Exploring Mixed-Reality TUI Manipulatives for K-5 Classrooms

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Abstract
Our research looks to understand how to best design manipulatives within a mixed-reality (MR) system for the classroom. This paper presents insights around how teachers currently use physical manipulatives to inform future MR designs in the K-5 classroom. Manipulatives are physical objects used for teaching; Examples include, coins, blocks, puzzles markers etc. K-5 teachers have been using physical manipulatives to help illustrate abstract concepts for decades. Physical manipulatives have proven high value for students [7] and their high level of adoption by grade school teachers makes them a potential candidate for introducing MR into the classroom. In this research, we use participatory design, journey maps and interviews to identify teacher challenges with current physical manipulatives and explore potential design directions for MR manipulatives in the classroom. Our preliminary findings suggest that MR could help improve autonomy around student learning and increase opportunity for collaboration between peers, as well as between teacher and student.

Author Keywords
Manipulatives; Tangible User Interfaces; Educational Technology; Mixed-Reality; Augmented Reality; Participatory Design; Journey Maps

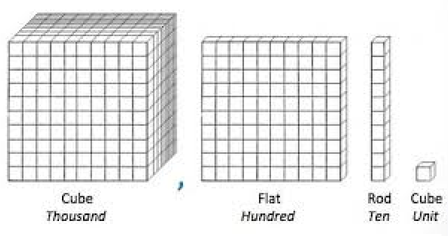

Figure 1 Base 10 blocks

ACM Classification Keywords

H.5.2 [User Interfaces]: User-Centered Design

Introduction

The recent adoption of augmented and virtual reality has resulted in these hardware solutions becoming more cost-effective. With this increase in affordability, the classroom is becoming a potential place for students to consume such technology. Yet we know little about how they might be used in educational settings. Most current MR solutions for classrooms are designed to bring locations and/or objects into the classroom [i.e. Google Expeditions and Microsoft's View Mixed Reality, [8]. Our research looks to understand how to best design MR for a classroom by starting with identifying teachers' needs. We investigate this phenomenon by first looking to better understand an activity which brings visual context to lessons and is well adopted in classrooms—physical manipulatives.

Grade school teachers have been using physical manipulatives to help illustrate abstract concepts for decades. Common physical manipulatives students use in the classroom include items such as coins, tangrams, interlocking cubes, pattern blocks, fraction bars, and probability spinners. The physical interaction with the objects specifically ties to meaningful structures of the content which is being taught. The most common physical manipulatives are base 10 blocks [Figure 1]. These are used to help students understand addition, subtraction, and number sense to name a few. For example, students will be asked to physically move the blocks to the number line to understand the concept of how much one number is compared to another.

To explore how mixed-reality could be applied to current challenges around physical objects in the classroom, our research approach was twofold. First, we wanted to identify current behaviors, motivations, needs and pain points of teachers who currently use manipulatives in the classroom. Secondly, we wanted to have teachers review and contribute to a series of high-level design concepts derived from past research completed in the manipulative space.

Related Work

Physical Manipulatives

Past research has shown that physical manipulatives in the classroom are effective because they are multi-sensory and can represent ideas and/or concepts in more than one way. For instance, with coins students can learn both two dimes and a nickel or five nickels equals twenty-five cents: Two solutions, both correct. This leads to greater understanding of complex concepts [7], promotes communication amongst students, and increases confidence, which lends to greater understanding and deeper learning [7]. Despite the successes of physical manipulatives, there have also been some notable challenges when trying to employ them in a classroom. These include a teacher's lack of pedagogical knowledge, time-consuming set-up, and availability of manipulatives [5,7].

Tangible User Interfaces to Support Children Learning

We further ground our work by borrowing concepts from a similar well-established HCI field – Tangible User Interfaces to Support Children Learning. TUIs are interfaces where the user interacts with a digital system through physical objects. Design implications in this field often pull from Mayer's cognitive theory of multimedia learning [6]. This theory stresses the

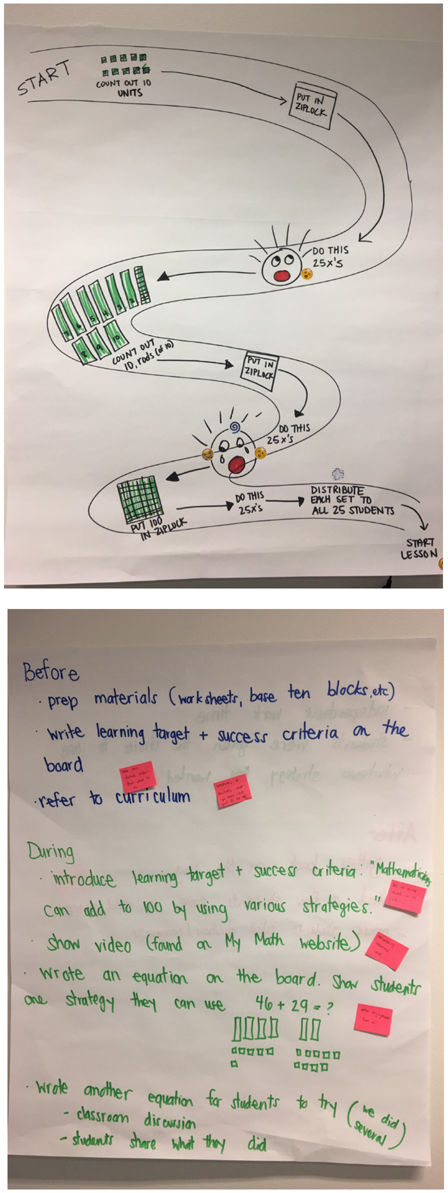

Figure 2, Two participant journey maps

importance of showing different multimedia formats (e.g. text, images, video) and spatial placement of the material to show content, which results in enhanced student learning. Further, by building connections related to the different multimedia formats, this will reduce overall cognitive load [6], a noted inhibitor of learning as per Sweller and Chandler's Cognitive Load Theory [3].

For example, Antle and Wise suggest ten guidelines to inform TUI design decisions specifically for spatial domains [1]. These guidelines are derived from a series of studies which look at supporting children's learning through table-top TUIs. To highlight a few key concepts, they suggest: Using world-based scenarios; slowing down interaction and trigger reflection; using primary schemas for input action to improve usability; distributing learning across modalities—including haptic—; and design objects that allow for spatial re-configuration to support exploration [1]. However, Antle et al, explicitly state that using such guidelines should not be viewed as "pre-determined, prescriptive heuristics" as a learning environment and design situations can call for different approaches [1]. Our preliminary research looks to expand this past work by looking at TUI's using a mixed-reality system as the interface, not the traditional table-tops or digital manipulative solutions [ex. 4].

User Study

Participants

We recruited a total of 12 participants. They were all currently teaching within the greater Seattle area. Teachers experience ranged from 2-10 years, with the median being 4 years' experience. We specifically selected teachers between grades 1 and 6 as prior research has shown that physical manipulative usage is most prevalent in grades 1-5. All but one participant was female, and all were selected as responding positively to learning new technologies in the classroom.

Study Method

Overall there were three data collection phases in a study session which in total lasted ~90 minutes. To understand their current motivations, behaviors, and challenges, phase 1 had teachers participating in a semi-structured interview. Questions focused around current usage, history of usage (why they use them, how often, classroom logistics of use), recalling the last time they used them (providing examples around that experience, general pain points etc.), and recalling scaffolding and modeling techniques they currently employ. After the interview, participants were asked to draw their journey of the last physical manipulative activity they had done in their classroom [see Figure 2], a journey map. A journey map is a visual representation of an overall story, and in this case, from the perspective of the participant. When this was done, participants then used post-it notes to add challenges they experienced throughout the journey.

The final phase included a participatory design activity specifically utilizing the technique of participatory envisioning and enactment [2]. This participatory design technique involves setting users in potential future settings. We achieved this by presenting design scenarios informed from the related work mentioned above. These scenarios were presented in a paper format and were pinned to the lab wall as storyboards [see Figure 3 Modeling Concepts Storyboard. The categories presented were general concepts to initiate

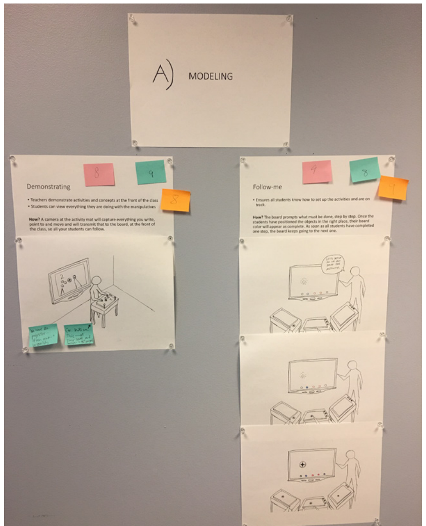

Figure 3 Modeling Concepts Storyboard

conversations and to allow users to see themselves in future settings. Designs were both described and illustrated as manipulatives with sensors, connected via the internet-of-things. Storyboard concepts included:

Scaffolding Concepts (3 Scenarios): The first, titled *Pre-Made Activities*, described teachers and students having access to pre-made manipulative activities. The second concept, titled *Immediate Feedback,* would provide students with real-time feedback as they were interacting with a manipulative. The third, titled *Delayed Feedback*, would allow the students to engage feedback when desired and would be presented with either "right" or "wrong" feedback.

Student Collaboration Concepts (2 Scenarios): The first, titled *Interdependent Work*, allowed teachers to gather student solutions and display them for discussion with the class. In the second, titled *Keeping Busy*, students can challenge each other to solve different solutions.

Modeling Concepts (2 Scenarios): The first concept, titled *Demonstrating*, allowed teachers to model an activity and students can easily see the modeling from their desk. The second concept, titled *Follow-Me*, showed teachers taking students through a step-by-step process of the manipulative activity. As soon as all students have completed one step, the teacher will be notified and can go to the next step.

Participants were asked to individually review each story, add comments and ideas using post-it notes and emoji stickers. Afterwards, participants discussed their comments and ideas with the group (or facilitator if they were the only participant in the session). They discussed how they saw the concept working in their classroom and ways to make the concepts better.

Session Groupings

There was a total of 6 study sessions, with varying numbers of participants. Sessions #1, #2 and #3 had 1-2 participants, while sessions #4, #5 and #6 had 2-3 participants. This variation in group size allowed us to focus more time on the semi-structured interviews with the first few sessions—because of the fewer participants—but then shift more time towards the participatory design component with the sessions that had more participants. This process of first exploring their overall experiences, then identifying challenges and successes, was intentionally done to prime participants and get *their head in the space,* to engage with the participatory design activity.

All visual and textual data was analyzed using coding techniques from grounded theory and triangulated between the three phases of data collection.

Findings

Teacher Behaviors & Personal Development

We found that teachers need to be able to tweak the activity to match their student needs, specifically in terms of student comprehension of the topic. Further, teachers receive little professional development around using manipulatives in the classroom and asked directly for more help making these activities more creative.

All participants reported to us that math manipulatives are core to the curriculum and highly adopted in grades K-4.

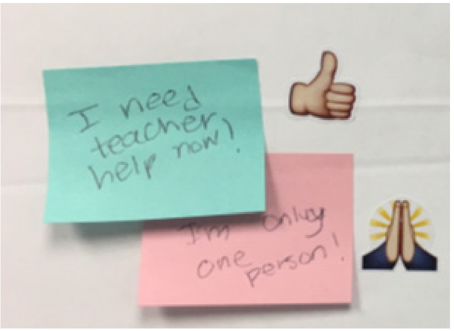

Figure 4 P4's Journey Map Pain Points

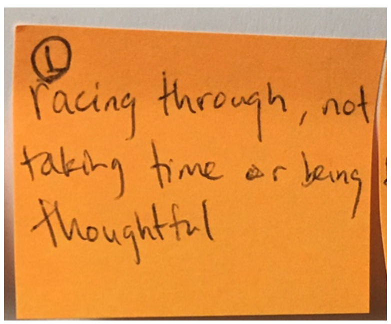

Figure 5 P1 Journey Map Pain Point

Challenges

Two of the initial themes we discovered which were outside past research includes: a) assessing student comprehension of the material and providing in-the-moment feedback; and b) students being at different levels and finishing at different times. Below we break these findings down into more detail.

Teachers have difficulty gauging comprehension of students during the activities and providing quality feedback in-the-moment. This is because teachers only gauge feedback via observations while walking around the class. P11 describes this during the semi-structured interview phase: *"[It's] hard to deal with manipulatives and to assess if they are getting it."* – P11

P11 is describing the challenge of having to gauge the comprehension challenges in the room only through observation or having to go up to the students individually one at a time.

In figure 4, we see P4's journey map displaying the student challenge (blue) and teacher challenge (pink) Here the teacher is challenged to get to all the students to provide help. This creates additional problems regarding reporting to parents and admins as to *why* students are struggling. Teachers are left with only observations. Further, teachers often must wait for formal assessments at later dates to really understand the student's comprehension of the subject.

Teachers also described having logistical issues with students finishing at different times. Teachers' frustration with students racing through activities to complete them instead of learning from them resulted in classroom management challenges. That is, teachers, having to create extra activities for the students to move onto. While this challenge might exist for other teacher experiences, we still believe it's an important challenge for manipulatives and should be addressed. In figure 5 we see P1's number one pain point on her journey map: "Racing through, not taking time or being thoughtful". Additionally, these two challenges interact with each other. If students race through the activity, it's hard for the teacher to gauge their understanding and provide the right extra activities.

Storyboard concepts

Many of the design concepts reviewed with participants aligned well with their current behavior and needs and addressed several challenges. Below we describe initial findings for one successful design concept, *Collaboration* and one unsuccessful design concept, *Immediate Feedback*.

Both the collaboration concepts, *Interdependent Work* and *Keeping Busy,* were well received. *Collaboration* concepts were perceived to allow teachers better insight into the progress of their class and to provide opportunities for dynamic discussion.

"It gets kids involved in the classroom. It develops engagement. [It supports] this idea that Math is a social endeavor. You can learn from each other." - P11

As mentioned above, the *Immediate Feedback* concept drew out numerous concerns. Specifically, participants called out issues around the immediate response potentially driving a trial and error behavior from the students to find the answer and not an attempt to understand the concepts. There were additional concerns with the *Modeling* concepts. *Demonstrating* simply did not add value to the teacher's current scenarios and *Follow-Me*, brought up concerns around hindered student autonomy to learn through exploring potential solutions themselves.

Discussion

Our preliminary findings described in this paper explore opportunities for potential mixed-reality solutions by taking the preliminary step of better understanding teacher needs around a well-adopted physical activity in the classroom, manipulatives. As mentioned earlier, manipulatives hold many parallels to mixed-reality benefits such as bringing visual context to lessons.

Based on teacher behaviors, identified challenges, and teacher feedback, the teacher needs we saw focused around enabling collaborative discussions with the class and enhancing student autonomy. Concepts that were unsuccessful, were rigid, provided little new value and was perceived to stifle the students' ability to explore concepts in their own way. In terms of mixed-reality solutions, this leans to the idea that these systems must provide flexibility.

Future Work

As a work-in-progress, we will continue to expand on the discussion and develop the design implications further. Beyond this study, our future work will look to evaluate a prototype, so both teacher and students can interact with the storyboard concepts. This research would involve students to better understand how their needs in the classroom mesh with that of the teachers.

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