Interactive Metaphor Interfaces for Young Children to Learn Color Mixing and Music Composition

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Abstract: Playful and collaborative learning tools facilitate children's learning. In this study, we conceptualized and explored two tangible user interfaces named *Paint-Matics* and *Slimo* using traces of use. The prototype has two parts: a tablet application implementing the digital trace idea and three unique pressure-sensitive slime boards. Children used their fingers to press the slime boards collaboratively to get their desired colors or tones. Ephemeral physical traces of use from a child and the other two children support their learning and understanding of color and music composition. We did two small user studies with nine children for *Slimo* and two for *Paint-Matics*. Our designs aim to help children: (1) learn how to count and perform basic mathematical operations in an interactive and collaborative way; (2) learn the concepts of color mixing and music composition. Main contributions were to: (1) use physical traces as a new tangible interactive metaphor for collaborative learning; (2) present how to make an interactive slim board for the *Do It Yourself* community; and (3) propose some innovative ideas for future interfaces for children.

Introduction

"One of the problems of art education in modern times is the need to find teaching methods…" Childhood is a critical period to cultivate a sense of color and music, which is a fundamental art skill. Understanding and learning color and music composition is a vivid experience or "an experience that is an experience" because it is embedded in many expressive activities of daily life. However, children's art classes are becoming less common in recent years. Therefore, finding a flexible and easy way to teach children color and music composition is crucial. Meanwhile, many young children have difficulties understanding mathematical concepts, e.g., counting and multiplication. Efforts have been made to redesign the learning tasks using diagrams, mediational representations, and number sentences. However, changing the learning method or environment could also be helpful. For example, Chen et al. (2012) utilized a collaborative cross-number puzzle game to help children develop their computing ability. Playful and collaborative learning environments are suitable for children learning mathematics.

Tangible User Interface (TUI), which is computationally enhanced to manipulate digital information to make *physical objects* and spaces into "interfaces between people and technology" (Ishii & Ullmer, 1997), is being used in education (Markova, Wilson, & Stumpf, 2012; O'Malley & Fraser, 2004), especially for children (Rodić & Granić, 2021). Physical objects provide a wealth of visual and tactile information and represent elements in various domains. However, it also has significant limitations. For example, physical objects do not provide an external record of physical states and actions. In other words, physical materials do not provide *a trace of actions* that allow the user to revisit and compare past and present states (Manches, O'Malley, & Benford, 2009). *Trace of use*, which refers to changes in the material that occur due to human interaction, could make up for this shortage (Rosner, Ikemiya, Kim, & Koch, 2013). In this study, we aim to: (1) help children collaboratively learn color composition with primary colors (i.e., yellow, blue, and red) and music composition with pitch, volume, and not length on a playful, tangible, and traceable interface; (2) engage children in a playful and collaborative learning activity, which has proven to be an integral element of design for children's learning.

Physical manipulatives

The manipulative properties of physical objects enhance passage between physical and digital representations, thus sustaining a transition between stages in the reasoning process (Starčič, Turk, & Zajc, 2015). Physical, sensory, and metaphoric qualities of manipulative interaction could enhance playfulness. However, physical manipulatives have three issues: First, it is challenging for children to understand the interactive results, which are not shown on the object intuitively (Kaput, 1995). In other words, physical objects do not provide an external record of physical states and actions from tangible interaction. It does not provide a trace of actions that allow the user to revisit and compare past and present states. Most previous studies used TUIs as a "controller" for gamified learning, which constrained it as a "mouse" interface. However, metaphor (i.e., meaning) of interaction is TUI criterion (Markova et al., 2012). Second, children feel a distance from an activity with manipulatives and have difficulty reflecting on it. As a result, it makes manipulatives *per se* not detrimental because they must take place in activities where some space for high-level thinking is provided. The effectiveness of TUI will mainly rely on activity design instead of interface design. TUI *per se* does not have independence. Finally, Clements (2000) proposed that "the danger of physical material is to constrain reflection and abstract thinking by blocking the learner in an *active mode*." The action depends on the mapping between physical and digital representation, physical material itself does not provide a mechanism for learning reflection.

Manches, O'Malley, and Benford (2009) used sectional videos to provide a trace of children's interactive actions. They found it was time-consuming and difficult for children to identify previous solutions by watching videos. Tangible designs could support reflective activities by providing records of certain *representational states*. Physical laws constrain an object's behavior, e.g., it is hard to leave traces on physical manipulatives to record (continuous) manipulations. However, finding a method to record and keep physical traces that result from interaction would help support children's reflective learning. These traces were also important assessment data to help teachers examine children's understanding. Therefore, if we think about changing manipulatives' physical properties, we can use *traces of use* as evidence of previous interaction to approach the three problems mentioned above.

Interactive Metaphor

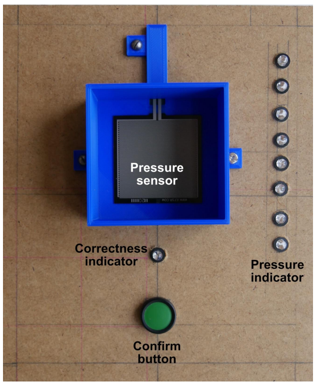
Traces of use refer to changes in materials that occur due to prior human interaction (Rosner et al., 2013). It has three advantages: First, it functions as an interactive guideline and can make the interface's affordance more apparent. Second, enhancing affordance's perceptibility can facilitate an intuitive interface design. Finally, traces are representations of meaningful relations, which can strengthen users' emotional bonds and shared understanding. In other words, it can increase people's engagement and foster human-to-human connections on functional and physical aspects and meta-social perspectives. Researchers have gradually used it as a concept and strategy to design TUIs, which provide a new interactive reflection.

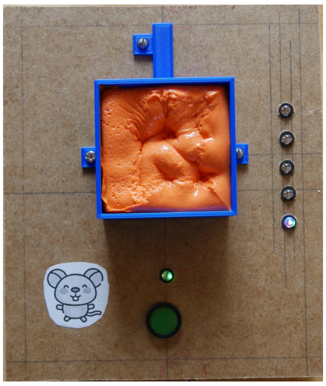
As far as we know, its application and effect on collaborative learning have not yet been studied. However, it has advantages in: (1) serving as a memory anchor point of previous (observed) behaviors; (2) increasing TUIs affordance to help students learn from physical representatives, e.g., logic connections. This argumentation is based on research in psychology, where imitating others' behavior and movement was a well-established and effective learning strategy. Transferring it into our design strategy, traces enable users to reflect on their interaction with the technology and make them visible to others. Therefore, traces of use can help users learn from both their interaction and the interaction of others.

Prototype

Technological Setup

Paint-Matics and *Slimo* were designed in a similar rationale. To explain the technological setup, we made *Slimo* as an example. As shown in Figure 1, *Slimo* board contains pressure indicators, confirm button, correctness indicator, and pressure sensor. Pressure indicators show the pressure level applied to the slime, or if children press the help button, it shows the correct pressure level. The correctness indicator lights red or green to give feedback on whether the submitted pressure is right or wrong. Finally, the pressure sensor can measure how much pressure children press on the slime. As shown in Figure 2, when using this prototype, we need to put the slime inside the box and press the slime to get the indicator concept. Figure 3 shows the setup with slime boards, a tablet to show graphical user interface, and a speaker for playing sound.





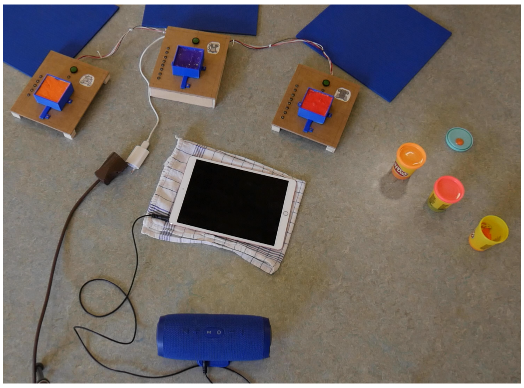


Figure 1. Technical details. **Figure 2.** Board with slime. **Figure 3.** Setup with slime boards, tablet, and speaker.

Arduino connects all the hardware, which runs on an ESP32 because of the built-in Bluetooth module required to communicate with the application running on the tablet. All the hardware parts got connected with a soldering iron. The boards are made with 5 mm thick cardboard wood. The graphical application provides the business logic to the whole construct. It communicates with the ESP32 of the tangible device using Bluetooth LE. The tangible device sends the current pressure values and button states to the application, and the application returns new states for the tangible device. Those states include whether the help light-emitting diodes (LEDs) on the level indicator should be visible and whether the last submitted values are right or wrong. Next to the business logic, the application's primary purpose is to display the tasks for the children sitting in front of the tangible devices.

Final prototype

Paint-Matics aimed to help children learn how to collaborate. One context was to learn how to count and perform basic mathematical operations in an interactive and collaborative way. In addition, children also learn the concepts of color mixing. As shown in Figure 4, the final prototype of *Paint-Matics* included two components: sketching and coloring. First, children need to connect the dots according to the pre-selected mathematical operation. Then, they started to make the desired colors for filling the sketch by using their physical slime boards. When a child presses the slime in one of the compartments, it leaves a physical trace. A harder press would leave a deeper trace and create a darker shade as an output. Hence, the traces left on the slime can help young children achieve a long-lasting understanding of color mixing. As shown in Figure 5, the color output was displayed in a virtual color palette in the tablet application, which also had eight compartments accordingly. Similarly, *Slimo* helps children make the melody's pitch, volume, and note length collaboratively. In addition, the tablet application could give instant feedback for hearing the sound.

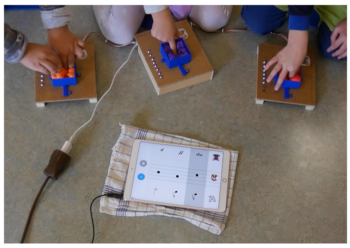


Figure 4. *Paint-Matics* prototype. **Figure 5.** *Paint-Matics* with a colored dog. **Figure 6.** *Slimo* prototype.

Discussion

Traces of use as a design strategy was applied to help children learn from their mistakes and understand color and music theory. Children could interact with *Paint-Matics* and *Slimo* collaboratively, creating close communications with each other. The slime material used in the study was creative for displaying ephemeral traces of use. It also helped the children to reflect on their interactions in the activities. This showed that even at this small scope, *Paint-Matics* and *Slimo* might support children in collaborative learning and involve them in the learning task explored before. From a trace of use perspective, children were easier to interpret or self-reflect on the mathematical performance. It also allows them to retrace which colors were mixed via TUI.

We used traces for collaborative learning. This could be an excellent contribution to our study. Because previous prototypes that were created based on this design strategy were vastly focused on individual usage. For instance, Robbins et al. (2016) created and experimented with product designs that incorporated traces but only taught individual users about the product's usage. However, our prototypes used traces in collaboration among multiple users and aimed to teach users' concepts and product usage.

Finally, we make interactive slim boards for the *Do It Yourself* community. As our used materials are children-friendly, easy-accessible, and playful, it could inspire more practical explorations of designing interactive metaphors to help children understand abstract knowledge. But, again, we would like to have an opportunity to discuss this with a broader community to explore the new possibilities.

Conclusion

Paint-Matics and *Slimo* aimed to help tackle learning challenges for young children by making the learning activity more appealing from their perspective. The results of the pilot user-testing showed that children found the products intriguing and were interested in the idea of using them in an actual school environment. Furthermore, the usage of traces proved to be an effective tool to teach the children about color and music theory, as they were able to correctly translate between the traces on the slime board and the results shown on the palettes. Lastly, the product was successful in facilitating collaboration. Based on these results, we can say that *Paint-Matics* and *Slimo*, as an idea, can help solve some of the issues that arise with learning and create a friendly classroom environment for young children.

Due to the global pandemic, schools were closed during our prototype's development and test phases. Thus, we could test *Paint-Matics* with only two children and *Slimo* with nine children. However, we intend to test them further to understand their effectiveness and usability better. At the same time, we want to include more perspectives by consulting professional teachers and educators in future work.

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