3-D Spatial Skills--A Key to the Effective Use of Computer Graphics Software?

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Abstract

Development and evaluation of 3-D spatial visualization skills is discussed. Correlations between measured spatial skills and ability to effectively use computer graphics software are analyzed and strategies to improve 3-D spatial skills are presented.

1. Background

Spatial skills have been a significant area of research in educational psychology since the 1920s or 30s. However, unlike other types of skills, there is no real consensus about what is meant by the term "spatial visualization skills." For example, some argue that "spatial visualization is the ability to manipulate an object or pattern in the imagination"[1], whereas others argue that "spatial visualization [involves] complicated, multi-step manipulations of spatially presented information"[2]. Still others maintain that "spatial visualization is the mental manipulation of spatial information to determine how a given spatial configuration would appear if portions of that configuration were to be rotated, folded, repositioned, or otherwise transformed"[3].

According to Piagetian theory[4], 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)[5] 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.

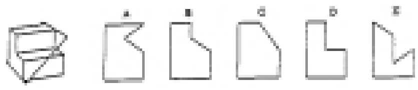

Figure 1: Sample Problem from the MCT

3. The Importance of 3-D Spatial Skills

Several educational research studies have been conducted in spatial visualization over the years. In 1964, Smith[6] conducted research in spatial visualization and concluded that there are 84 different careers for which spatial skills play an important role. Maier[7] concluded that for technical professions, such as engineering, spatial visualization skills and mental rotation abilities are especially important. Barke[8] found that well developed spatial skills are essential for understanding basic chemistry and structural chemistry.

Ferguson points out that the very first engineers started as artists during the Renaissance[9]. 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

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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.

In a previous research study conducted by Norman[10] it was found that a person's spatial visualization skills were the most significant predictor of success in his/her ability to interact with the computer interface in performing database operations. In Norman's study, it was found that subjects with low spatial ability took twice as long to perform database manipulation tasks as did those with high spatial ability. He further claims that graphical user interfaces (icons and pictures) could further aggravate differences in spatial visualization ability.

4. Present Study

In the Fall of 1998, approximately 100 engineering students enrolled in GN135-Introduction to Computer Aided Drafting and Design at MTU. GN 135 is a 2-credit course with an emphasis on 3-D solid modeling. It meets for one hour of lab lecture and one two-hour computer lab per week. Of the nine lab periods, five utilize the 3-D parametric modeling capabilities of I-DEAS Master Series software and four utilize IntelliCAD 2-D drafting software. Students complete seven homework assignments during the course. Four of the assignments are based on I-DEAS software and three are based on IntelliCAD. In addition, students complete a design project for the course which utilizes the 3-D solid modeling capabilities of I-DEAS software. Thus, significantly more than 50% of the course work is performed in a 3-D modeling environment.

Students were tested at the beginning of the course with the MCT to assess their spatial abilities. The average score for the students taking the test was 48.9% with a standard deviation of 19.6. For each of the seven homework assignments in the course, students were required to complete a questionnaire regarding their ease in completing the required work. A copy of the questionnaire is shown in Figure 2. Results from the questionnaires were recorded for each homework assignment in the course. Responses for questions 2-6 were input as straight numerical values and the response to question #1 was input as 1=More than 4 hours, 2=2-4 hours, 3=1-2 hours and 4=Less than one hour. A Principal Component Analysis was performed on the student responses using the SAS statistical software package. With this analysis,

1. Approximately how much time did you spend on this assignment?

a. Less than one hour b. 1-2 hours c. 2-4 hours d. more than 4 hours

2. What is your perception of the difficulty of this assignment?

Very Difficult — Very Easy
1 2 3 4 5

3. How much do you feel you struggled with the conceptual aspects of creating this object/drawing, i.e., about the procedures you would follow to create the object/drawing?

Very Much — Very Little
1 2 3 4 5

4. How much do you feel you struggled with the software itself, i.e., having the software do what you thought it should?

Very Much — Very Little
1 2 3 4 5

5. How much help did you receive from another person(s) (including the TAs) in completing this assignment?

Very Much — Very Little
1 2 3 4 5

6. How did you feel when you started work on this assignment?

Overwhelmed — Confident
1 2 3 4 5

Figure 2: Homework Questionnaire

loadings for each question were obtained so that a composite score for each student on a particular questionnaire could be determined. The principal component analysis was performed for each questionnaire, with slightly different results obtained in the form of the appropriate loadings. The principal components scores used in this analysis to represent a composite scores, accounted for between 37% and 65% of the variability in responses (mean=53%).

Correlations were computed between a student's composite score on the questionnaire and his/her score on the MCT. For assignment #1 the question regarding time spent on the assignment was omitted from the analysis since this was the first assignment completed with the software package. The computed correlations for the first four homework assignments (those involving working in a 3-D environment) are compiled in Table 1 with levels of significance indicated for those correlations that were considered to be significant or marginally significant. Figure 3 shows a scatter plot of

Assignment	MCT
HW1 (n=93)	0.17131 p=0.102
HW2 (n=80)	0.39328 p=0.0004

Table 1: Correlations between Composite Scores and MCT Score

Assignment	MCT
HW3 (n=77)	0.28977 p=0.0111
HW4 (n=69)	0.22930 p=0.060

Table 1: Correlations between Composite Scores and MCT Score

the composite scores and the MCT for homework assignment #2. Thus, its seems that a person's 3-D spatial ability to mentally slice through an object correlates to his/her ability to work effectively in a 3-D modeling environment.

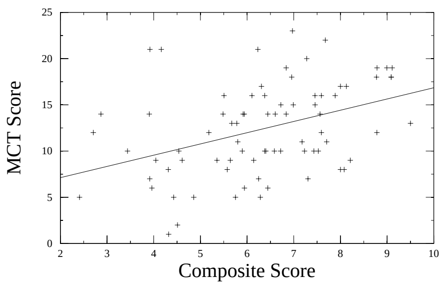

Figure 3: Correlation Between MCT Score and Questionnaire Composite Score

For the three homework assignments utilizing the 2-D drafting software, the students were divided into two groups. The first group (n=17) was comprised of those students who had previous experience with the 2-D software used in the class and the second group (n=55) had no previous experience with the software. Correlation analyses were again performed between a student's composite score and his/her score on each of the three spatial tests given. In this analysis, there were no statistically significant correlations between composite scores on the questionnaire and any of the spatial tests for either group. This implies that a person's 3-D spatial ability as measured by the MCT does not effect his/her ability to work in a 2-D drafting environment.

Correlation analyses were also performed between a student's final score in GN135 and his/her score on the MCT. The correlation between a student's score on the MCT and his/her course grade was statistically significant (r=0.20248, p=0.0585).

5. Conclusions

Three-dimensional spatial visualization skills are critical to success in engineering and there are instruments available to assess a person's spatial skill level. A person's ability to mentally slice through an object was found to be critical to their success in learning 3-D computer aided design software and to their overall success in the course GN135 offered at MTU. A person's 3-D spatial skills were not critical to success in learning 2-D drafting software.

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