interface, instead mapping closely to the child's age. The oldest child, aged 10, engaged exclusively in procedural and critical reflections, while the remaining children, at age 8 or younger, engaged almost exclusively in result-based reflections. This result suggests that younger children may not be able to take full advantage of the depth of reflection available through the augmented interface.

Evidence of Transformation

In several instances, children's reflections presaged *transformations* in their behavior and understanding. For children B, D and E, the *Piece Usage* graphic made them aware of pieces they had not yet used. For example, upon realizing the existence of the *screw* component, child E incorporated it into his next design. Children tended to be more interested in the types of pieces they used rather than their frequency of use.

Examples also encouraged children to use pieces in new ways. In the *comparison* mode, children C and D both came across an example that used the inclined plane upside down. Upon seeing the example, child D proclaimed, "I'm trying that [example] because I have no idea how that could possibly work!" After testing the example, the children realized that the piece could be used in both directions, which they then incorporated into their later designs.

Reflection Interface Preferences

Users exhibited a variety of preferences for reflection interfaces. Each interface was selected as the preferred interface by at least one child (Table 1). *Comparison* was the most popular interface: Child A stated "I kind of like this one more because you get to see other people's examples and it's fun to see what they did." Child C, who appeared not to enjoy the other reflection interfaces, became engaged with *Comparison* when she chanced upon a recording made by her sister. Child D tested all the alternative designs and listened to audio reflections in their entirety before selecting an example for comparison.

Two users preferred the *Design Question* mode for the facility of recording their own voice. These users also engaged more consistently with the Portfolio interface, particularly Child A, who spent additional time viewing her portfolio and listening to her own recordings. *Playback* was only chosen as the favorite by one child, but the majority of children appeared to be engaged with the abstracted replay nonetheless. Child E was particularly engrossed and even chose to sit on the floor to watch his design unfold to completion. The heatmap was a curiosity to the children, but only the oldest came close to understanding its meaning.

The effectiveness of the reflection modes was sometimes obscured by mismatches between the child's design process and the reflection interface. On several occasions, a child would solve a design in one try, only to be faced with a rapid *Playback* that appeared static. Conversely, lengthy episodes with multiple failed attempts were occasionally followed by the *Comparison* mode, which reduced the elaborate process to a single design. These mismatches were suboptimal in prompting deep reflection.

Emergent Interactions

As is often the case in testing with children, the subjects interacted with the system in several unexpected ways. Some became so accustomed to verbally reflecting that they started to express their thoughts without being prompted (child C, D, and F). For example, while listening to the audio reflections, Child D would criticize alternative designs as not reliable and agree or disagree with the recordings.

Children also seemed more confident when answering the system rather than the researcher. This was particularly surprising because the audio prompts were recorded in the same voice as the researcher. The recordings, perhaps, provided a non-judgmental way for children to share their thoughts.

Children demonstrated increased fluidity in describing their designs; all children used the vocabulary of the simple machines in their reflections (inclined plane, lever, etc.). Thus, the use of auditory media enabled children to practice communicating and demonstrating their understanding of the system.

Conclusions & Future Work

In this paper, we describe the design of several meaningful reflection interfaces with Mechanix. Children demonstrated evidence of transformation in their awareness of their own design patterns and the potential for novel design approaches. These results are significant as self-awareness and awareness of alternative strategies are pedagogically important foundations for subsequent growth. Furthermore, there are many instances in which children's interactions are expected to be short (e.g., museum exhibits), so achieving our results within a limited time frame suggests promising design opportunities.

These preliminary findings suggest several emerging design principles for developing reflective interfaces in interactive media for children. Incorporating children's reflections into subsequent interactions motivates learners and makes reflections meaningful. Multiple reflection interfaces help broaden the reflection experience for each user and support varied preferences across all users. However, the reflection modes should be appropriately matched with children's design behavior to maximize learning potential. Finally, audio recordings can enhance learning by providing opportunities to communicate understanding, reinforce interface-specific vocabulary, and forefront misconceptions.

Our future work includes developing appropriately matched interfaces that can support a broad range of ages and depths of reflection and providing better search mechanisms for finding meaningful examples.

Acknowledgements

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