Improving 3-D Spatial Visualization Skills with Multimedia Software

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Abstract

Development and evaluation of 3-D spatial visualization skills is discussed. Strategies for improving spatial skills are presented and multimedia software being developed by the authors is described. Initial assessment data from beta-testing the software is presented.

1. Background

Spatial skills have been a significant area of research in educational psychology since the 1920s or 30s. According to Piagetian theory[1], spatial skills are developed in three stages. In the first stage, topological skills are acquired. Topological skills are primarily two-dimensional and are acquired by most children by the age of 3-5. With these skills, children are able to recognize an object's closeness to others, its order in a group and its isolation or enclosure by a larger environment. Children who are able to put together puzzles have typically acquired this skill. In the second stage of development, children have acquired projective spatial ability. This second stage involves visualizing three-dimensional objects and perceiving what they will look like from different viewpoints or what they would look like if they were rotated or transformed in space. Most children have typically acquired this skill by adolescence for objects that they are familiar with from their everyday life experiences. If the object is unfamiliar or if a new feature such as motion is included, many students in high school or even college have difficulty in visualizing at this stage of development. In the third stage of development, people are able to visualize the concepts of area, volume, distance, translation, rotation and reflection. At this stage, a person is able to combine measurement concepts with their projective skills.

2. Evaluation of 3-D Spatial Skills

Most spatial skills tests have been developed to assess a person's skill-levels in the first two stages of development. At the second stage of development, there are numerous tests designed to assess a person's projective skill levels. Since these are 3-dimensional tests, a great deal of research has been conducted by engineering graphics educators using these instruments.

The Mental Cutting Test (MCT) [2] was first developed as part of a university entrance exam in the USA and consists of 25 items. For each test problem, students are shown a criterion figure which is to be cut with an assumed plane. They must choose the correct resulting cross-section from among five alternatives. A sample problem from the MCT is shown in Figure 1.

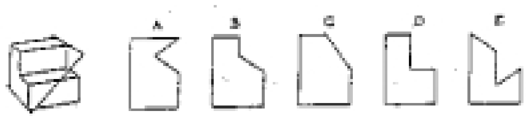

Figure 1: Sample Problem from the MCT

The Differential Aptitude Test: Space Relations (DAT:SR)[3] consists of 50 items. The task is to choose the correct 3-dimensional object from four alternatives that would result from folding the given 2-dimensional pattern. A sample problem from the DAT:SR is shown in Figure 2.

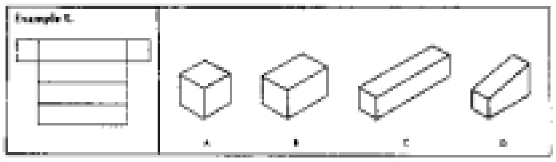

Figure 2: Sample Problem from the DAT:SR

Several tests have been developed to assess a person's skill levels with regards to mental rotations. The Purdue Spatial Visualization Test: Rotations (PSVT:R) was developed by Guay and consists of 30 items[4]. With this test, students are shown a criterion object and a view of the same object after undergoing a rotation in space. They are then shown a second object and asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. Figure 3 shows an example problem from the PSVT:R.

3. The Importance of 3-D Spatial Skills

Several educational research studies have been conducted in spatial visualization over the years. In 1964, Smith [5] conducted research in spatial visualization and concluded that there are 84 different careers for which spatial skills play an important role. Maier [6] concluded that for technical professions, such as engineering, spatial visualization skills and mental rotation abilities are especially important.

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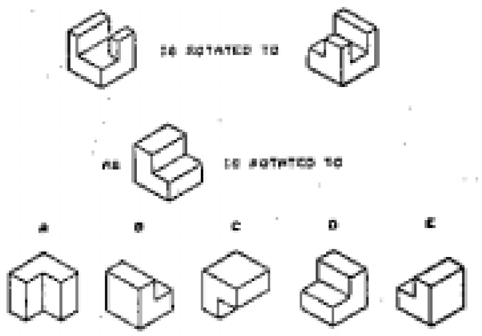

Figure 3: Sample Problem from the PSVT:R

Ferguson points out that the very first engineers started as artists during the Renaissance[7]. Early engineers such as Francesco di Giorgio, Leonardo da Vinci, Georg Agricola and Mariano Taccola were artists first and engineers second. Ferguson also claims that the engineering education of today has diverged too much from its artistic, visual beginnings and that our curriculum relies too heavily on analytical methods and not enough on tactile and visual perception. He maintains that many of the well-publicized engineering failures in the recent past (including the Challenger explosion, the Hubble space telescope, the Tacoma Narrows Bridge, and the USS Vincennes Aegis system among others) occurred largely because of the elimination of visual, tactile, and sensory aspects from the engineering curriculum of today.

4. Improving Spatial Skills

Since 1993, MTU has offered a special course aimed at improving the spatial skills of students who have a demonstrated weakness. Entering first-year students in mechanical, civil, environmental, general, geological and metallurgical engineering take the PSVT:R during orientation prior to the start of the academic year. Students who fail the PSVT:R (scoring 60% or lower) are encouraged to enroll in a special course on spatial visualization.

During the summer of 1998, four new multimedia software modules were developed for use in the spatial visualization course. The four new modules included: 1) Making isometric drawings, 2) Orthographic projection, 3) 2-D Patterns folding to 3-D objects, and 4) Rotation of objects about a single axis. These modules were pilot tested in the course during the fall of 1998 and will be fine-tuned as necessary in the coming months. Students were asked to assess each of the individual modules separately. Five additional modules will be developed prior to the 1999-2000 academic year. These modules include: 1) Rotation of objects about two or more axes, 2) Reflection of objects and symmetry, 3) Cross-sections of objects, 4) Surfaces and solids of revolution, and 5) Combining solids.

For the fall of 1998, thirty-six students enrolled in the course. The course was taught in much the same way that it had been for the past five years with the exception that the four new multimedia software modules were incorporated into the computer lab component of the course.

The multimedia modules were designed with two components each. The first component contained instructional material about a particular topic and the second component contained exercises for students to apply the techniques just learned. Each component was divided into sub-topics appropriate to the individual modules. For the multimedia software modules, students were asked to evaluate each of the sections of the software separately on a four-point scale where 1=confusing, 2=slightly confusing, 3=somewhat helpful, and 4=helpful. Students were also invited to make comments regarding each section of the software modules. The average ratings of the software modules are shown in Table 1.

Module	Instructional Portion	Exercises
Isometric	3.64	3.68
Orthographic	3.67	3.59
Pattern Folding	3.50	3.70
One-Step Rotations	3.68	3.65

Table 1: Average Student Ratings of Multimedia Modules

Each component of the various modules were rated highly by the students in the course. The written comments were generally good about each of the software modules. Further, students seemed to genuinely enjoy this type of instructional material. Students also pointed out some specific problems with the software, which animations did not work the way they were supposed to work, and where things worked differently than expected. Student feedback on each subdivision of the software will be used in the coming months to fine-tune and further develop the modules.

As a final evaluation of the multimedia software, students were asked to provide an overall assessment at the end of the term in their course evaluation. Students were to respond to each statement with A=Agree, D=Disagree, or U=Uncertain. They were also allowed to provide written comments if they wished on the evaluation form. The frequency of responses to the items are shown in Table 2.

Some of the more prevalent written comments found

Statement	A	D	U
1. The modules helped me learn the course material.	32	1	2
2. The multimedia modules were fun to use.	31	2	2
3. The topics covered in the modules were appropriate to the course.	35	0	0
4. The multimedia modules were easy to use (i.e., user friendly).	28	4	3
5. I would rather learn using the multimedia materials than using written materials.	21	5	9
6. The exercises in the multimedia modules were at the right difficulty level for me.	18	17	0
7. There were enough exercises at the end of each module to find out whether or not I understood the material.	22	8	5
8. It took me the entire hour of lab time to complete each module.	1	31	3
9. This is my first time using multimedia educational software.	24	10	1
10. Multimedia software is an effective tool for helping students develop their 3-D spatial ability.	32	1	2

Table 2: Frequency of Student Responses on Overall Evaluation of Multimedia Software

on this evaluation sheet are paraphrased in the following: 1) the software was easy to use and to understand, 2) a combination of software and written materials is best for learning the course material, and 3) the exercises on the multimedia software were generally too easy.

Besides the PSVT:R, students were also pre-tested with other tests designed to assess their ability to visualize in three dimensions including the MCT and the DAT:SR. Students were post-tested at the end of the 10-week term with these same tests and statistically significant gains on each of the tests were obtained. The results of the pre- and post-testing for fall 1998 are summarized in Table 3 along with data from previous offerings of the course for comparative purposes. For the averages presented in this table, there were 26 students in 1996 and in 1997, and 36 students in 1998.

Test	Year	Average Pre-Test	Average Post-Test	Ave. Gain	Level of Significance
PSVT:R (30 pts)	1996	15.0	24.5	9.42	$p<0.0005$
	1997	14.5	23.4	8.89	$p<0.0005$
	1998	15.2	21.8	6.53	$p<0.0005$
MCT (25 pts)	1996	9.4	12.7	3.27	$p<0.005$
	1997	10.2	13.4	4.42	$p<0.005$
	1998	9.8	13.3	3.51	$p<0.0005$
DAT:SR (50 pts)	1996	32.5	42.1	9.54	$p<0.005$
	1997	35.8	39.3	3.52	$p<0.01$
	1998	26.8	36.8	9.94	$p<0.0005$

Table 3: Gains in Spatial Abilities as Measured by Standardized Tests

5. Conclusions

Three-dimensional spatial visualization skills are critical to success in engineering and there are many instruments available to assess a person's spatial skill level. Spatial skills can be improved through practice and multimedia software is an effective tool in developing these skills.

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