Oppenheimer Award Winner

Improving Cognitive Visualization with a Web Based Interactive Assessment and Training Program

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ABSTRACT

The ability to visualize objects and situations in one's mind and to manipulate those images is a cognitive skill vital to many career fields, especially those which require work with graphical representations such as visual arts and engineering. Spatial abilities have been widely studied and are known to be fundamental to higher level thinking, reasoning, and creative processes. However, individuals vary widely in these skills. Research on mental imagery has shown that several of the component skills can be improved by training.

Although native ability is a factor, there are also several additional variables that have been shown to impact performance. For example, students may have their confidence undermined by the emphasis that our culture places on native ability as opposed to effort. A program that demonstrates to a student that spatial skills CAN be improved should have an impact that goes beyond performance on a specific task. At Penn State Erie a prototype web-based tool to assess and provide training on spatial skills is currently being co-developed by faculty in engineering graphics and cognitive psychology with the help from Penn State's Center of Academic Computing at University Park. The program will first assess three types of spatial skills; then based on the user's scores, it will provide exercises designed to improve that skill. Using a participatory design process, we have a group of psychology and engineering students working in teams to help design and evaluate the learning activities.

The program will be first be used in the freshman seminar being developed for engineering by the first author, but it would be available to students in a variety of fields. Eventually the program will be made available to high schools and outreach programs to help prepare students interested in fields which require visualization skills.

Introduction

Career fields such as engineering and visual arts require one to mentally visualize and manipulate objects and situations. With the advent of powerful computers and the resulting ability to program 3-D graphic visualizations of everything from works of art, to chemical molecules, to statistical trends in data, it is likely that these spatial skills will become even more important. Research on imagery has shown that spatial skills can be improved by training (Sorby, 1999). This may be especially important for women who remain poorly represented in many technical fields. Women as a group do tend to perform at a lower level on some spatial tasks, especially those involving mental rotation. However, this difference is not nearly large

enough to explain the low number of women in fields such as engineering. A more important factor is that societal stereotypes reinforce the view that women are less competent in a wide variety of mathematical and spatial abilities. This view persists despite evidence that girl's grades are as high or higher than boys. In addition, if spatial skills are viewed as a purely innate ability then any person who has been told that they have poor spatial skills will be likely to avoid activities and courses that might actually improve those skills. This emphasis on innate ability verses personal effort and practice is not a universal phenomenon and is much is more prevalent in individualistic cultures such as the US (Geary, 1996). Thus, a training program that demonstrates to a student that spatial skills CAN be improved should have an attitudinal impact that goes beyond basic skill improvement (Peters, Chisholm & Laeng, 1995).

During Fall semester 1997, the first two authors conducted a pilot study at Penn State Erie, The Behrend College examining freshman engineering major's visualization skills. The engineering students with previous drafting experience showed stronger visualization skills in the freshman graphics course. Although the correlations were modest, course grades at the end of the semester were related to more accurate mental rotation scores at the beginning. Using the proper tools, we could identify the visualization skills of students as, or even before, they arrive at Penn State Erie and give them enjoyable and meaningful exercises to practice, thus helping to level the playing field and build their level of confidence (Blasko and Holliday-Darr, 1999).

Measuring and improving spatial abilities
There are several tests designed to assess spatial skills. However, we were unable to find any existing software that both assessed and improved specific areas of spatial skill and was web based to make it widely accessible. We did locate one Web site that tests mental rotation abilities using the standard Mental Rotation Task (MRT) (Vandenberg & Kuse, 1978) (http://www.olemiss.edu/PsychExps/). However, graphics are poor, and it is limited to just one task. There is a commercial package, VizAbility™ (PWS Publishing Company), designed to enhance visual thinking which has some relevant components such as a block building task, but it does not do testing and is limited in the spatial skills it addresses.

Project Development

The goals of our project are to develop a program that is highly accessible, assesses current skills, provides immediate feedback and provides training exercises tailored to each student's skill level. We received a grant for funding and programming from the Center for Academic Computing (CAC) at University Park. The project team is composed of an instructor in engineering graphics, an associate professor in experimental psychology, a senior instructional designer, a graphic designer, and a programmer/analyst. In the current phase of the project we are developing a web-based shell of the program and three basic prototype exercises. Additional exercises will be added in the future.

We felt it was important to involve students throughout the project. Using a participatory design we are offering a 1-credit independent-study course in educational software design for a group of engineering and psychology students. The students are working in project teams to evaluate the testing portion of the software and to help design training "games" that will interest and motivate their peers.

The program will assess and train the users on the three types of spatial skills that have been identified in a large scale meta-analysis (Voyer, Voyer & Bryden, 1995). They include (1) spatial perception (the ability to determine spatial relationships among objects despite distracting information), (2)
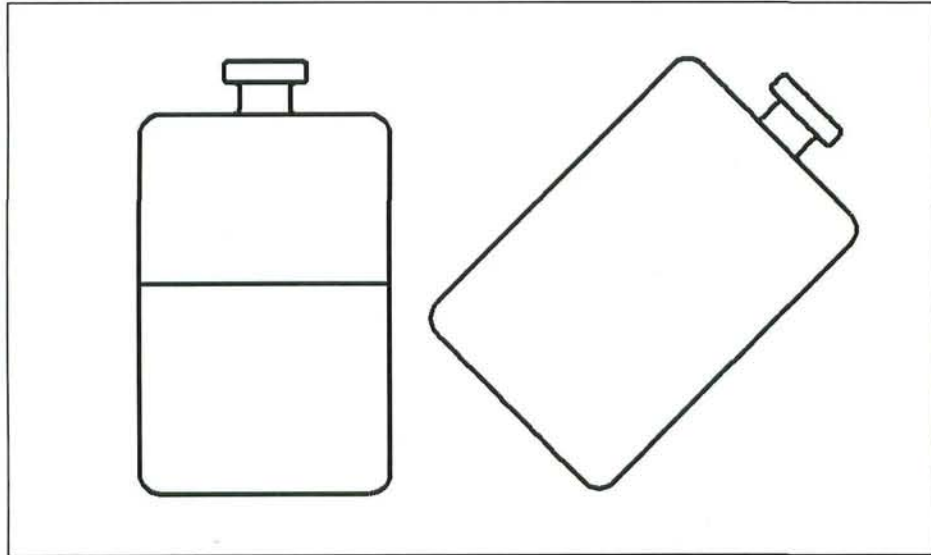
Figure 1 - *Using your mouse, draw a line depicting the water line in the jug on the right.*

spatial visualization (the ability to manipulate complex spatial information when several stages are needed to produce the correct solution), and (3) mental rotation (the ability to quickly rotate in their imagination 2 or 3 dimensional objects).

The Piaget Water Test (Piaget & Inhelder, 1956) (*Figure 1*) is a test of spatial perception. Students will be asked to draw in the correct water level, while different containers are tilted to different degrees. This task appears to measure the degree to which an individual is able to assess spatial direction in the presence of misleading contextual cues. Although it appears obvious to the expert (after all, the water line should always be horizontal) people vary widely in the degree to which the tilt of the bottle influences their judgment. After the assessment portion, animations will be used to demonstrate the correct answers, e.g., a glass of water tipping over and spilling. Students will access exercises ranging in degrees of difficulty. For example, a student would be instructed to draw the horizon inside a window frame (*Figure 2*). The degree

of difficulty will be determined by the number of distractors, such as crooked curtain rod, face looking into a window, etc.

Spatial visualization will be measured with an adaptation of the paper folding test Differential Aptitude Test: Space Relations (DAT:SR) (Bennett, Seashore, and Wesman, 1973) (*Figure 3*). Students will select which of
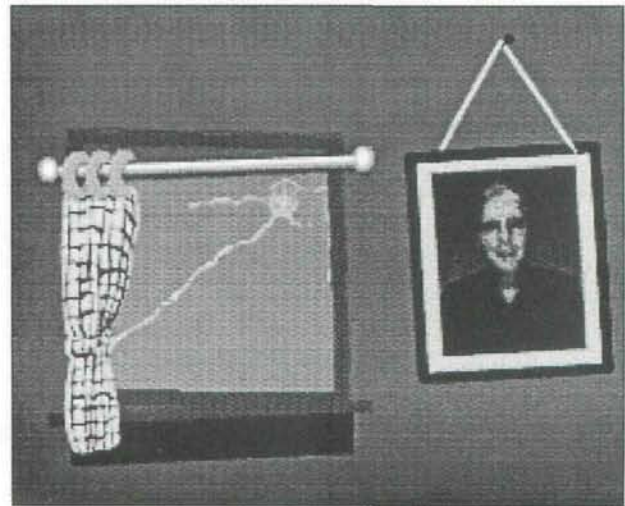

Figure 2 - *Using your mouse, draw a line inside the window frame depicting the horizon. Assume the ground is level.*

the unfolded objects equals the folded target. If they need hints in the practice portion of the test, they may click on the Hint button (*Figure 4*). After the assessment portion, interaction with engaging animations that show different objects, at their skill level, folded and unfolded can be used to improve skills.

A third set of exercises will be based on the Mental Rotation Task in which students must decide as quickly as possible whether one object when rotated in dimensional space would look the same as another (*Figure 5*). If the student selects the incorrect answer, in the practice portion of the test, animation will be used to show the correct answer. After the assessment portion, students will play a fast moving video style game at a level designed for their abilities. For example, students could be asked to match a target shape with one of several moving objects, which they will need to mentally rotate to compare to the target. In all cases, music, color, and some type of scoring could be used to engage and motivate students (Seddon & Shubber, 1985).

Software and Hardware Requirements

Because we would like as large an audience as possible, we must consider the hardware limitations of the typical user on an home machine in comparison to college students working in a high end engineering graphics lab. We also would like to have the program usable on most available platforms and operating systems. Therefore, we are trying to balance file size and quality considerations along with loading time for those with slower modems

and ease-of-use. One of the greatest challenges that we have faced so far is the difficulty that browsers have with handling animations and special effects without using mind boggling numbers of separate plug-in programs.
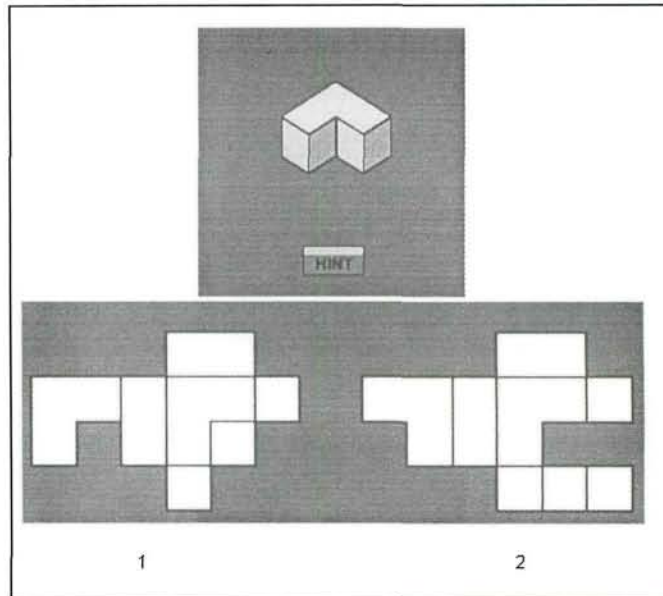

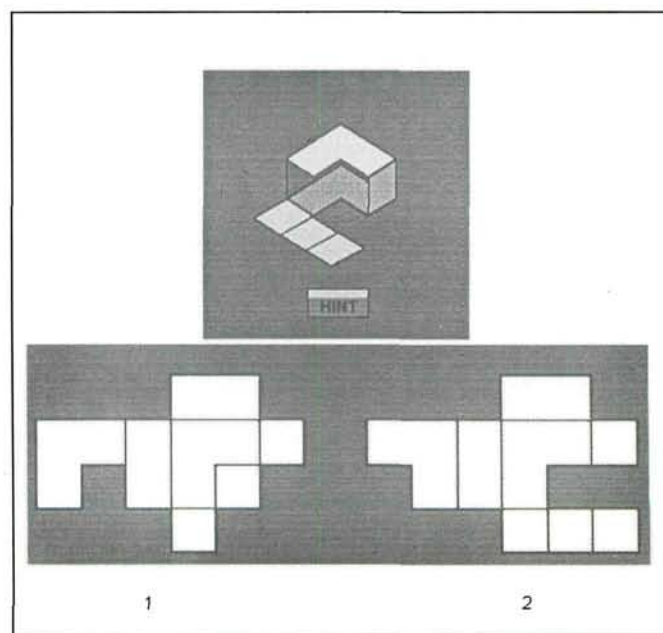*Figure 3 - Which flat pattern corresponds with the given 3-D object?*

Figure 4 - During the folding practice session, the student may click on the Hint button for help.
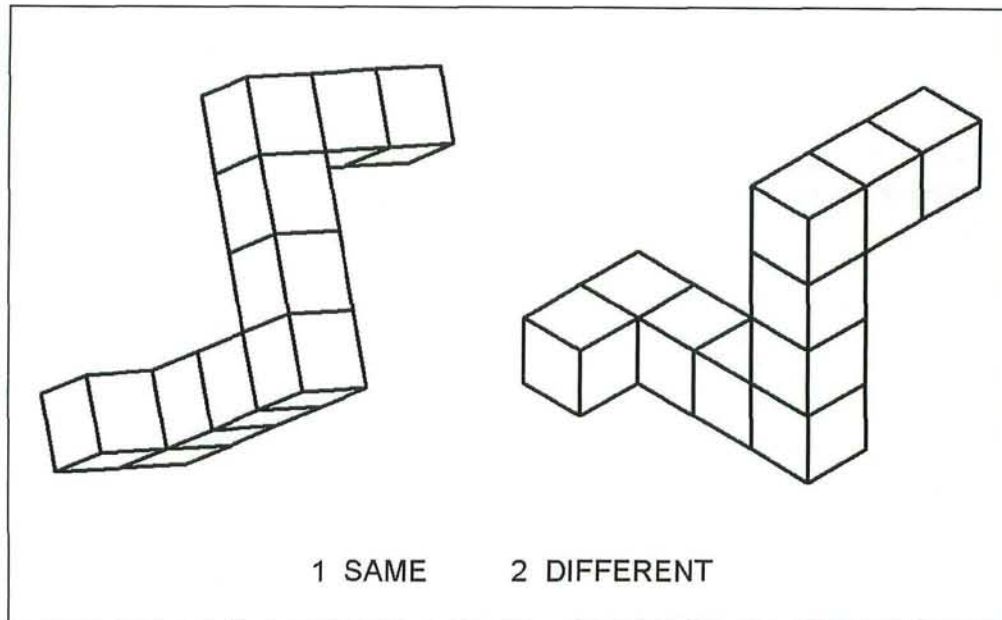
1 SAME   2 DIFFERENT

Figure 5 - *Is the object on the right the same object as on the left, but perhaps rotated in space?*

The project will require several software programs in order to create the graphics and animations, program the interactions, store students' data for later use, and design the web pages. Multimedia software, such as Authorware®, can be programmed to require the student to log on, allowing each student's data to be stored in a database. This data will allow the program to monitor the student's progress, what exercises the student has completed, and where the student stopped in a previous session. It will also allow the student to track his own progress. In addition, the program will collect information that will be useful for the instructor as well as providing data for the evaluation and improvement of the program (e.g., sex, age, accuracy, number of games played, amount of time played). Our goal is to create a system where the data can be collected, and easily output to a spreadsheet (e.g. Excel® and Access®). A number of other software programs are being used to create the graphics and interactive animations including SolidWorks®, Pro-Engineer®, Photoshop®, and Flash®.

Long term Goals

One goal of the project is to increase retention of engineering students, especially women, by building their visualization skills, thus building their confidence level. The program will be used in several outreach programs. One program is the federally funded Tech Prep program, designed to prepare high school students who have been pre-approved for admission into two-year engineering technology programs. The second program is a portion of the Black Achievers program, sponsored by the local YMCA. Penn State Erie offers a camp that is designed for high school minority students interested in engineering and/or engineering technology. A third program, Math Options sponsored by Penn State Erie, is for middle and high school female students trying to make them aware of possible careers in math, science, and engineering.

In the second phase of the project we will add more exercises designed to enhance the visualization skills not only of engineering students, but in other disciplines. In addition

we would like to design advanced activities for engineers that will cover basic terminology such as gears, cams, nuts, bolts, etc., as well as contain interactive exercises dealing with everyday objects. For example, the parts to a simple lock mechanism could be randomly placed about the screen. Each part would have a description of its function displayed as the cursor is passed over it. The students will be required to rotate the parts into position. Once the lock is assembled correctly, the lock will be animated to show how the parts work together. The response from Penn State Erie's engineering faculty, with respect to this phase of the project, has been very positive.

Conclusion

Web-based training offers a great deal of potential for the training of cognitive skills Although it holds a number of challenges, the benefits seem to vastly outweigh the costs. Spatial skills have been shown to be enhanced by regular practice and training, however many of the games that are on the market are extremely violent. There is a need for training that targets a wide range of spatial skills, is inexpensive and widely accessible. The most logical approach would be to combine the efforts of several interested schools/institutions in one collaborative enterprise.

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