TICLE: a Tangible Interface for Collaborative Learning Environments

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ABSTRACT
This work explores new ways that technology can enhance education. We are developing a system that "watches" students as they play with a Tangram puzzle on a physical tabletop, and offers help at appropriate times. Thus instead of making the computer a central part of the educational experience, our system acts as a "guide on the side" that students may either turn to for occasional help or ignore completely. This system will be installed and evaluated at the Goudreau Museum of Mathematics in Art and Science during spring 1999.

Keywords
3-D interface, education applications, input devices, interaction design, ubiquitous computing, tangible interface, multimedia

INTRODUCTION
Despite many best efforts, a large number of children are still turned off by math and science. Yet everyone likes puzzles. By showing them that mathematicians and scientists essentially solve puzzles, and by allowing them to work on these puzzles together, we may get more of these children excited about math and science. However these same children tend to hang back and let someone else control the mouse when asked to work on a computer program as a team. If we use technology at all, we must find new ways for the computer to enhance learning without dominating the experience or intimidating the children.

Puzzles play an integral role at the Goudreau Museum of Mathematics in Art and Science in New Hyde Park, NY. In fact, one of the most popular aspects of the museum is its mathematical puzzles and activities. Yet when visitors find themselves unable to progress with a particular puzzle, knowledgeable teachers need to provide guidance. With up to 35 visitors working on more than 20 puzzles at once, this help is not always available. Our project aims to fill in the gaps, supplementing the teachers' instruction and helping students to maintain interest.

We are exploring these issues with our tangible interface for collaborative learning environments (TICLE). With this system a computer responds to one's very natural manipulations of objects in the physical realm. This allows people to focus on the task at hand without having to worry about how to give instructions to a machine. Students may turn to the computer for help and further information, or they may ignore the computer completely and still have an enriching educational experience.

Although our project focuses on enhancing free play with physical puzzles, the interface techniques that we are exploring may apply to a wide variety of educational experiences. These may include anatomical models that students "dissect" in a biology lab; physics experiments that involve an arrangement of levers and pulleys; molecular models constructed in a chemistry class. It may also be used to "check" the assembly of models, furniture, even equipment.

This project is related to past work on ubiquitous computing and current work on tangible media [1, 5], self-sensing devices [6], and programmable toys [2]. Yet our work is unique in that it

- uses computers to enhance a physical collaborative learning environment, rather than dominate it,
- responds to student actions (or inaction) as it attempts to guide students without giving them the answers, and
- focuses on middle school-age children with an aversion to math, science, and computers.

IMPLEMENTATION
We have chosen to implement a prototype tangible interface for the Tangram, an old Chinese geometric puzzle. We are developing this system in three parts.

Tracking the Puzzle Pieces
Computer vision techniques help us to track the puzzle pieces as they are moved about. We are extending Underkoffler's approach [5], tagging the pieces with reflective markings and tracking them with a QuickCam mounted next to a light source. A technical report [3] describes this tracking approach and alternative approaches that were rejected for now.

After identifying the location and orientation of the pieces, we generate an encoded string that uniquely represents the spatial relationships among the puzzle pieces. The spatial relationships and the strategy for encoding them is described in [4]. This is generated approximately once every second.

Interpreting User Actions

Given the spatial relations among the puzzle pieces, our system then decides what the appropriate response is. Some of the conditions that it checks for are:

- A solution has been found. The players are congratulated, and the interface offers to explain underlying geometric principles.
- A partial solution has been found. The system encourages the players, telling them that they are on the right track.
- Puzzle pieces are being put together the wrong way. The system gently remarks that that will not lead to a solution, and offers to give the players a hint.
- Players hesitate for a long period of time. The system offers to either give the players a hint or review the rules and goal of the game.
- Puzzle pieces are removed from the table, or stacked on one another. The system reminds the students that all puzzle pieces must be flat on the table, and offers to review the rules and goal of the game.

A key factor in this system is determining the appropriate response rate. If the computer reacts to every move every second, it is likely to become annoying. If, however, it waits too long, it may become ineffective.

Multimedia Feedback

The system responds the players actions (or inaction) with audio, graphics, and animation. A color graphics monitor located near the game provides the visual feedback. A mouse (on a mouse pad) near the monitor allows players to communicate with the computer. In most cases, players will only need to click the mouse button (without pointing) to answer "yes" to a question such as "Do you want a hint?".

Because most players will view the screen from a distance, we are striving to keep the display as clear and simple as possible. Graphics and animations employ bold two-dimensional figures. On-screen text is kept to a bare minimum. For the audio portion, we are using a recorded female voice. We have rejected synthetic voices because they are not as clear. We have also rejected the use of background music and extraneous sound effects.

FUTURE WORK

We are currently finishing our Tangram prototype, and plan to install it at the Goudreau Museum this spring. Once it is there, we plan to take the following next steps.

First we need to evaluate our prototype. We will conduct interviews with visitors to the museum that will likely yield suggestions for improvements to the system. We plan to implement the best suggestions in several iterations of the system. Our evaluation will also rely heavily on museum staff's and our own observations of students using the system. This will help us to determine how useful this approach to learning is.

If our system proves to be as useful as we expect it to be, we will then use our evaluations to formalize an approach to developing these puzzles. Ultimately we would like to create a system that would allow instructors to develop their own puzzles.

In another important step, we will explore extensions of these ideas to the third dimension. This will allow us to build interfaces to three-dimensional puzzles and models.

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