Spatial Abilities and their Relationship to Computer Aided Design Instruction

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Abstract

Improving spatial visualization skills is often cited as an educational goal of engineering design graphics instruction. Many engineering design graphics faculty contend that working with 3-dimensional solid modeling software enhances the spatial abilities of their students. However, recent studies conducted at Michigan Technological University (MTU) indicate that merely working with 3-D software does not improve the spatial abilities of students by a significant amount when compared to the gains achieved by activities associated with traditional graphics instruction (i.e., sketching, orthographic projection, isometric drawing, etc.). In the fall of 1998 a study was conducted at MTU to ascertain whether a student's level of spatial ability is related to their ability to learn and use 3-D solid modeling software and/or 2-dimensional drafting software. In this study, students were administered three different tests designed to assess their level of spatial ability at the beginning of a computer aided drafting and design course. A questionnaire was developed to assess their level of ability in utilizing both the 3-D solid modeling software as well as a 2-D drafting package. Students turned in a copy of the completed questionnaire along with each homework assignment for the course. Correlation analyses were performed to determine if a person's spatial skill level was an indicator of his/her ability to effectively use either of the software packages utilized in the course. The findings from this study are presented in this paper.

Introduction

In a research study conducted at MTU in 1997, it was shown that the mere act of working with 3-D computer models in a solid modeling environment does not develop visualization skills as well as traditional techniques like sketching [1]. In this study, students in various courses at MTU were administered spatial testing instruments as both pre- and post-tests. The tests that were administered include the Purdue Spatial Visualization Test: Rotations (PSVT:R) [2], the Mental Cutting Test (MCT) [3], and the Mental Rotation Test (MRT) [4]. Two of the courses in this study were essentially computer aided design courses with an almost exclusive emphasis on 3-D modeling using I-DEAS software. In the remaining two courses sketching and/or hand drawing was the primary emphasis of the course work--one course focused on engineering graphics (EG) and the other course consisted of work in both descriptive geometry and engineering graphics (DG and EG). It should be noted that in the EG course many students with previous drafting experience were able to receive placement credit for the course, thus lowering the mean test scores for the

remaining group. Table 1 lists the results of the pre- and post-testing in these courses. In each case, the gain scores in the courses that empahsized sketching and hand drawing were higher than those obtained in either of the CAD courses. In fact, for the course labelled CAD#2, gain scores on the PSVT:R and the MRT were not statistically significant.

Table 1: Average Pre-/Post-test Scores, and Gains in Percent Correct

Course	MRT			MCT			PSVT:R		
	Pre-Test	Post-Test	Gain	Pre-Test	Post-Test	Gain	Pre-Test	Post-Test	Gain
DG and EG (n=118)	74.6	86.6	12.0 (p<.005)	60.8	76.0	6.2 (p<.005)	NA	NA	NA
EG (n=36)	72.5	82.4	9.9 (p<.005)	51.4	60.0	8.6 (p<.005)	77.2	84.7	7.5 (p<.005)
CAD #1 (n=62)	71.0	78.6	7.6 (p<.005)	49.6	54.5	4.9 (p<.005)	75.6	79.7	4.1 (p<.005)
CAD#2 (n=88)	66.0	66.8	0.8 (p>.10)	54.8	59.0	4.2 (.005<p<.01)	79.6	80.3	0.7 (p>.10)

Furthermore, of the 62 students enrolled in the CAD#1 course and the 36 enrolled in the EG course, 14 were enrolled in both courses. If these students are removed from the database and gain scores for the students who were enrolled only in CAD#1 and/or the EG course are analyzed separately the results shown in Table 2 are obtained.

Table 2: Average Pre-/Post-test Scores, and Gains in Percent Correct

Course	MRT			MCT			PSVT:R		
	Pre-Test	Post-Test	Gain	Pre-Test	Post-Test	Gain	Pre-Test	Post-Test	Gain
CAD#1 without EG (n=48)	70.1	77.9	7.8 $p<.005$	49.7	53.9	4.2 $0.01<p<0.05$	76.0	78.3	2.2 $0.05<p<0.1$
EG without CAD#1 (n=22)	66.8	81.6	14.8 $p<0.005$	48.2	56.9	8.7 $p<0.005$	81.3	85.3	4.0 $0.05<p<0.1$

Thus, it does not seem that merely working with 3-D modeling software improves spatial visualization skills as much as the traditional instructional techniques such as sketching employed in "traditional" engineering graphics courses.

In a previous research study conducted by Norman [5] 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.

Present Study

In the Fall of 1998, approximately 100 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 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. The topics in 3-D modeling that are covered in the course include profile extrusion, profile revolution, combining solids (cut, join, intersect), modifying objects, lofting, sweeping, assembly modeling, and drawing set-up. The 2-D drafting techniques in the course include drawing geometric entities (lines, circles, arcs, etc.), modifying geometry, adding annotation in the form of dimensions, labels and cross-hatching, dealing with layers in a drawing, inserting blocks, and managing a drawing (setting limits, etc.). The various ways of viewing objects and/or drawings are covered for each software package.

Students were pre-tested at the beginning of the course with three different tests designed to assess their spatial abilities. These tests included the PSVT:R [2], the MCT [3] and the DAT [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. The questionnaire consisted of six questions shown in Figure 1.

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, multipliers for each response were obtained so that a composite score for each student on a particular questionnaire could be determined. For example, for the questionnaire corresponding to homework assignment #3, the multipliers were (0.404164, 0.471080, 0.440760, 0.428852, 0.376992 and 0.307292) for the responses to each of the six questions, respectively. Use of these multipliers accounted for more that 50% of the variability in student answers on this particular questionnaire. The principal component analysis was performed for each questionnaire, with slightly different results obtained in the form of the appropriate multipliers. Correlations were computed between a student's composite score on the questionnaire and his/her score on each of the spatial visualization tests administered. For assignments #1 and #5, the question #1 was omitted from the analysis since this was the first assignment completed with each software package. A description of each homework assignment and the computed cor-

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 objec/drawingt?

   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   Confidant
      1   2   3   4   5

Figure 1

relations are compiled in Table 3 (Note that the number of respondents for each questionnaire varied slightly).

Table 3: Correlation Factors between CAD Assignments and Spatial Tests

Homework Assignment	PSVT:R	MCT	DAT
HW#1-Sketching and Extruding to form a solid. Sketching on a Face and Extruding/Protruding from the solid. (Time variable removed from the analysis for this assignment)	0.0090	0.17131 $p<0.1$	0.14436
HW#2-Sketching and Constraining, Cut, Join, Intersect, Modifying an object.	0.06379	0.39328 $p<0.001$	0.27909 $p<0.01$
HW#3-Lofting and Sweeping, Cut, Join and Intersect to form an object.	0.13917	0.28977 $p<0.01$	0.17486
HW#4-Creating objects and Assembling in a System, Creating drawings from objects	0.10253	0.22930 $p<0.1$	0.10779

Table 3: Correlation Factors between CAD Assignments and Spatial Tests

Homework Assignment	PSVT:R	MCT	DAT
HW#5-Creating a simple 2-D drawing (Time variable removed from the analysis for this assignment)	-0.0746	0.24568 $p<0.05$	0.06732
HW#6-Creating a 2-D drawing with hatch regions	-0.0091	0.15239	0.14082
HW#7-Creating a 2-D drawing with dimensions and other annotation	-0.01809	0.16599	0.18135

Thus, its seems that a person's 3-D spatial abilitity as measured by the MCT correlates to his/her ability to work effectively in a 3-D modeling environment. However, the type of 3-D spatial skills measured by the PSVT:R and the DAT do not correlate to a person's ability to work in a 3-D computer modeling environment. This is interesting in light of the fact that in two previous studies, the PSVT:R and the DAT were found to be significant predictors of student performance in traditional engineering graphics courses. In 1985, Gimmestad found that a person's score on the PSVT:R was the most significant predictor of success in an engineering graphics course of 11 variables tested [7], and in 1998 Medina et. al., found that a person's score on the DAT was the most significant preditor of success in an engineering graphics course of four spatial exams given [8]. Furthermore, it seems that a person's spatial abilities as measured by these testing instruments are not significant predictors of their ability to work with 2-D drafting software.

Correlation analyses were also performed between a student's final score in GN135 and his/her scores on each of the spatial exams administered. Weakly statistically significant correlations were obtained between a student's course grade and his/her score on the MCT. Thus, it seems that even those students who have weak spatial skills are able to overcome those weaknesses through perserverence and hard work.

Conclusions

It seems that merely working with 3-D modeling software does not improve a person's spatial skills as much as activities such as sketching and/or hand drawing. However, a person's spatial skills as measured by the MCT are a significant factor in their ability to interact with a computer in a 3-D modeling environment. The type of spatial skills measured by the PSVT:R and the DAT:SR do not seem to be significant predictors of a person's ability to work in a 3-D modeling environment. Spatial skills do not seem to be critical to success in effectively utilizing 2-D drafting software.

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