Education IRL: Virtual Reality and Physical Manipulatives

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Abstract
Schools frequently use mathematics manipulatives for instruction despite the difficulties teachers can encounter in using them. ICTs can allow us to not only help teachers to more effectively use manipulatives but also provide one-to-one tutoring to early elementary students. This project involves computer vision being used to track physical manipulatives in education in just the same way that computer vision is used for activity recognition. Furthermore, we use interaction planning to provide instruction to individual students as they work through problems at their own pace. Technology allows us to more effectively use mathematics manipulatives *in real life*.

Keywords
architectures for educational technology systems, interactive learning environments, interdisciplinary projects, pattern recognition, perceptual grouping

ACM Classification Keywords
K.3.1 Computer Uses in Education; I.2.10 Vision and Scene Understanding

Introduction
We have been investigating the use of physical manipulatives in the classroom and the ways in which technology can assist in their use. Visitors to early elementary classrooms can't help but notice that

objects, known as manipulatives, are used frequently for classroom instruction. The standard argument for using manipulatives is that physical objects provide a concrete representation that students can use to bootstrap the acquisition of abstract concepts in math and science. The objects used range from plastic coins to various blocks, such as Cuisenaire Rods – used to teach everything from basic arithmetic to quadratic equations – and Tangrams – a tiling puzzle used for teaching various things, including geometric concepts.

To give a sense of just how frequently manipulatives are used, we'll note a US Dept of Education study that found 61% of full-day kindergarten classes use mathematic manipulatives *every day* [9]. Manipulatives remain important in early elementary but become less prominent as students get older. By the time students reach eighth grade, only 46% still use them even once a month [11].

Difficult to follow all students

With a class full of students, teachers cannot view the process each student goes through – how they solve problems. The issue is that some claim "by understanding how students solve problems, teachers can troubleshoot or fine tune the individual student's process and make him or her a more efficient learner" (p.17, [13]). It is impossible to watch physical manipulatives as 25 students go through the process of using them. At best, teachers can select some students to observe in series. At worst, teachers only see the product of manipulative use.

Difficult to follow all objects

Even with computer support, following the set of objects a single student uses can be an issue. While there tend to be small numbers of distinct objects (e.g., there are ten different rods in Cuisenaire Rods, seven different tiles, called *tans*, in Tangrams, and only four common US coins), these are often presented to the child in large numbers. The child could have upwards of 50 rods or two dozen tans or coins.

Researchers have attempted to instrument objects to be used in instruction. For example, The Smart Kindergarten project [12] set out to instrument a full classroom and wound up developing a smart table for the use of educational materials. Work on digital media tables began with wired objects [3] and has since moved to wireless approaches and machine vision [6]. Prior to the use of machine vision, a common problem was that it would be difficult to simultaneously follow the dozens of objects that a single student might use. Even with the ability to resolve many objects, some technologies (notably RFID) have difficulty in determining relative position or orientation on the table top.

One solution to the object tracking problem is virtual manipulatives [10]. Virtual manipulatives have been created in many labs and adopted in schools [10, 7]. Many of the gains associated with physical manipulatives are seen with virtual manipulatives and virtual manipulatives can have unique benefits [4]. However, some would argue that the motor movements associated with objects (Papert's "body syntonicity" [8]) provide transparency to the learner and, when these movements are involved in problem solving, they are an important part of the experience of using math manipulatives. Thus, many teachers feel that physical objects are key [2].

What we are doing

Our goal is to support the current practices of teachers while, at the same time, providing additional capacity to instruct and evaluate their students. We are doing this by allowing the teachers to use the physical manipulatives that are already in their classrooms and providing a netbook-based application that assigns individual problems to students, follows their progress, and assists them as they work to solve those problems. Problems are selected from a large problem space that we are developing in conjunction with kindergarten through second grade teachers in an effort to provide problems that are appropriate for students in this range.

Our system has three basic components. First, there is a component that follows the manipulatives as students use them. Second, there is an interaction planner that selects the problems, hints, and feedback provided by the system based on the student's progress. Third, we display the problems, hints, and feedback for the student.

Observing the manipulatives

To the extent possible, we determine pedagogically relevant "observable" phenomena for the system to watch. To follow the manipulatives, we have developed a computer vision component that watches what students are doing. In particular, we watch for student-defined clusters of objects selected from the objects on the desk. We use a standard camera (such as the one on laptop lids) to watch the desk in front of students and track the objects as students move them. We can see if the students are moving them in such a way that they will reach a solution to the task or not. We can recognize common errors or non-goal directed movements.

Planning the interaction

Taking various pieces of data (e.g., movement toward goal, time since assignment, Facial Affect Coding [1], etc.) as input, we use POMDPs to give the students new assignments, hints on the current task, or feedback on a recently completed task.

To determine assignments, we worked with teachers to define a range of tasks, which we verified as appropriate by deploying a Java Taplet version of the application in K-2 classrooms. The order of assignments was heuristically determined but we are working on a more principled approach to be used in our final version.

We want to deliver the same types of hints and feedback that a teacher would deliver if they were watching the child working. To this end, we are currently analyzing videotapes of a teacher providing one-on-one instruction to students using manipulatives. We are observing the teacher for the information she provides as well as the contextual variables that elicited the communication from the teacher. That is, we are looking at what the teacher said and did as well as the aspects of the students' behavior to which the teacher was responding.

Providing input to participants

To reflect what the teacher says or does, we provide both auditory and visual information. We use a speaker on the computer and a text-to-speech engine for assignments and feedback. In practice, we have found that the teachers with whom we are working do not mind the sound in their classrooms. We also use the display on the laptop to show the student information. We can "mark up" on-screen video much in the same way as standard mobile augmented reality applications. Finally, we are pursuing a method to use an integrated pico-projector to actually project the hints or feedback onto the physical manipulatives.

Yet to be done

While we are still working on each of these components, there is a fourth component that we believe will be important for such a system. In addition to student outputs, we plan to inform the teacher of student outcomes. We'd like a teacher to be able to get a summary for each student at any point in time as well as "real time" feedback about what a child has been doing in the recent past. This could be delivered to a mobile device or desktop for the teacher. We have been talking to our collaborating teachers about this but have yet to develop this part of the system.

Summary

Recent advances in machine vision make it a more viable candidate for supporting a range of educational scenarios. We believe that a fruitful area for HCI work is to investigate ways in which this technology can support existing practices around the use of manipulatives. For example, we hope to investigate ways of “marking up” manipulatives for students and believe that both augmented reality interfaces and on-object projection [as in 5] could be interesting not only for our own work but also that of others.

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