Experiments in Using Tangible Interfaces to Enhance Collaborative Learning Experiences

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ABSTRACT
TICLE (Tangible Interfaces for Collaborative Learning Environments) is a project that explores new ways that a computer can enhance learning without dominating the educational experience. We have developed a prototype system that "watches" as students play with Tangram pieces on a physical tabletop, and acts as a "guide on the side" by offering help at appropriate times. This system is currently installed at the Goudreau Museum of Mathematics in Art and Science. Our paper describes the implementation of our prototype and results of a usability study conducted at the museum. We also discuss ongoing enhancements and plans for further testing. Although this work focuses on learning with mathematical puzzles, it has implications for other physical learning activities.

Keywords
Tangible interface, K-12 math education, multimodal interaction, multimedia user interface, guide on the side

INTRODUCTION
Educators and governments have been searching for ways to improve learning in our schools, particularly in math and science. Yet as educators come to recognize the importance of collaborative activities, learning through play, and teacher guidance, shrinking school budgets severely limit teachers' opportunities to use these approaches. Tangible Interfaces for Collaborative Learning Environments (TICLE) was conceived in response to this need [1].

TICLE embodies a different notion of support for collaborative learning, combining the advantages of physical learning activities with those of computer tutors. With TICLE, children are given a set of physical puzzle pieces and a specific goal designed to teach some math or science concept. A computer system observes the children as they work with the puzzle, encouraging them as they make progress and offering to give them "hints" when they don't. The hints encourage thinking about the problem by asking children to consider smaller related problems. TICLE is unique in that it …

- Fosters group participation, allowing children to focus on the puzzle without worrying about how to use the interface or whose turn it is to use the mouse;
- Allows the computer to act as "guide on the side" by providing help and information only when it is needed, without dominating the educational activity; and
- Extends the realm of possibilities for tangible interfaces, prescribing a strategy for uniquely representing the state of a puzzle such that the system can rapidly check for solutions or partial solutions.

Although we focus on puzzles that teach math concepts, the TICLE approach may be applied to a wide variety of educational activities. We envision this sort of system being installed in museums, such as the Goudreau Museum, where exhibits are increasingly interactive, group participation is encouraged, and learning occurs without the presence of a human instructor. We also see this as a potential aid to teachers in the classroom, providing supplemental educational activities during down times. Ultimately, we would like to develop an interface that would enable teachers to create their own activities.

APPROACH
We chose to implement a prototype system based on the Tangram, an old Chinese geometry puzzle. The object of this puzzle is to recreate a given figure (e.g. a square) from the Tangram's seven simple shapes. The Tangram is a good choice because it can be used to show what "area" and "congruence" are without having to resort to formulas. Playing with it can also develop a geometric intuition in children, helping them to better grasp more complex geometric concepts later in their school careers.

In this implementation, we use computer vision techniques to track the puzzle pieces as they are moved about. We tag the pieces with reflective markings and track them with a videocam mounted next to a light source. The videocam and lights are located under a Plexiglas playing surface, which virtually eliminates the problem of accidental obscuration.

Once the system knows where the puzzle pieces are, it generates a string representing the state of the puzzle using a shorthand notation that we developed for this purpose. A substring is generated for every pair of puzzle pieces that are touching; no substring is generated if the pieces do not touch. We sort (alphabetically) and concatenate the substrings to produce a unique representation of the puzzle state that is translation and rotation invariant. Our system can then quickly and easily detect partial solutions (one of the substrings comprising the solution is found in the current state string) or a complete solution (the current state string is equivalent to the solution string).

Based on the state of the physical puzzle, our system can provide appropriate feedback to the players. A computer display shows a current view of the puzzle beside two very large buttons, which are used to review the objectives of the game and get hints. Each hint is framed as a question (audio) about a subset of the Tangram pieces (shown on the screen). The animation then pauses until someone clicks the mouse button, after which the answer is shown. In the current implementation, the system cycles through a logically ordered set of hints. A female voice offers encouragement as players make progress, and reminds the students of their options when no progress is being made.

EVALUATION

After installing the Tangram prototype in the Goudreau Museum, we conducted a usability study to find out if

- Feedback from the computer system keeps students engaged, so they don't give up so quickly;
- All students actually do participate and work together;
- Hints stimulate metacognitive thought processes, leading to understanding and solving the puzzle; and
- Understanding gained from the activity transfers to similar problems.

We conducted three test sequences using 4th and 5th graders, with two groups of three children participating in each test sequence. In the first phase of the test, one group worked with our Tangram system while the other group, the control, used a physical puzzle with no supplemental guidance. We videotaped both groups as they attempted to construct a square using all seven Tangram pieces. Each group was given 15 minutes to complete the task. In the second phase of the test, the children were asked to use the same pieces to construct a "house" shape. In the third phase of the test, students were asked a set of questions that included their impressions of TICLE.

We learned much from this study. For instance, all of the groups initially tried to solve the puzzle unaided, but eventually asked for help. The hints that our system gave did seem to help: although no one solved the puzzle, those using TICLE came closer, putting more of the pieces together the right way. The hints also seemed to inspire thoughful discussion within the groups. In general, the control groups wanted to "give up" sooner than those using TICLE. In the second phase of the test, all participants were able to construct the "house" shape.

The subsequent interviews were also revealing. When asked about the TICLE interface, two thirds thought that the computer's feedback was helpful. The remainder thought that getting hints was "cheating", or found the feedback to be distracting. When asked how TICLE could be improved, 55% suggested creating more or better hints; another 22% thought that the hints should simply remain on-screen for longer. Other suggestions included making the puzzle pieces smaller or out of different materials, and providing an outline to place the pieces in.

ONGOING WORK

Our study suggested several improvements to the TICLE prototype, which are being implemented. These include:

- Developing more hints that more fully reflect meta-cognitive dialogs, support scaffolding, and present similar concepts different ways;
- Increasing context sensitivity by developing a simple rule base that is triggered by the presence (or absence) of solution substrings in the current state;
- Supplementing the audio with text, to compensate for excessive noise in the museum; and
- Using a touch screen (instead of a mouse) to interact with the computer (i.e. ask for hints).

Our case study also demonstrated a need for more rigorous testing methods. In our next study, we plan to:

- Use a cognitive-metacognitive framework to transcribe, label and analyze dialogs and actions;
- Observe the second part of the test in the same way to help determine what was learned; and
- Show videotapes of sessions to the subjects during the interview, and ask what they were thinking.

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