2006-2233: DO SPATIAL ABILITIES IMPACT THE LEARNING OF 3-D SOLID MODELING SOFTWARE?

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Do Spatial Abilities Impact the Learning of 3-D Solid Modeling Software?

Abstract

With the prolific use of 3-D solid modeling packages, should engineering graphics courses designed to improve spatial visualization skills continue to be an important foundation topic in engineering education? Does a person's spatial ability influence their ability to learn and use 3-D solid modeling packages? In the fall of 2005, a study was undertaken at Michigan Technological University to answer these questions. Two different tests were administered at the beginning of an introductory engineering course to determine the students' level of spatial ability: the Purdue Spatial Visualizations Test: Rotations and the Mental Cutting Test. In the introductory engineering course, students receive five class periods of instruction in engineering graphics (isometric sketching, orthographic projection, rotations, and other topics) and three class periods of instruction in a 3-D solid modeling package. Some of the students received instruction in engineering graphics before learning 3-D modeling software, and some after. Upon completion of the 3-D solid modeling module, students filled out a questionnaire to assess their ease of learning and using the modeling software. The questionnaire was related to a common assignment and asked students to track the amount of time they spent completing the assignment, how much help they needed, and how difficult they found the assignment to be. Students were also asked to compare their ability to use the software and their ease in learning the software with their teammates'. Correlation analyses were performed to determine if a person's spatial ability is correlated to his/her ability to effectively learn to use the 3-D solid modeling package and to determine if spatial visualization instruction prior to 3-D modeling instruction improves student success with learning the modeling package. The findings from this study are presented in this paper.

Introduction

In a research study conducted at Michigan Technological University 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 [1]. A 1994 study by Norman [2] found that a person's spatial visualization skills were the most significant predictor of a person's success in interacting with a computer interface to perform database operations. A 1999 study by Sorby [3] found little correlation between spatial abilities and the ability to work with 2-D drafting software, but found an apparent correlation between spatial abilities and the ability to interact with a computer in a 3-D modeling environment. However, in that previous study there were some potential errors in data-gathering and in survey instrument design. Further, at the time, graphics at Michigan Tech was taught as a stand-alone course whereas it is now taught so that it is integrated with other topics. Between 1999 and the present, the 3-D graphics package used at Michigan Tech has also changed from I-DEAS to Unigraphics UGNX3. For these reasons and to determine if the results were repeatable, it was decided to conduct a modified study on 3-D spatial skills and their relationship to learning 3-D modeling software under the new system.

Present Study

To assess the influence a person's spatial ability has on their ability to learn and use a 3-D solid modeling package, a study was undertaken at Michigan Tech in the fall of 2005. This study involved students enrolled in the first of two introductory engineering courses, ENG1101. Students were pre-tested at the beginning of the course with two different tests designed to assess their spatial abilities. These tests included the Purdue Spatial Visualization Test: Rotations (PSVT:R) [4] and the Mental Cutting Test (MCT) [5].

In ENG1101 students receive instruction in both sketching-based engineering graphics and 3-D solid modeling. Five 1.5-hour class periods are devoted to engineering graphics via sketching; the topics covered include isometric sketching, object transformations, and orthographic projections. It should be noted that additional graphics/modeling instruction is included in the second introductory course; however, their initial exposure to these topics is in ENG1101. Solid modeling is introduced in three or four class periods using Unigraphics UGNX3. The topics in 3-D modeling that are covered in the course include computer-based 2-D sketching and constraints, profile extrusion, combining solids, and creating a drawing layout. Of the twelve sections of ENG1101 (n=627) taught in the fall of 2005, four sections (n=178) covered solid modeling prior to sketching, while the remaining eight sections (n=449) covered solid modeling after sketching. Due to the academic and holiday calendar four days were devoted to 3-D modeling in the four sections covering 3-D modeling first, while only three days were spent on 3-D modeling in the eight sections that covered the 3-D modeling after sketching.

Upon completion of the solid modeling sessions, students were given a common homework assignment that required them to model a part and create an engineering drawing of that part. To assess their ability to learn and use a 3-D modeling program, the students were asked to complete a questionnaire regarding their ease in completing the assignment. Assuming that our undergraduate student teaching assistants are representative of the students enrolled in the course, the questionnaire was pilot tested with teaching assistants prior to implementation with the student-subjects. The questionnaire consisted of sixteen questions and is shown in Figure 1. In accordance with Michigan Tech's policy regarding the use of human subjects in research projects, the completion of the survey was strictly voluntary. Of the 627 students enrolled in the course, 329 students completed and returned the questionnaire.

ENG 1101 UGNX3 Feedback Name:________________________

Your completion of this survey is strictly voluntary. Information that can identify you individually will not be released to anyone outside of the study. Information from this study may be used for publication or education. Any information we use for publication will not identify you individually.

1. What is your previous 2-dimensional CAD experience?
   Expert User Competent Familiar Very little No experience
   1 2 3 4 5
   Please circle and/or list which programs you have had experience in:
   AutoCad Cadkey Other _______________
2. What is your previous 3-dimensional CAD/solid modeling experience?
   Expert User Competent Familiar Very little No experience
   1 2 3 4 5
   Please circle and/or list which programs you have had experience in:
   ProE IDEAS Solid Works Solid Edge UGNX Inventor Other ____________
3. How did you feel when you started work on the assignment?
   Confident Not worried A little worried Quite worried Overwhelmed
   1 2 3 4 5
4. How much did you feel you struggled with planning the steps you would use to create the object?
   Not at all Very Little Some Considerable Amount A lot
   1 2 3 4 5
5. How much did you struggle with the software itself, i.e., having the software do what you thought it should?
   Not at all Very Little Some Quite a bit A lot
   1 2 3 4 5
6. Approximately how much time did you spend planning and creating the part for this assignment?
   a. less than 30 min b. 30 – 60 min c. 1 -2 hrs d. 2-3 hrs e. More than 3 hrs
7. How many times did you scrap your work and start over on this assignment?
   a. zero b. 1-2 c. 3-4 d. 5-6 e. More than 6
8. Approximately how much time did you spend creating the engineering drawing of the part for this assignment?
   a. less than 30 min b. 30 – 60 min c. 1 -2 hrs d. 2-3 hrs e. More than 3 hrs
9. How many times did you scrap your engineering drawing for this assignment and start it over?
   a. zero b. 1-2 c. 3-4 d. 5-6 e. More than 6
10. Did you find this assignment difficult?
    No Yes If Yes, Why?
11. We have encouraged you to ask for help on individual homework assignments when necessary. This help can be from another student, your TA, or your instructor. How much help did you receive from another person(s) in completing this assignment?
    None Very little Some Quite a bit A Lot
    1 2 3 4 5
12. In comparison to your team mates, how would you rate your ease of learning UGNX?
    Much easier Slightly easier Average Slightly harder Much harder
    1 2 3 4 5
13. In comparison to your team mates, how would you rate your ability to use UGNX?
    Much better Slightly better Average Not too well Not at all well
    1 2 3 4 5

Figure 1: Homework Questionnaire

Responses to the questionnaire were recorded. The responses to questions 1-5 and 11-13 were input as straight numerical values. The responses to questions 6, 7, 8 and 9 were recorded as 1=a. response, 2=b. response, 3=c. response, 4=d. response, 5=e. response. In this manner, responses of a low number indicate greater confidence, ease, and ability in completing the assignment than responses of a higher number. There were three additional open ended questions not shown on the questionnaire in Figure 1 designed to elicit feedback for course improvement.

Correlations between student scores on the MCT and the PSVT:R and the questionnaire responses were calculated in Excel and are shown below in Table 1. Because the questionnaire responses were scored such that lower values correspond to less time and less difficulty with the assignment and software, all correlations were found to be negative (i.e. a student with a high MCT score would spend less time on the solid modeling assignment). The highest correlations between MCT score and student response were in rating their confidence in starting the assignment and their ease in planning the modeling approach. It was found that the correlation between the MCT scores and the responses to the questionnaire were statistically significant for all responses except if they found the assignment to be difficult. Correlations between PSVT:R scores and student responses were statistically significant with the exception of rating how much they struggled with the software, the amount of time spent on creating the engineering drawing, the number of times students scrapped their work and started over on the engineering drawing and whether or not they found the assignment difficult. Overall, correlations were higher between the MCT scores and student responses than the PSVT:R scores and student responses, suggesting the MCT may be a better predictor of student success in learning to use solid modeling software.

Table 1: Correlations between pre-test scores and questionnaire responses

	MCT (n= 328)	**PSVT:R (n = 299)**
Confidence in starting assignment	$r = -0.319$ ($p < 0.0005$)	$r = -0.284$ ($p < 0.0005$)
Ease in planning modeling approach	$r = -0.300$ ($p < 0.0005$)	$r = -0.212$ ($p < 0.0005$)
Time spent modeling part	$r = -0.199$ ($p < 0.0005$)	$r = -0.197$ ($p < 0.0005$)
Number of times starting over in creating model	$r = -0.167$ ($p = 0.005$)	$r = -0.198$ ($p < 0.0005$)
Time spent creating engineering drawing	$r = -0.219$ ($p < 0.0005$)	$r = -0.016$ ($p = 0.4$)
Number of times starting over in creating engineering drawings	$r = -0.168$ ($p = 0.005$)	$r = -0.080$ ($p = 0.1$)
Ease of working with software	$r = -0.102$ ($p = 0.05$)	$r = -0.070$ ($p = 0.2$)
Was assignment difficult?	$r = -0.075$ ($p = 0.1$)	$r = -0.139$ ($p = 0.01$)
Amount of assistance required	$r = -0.239$ ($p < 0.0005$)	$r = -0.227$ ($p < 0.0005$)
Ease in learning compared to teammates	$r = -0.240$ ($p < 0.0005$)	$r = -0.210$ ($p < 0.0005$)
Ability to use software compared to teammates	$r = -0.210$ ($p < 0.0005$)	$r = -0.154$ ($p = 0.005$)

Comparisons between student responses based on timing of solid modeling instruction were also made. Table 2 compares the correlations between student responses and MCT scores for those students who had solid modeling instruction before sketching instruction with correlations for students who had sketching instruction prior to solid modeling. Correlations were higher for students having solid modeling instruction first for all responses except those regarding the amount of assistance required and the amount of time to construct the solid model. From previous studies it has been shown that completing sketching exercises significantly increases a person's spatial ability[1]. Therefore, the pre-tests given at the beginning of the semester may have been less accurate in predicting true 3-D spatial skills at the time they were completing their solid modeling instruction for students who had sketching prior to solid modeling. This also points to a possible need to include sketching exercises before solid modeling in traditional graphics courses.

Table 2: Correlations between MCT scores and student responses based on timing of solid modeling instruction

	Solid Modeling Instruction before Sketching (n = 103)	**Sketching Instruction before Solid Modeling (n = 225)**
Confidence in starting assignment	r = -0.365 (p < 0.0005)	r = -0.302 (p < 0.0005)
Ease in planning modeling approach	r = -0.418 (p < 0.0005)	r = -0.241 (p < 0.0005)
Time spent modeling part	r = -0.189 (p = 0.05)	r = -0.211 (p = 0.001)
Number of times starting over in creating model	r = -0.255 (p = 0.005)	r = -0.138 (p = 0.025)
Time spent creating engineering drawing	r = -0.281 (p = 0.005)	r = -0.191 (p = 0.001)
Number of times starting over in creating engineering drawings	r = -0.216 (p = 0.025)	r = -0.148 (p = 0.025)
Ease of working with software	r = -0.280 (p = 0.005)	r = -0.035 (p = 0.3)
Was assignment difficult?	r = -0.107 (p = 0.2)	r = -0.072 (p = 0.2)
Amount of assistance required	r = -0.235 (p = 0.01)	r = -0.258 (p < 0.0005)
Ease in learning compared to teammates	r = -0.317 (p = 0.001)	r = -0.206 (p = 0.001)
Ability to use software compared to teammates	r = -0.276 (p = 0.005)	r = -0.177 (p = 0.005)

Student survey responses were compared for three groups of students (above average, slightly below average, and significantly below average) based on their MCT score. The mean score on the MCT for all the students in the study group was 14.36 out of 25 or 57.4%. Students in the above average group (Group 1) had MCT scores >60% (n=145), the average or slightly below average group (Group 2) had scores from 41 to 60% (n=99), while the significantly below average group (Group 3) scored 40% or less (n=84). Table 3 lists the mean responses for each question based on these categories. Students with significantly below average MCT scores (Group 3) had higher responses (indicating a greater level of difficulty) for all questions. Students with slightly below average MCT scores (Group 2) had higher responses for all questions than students with above average MCT scores (Group 1) with the exception of responses regarding the ease of working with the software and time spent in creating the solid model. Overall, students with higher MCT scores spent less time on the assignment and asked for less help than students with lower MCT scores. The biggest differences between mean responses of students with significantly below average MCT scores compared to responses of students with above average MCT scores were in the areas of level of confidence when beginning the assignment and in comparing their ease of learning and ability to use the software with their teammates'. The smallest difference in responses between the groups was in whether or not they found the assignment to be difficult.

Table 3: Mean questionnaire responses based on MCT score

	Group 3 (n=84)	**Group 2 (n=99)**	**Group 1 (n=145)**
Confidence in starting assignment	2.75	2.12	1.91
Ease in planning modeling approach	2.64	2.08	1.91
Time spent modeling part	2.29	1.81	1.84
Number of times starting over in creating model	2.04	1.69	1.65
Time spent creating engineering drawing	1.59	1.35	1.23
Number of times starting over in creating engineering drawings	1.61	1.41	1.37
Ease of working with software	3.02	2.64	2.73
Was assignment difficult?	1.28	1.21	1.20
Amount of assistance required	2.33	2.17	1.77
Ease in learning compared to teammates	2.87	2.49	2.35
Ability to use software compared to teammates	2.82	2.49	2.39

A statistical analysis was performed to determine if differences in means for the three groups were statistically significant. It was found that the mean responses for the group with average and slightly below average MCT scores (Group 2) was not statistically different than mean responses for the group with above average MCT scores (Group 1) with the exception of the amount of assistance required on the homework ($p = 0.005$). Table 4 shows the statistical significance of the difference in mean responses of students with significantly below average MCT scores (Group 3) with the two groups that scored higher on the MCT. Differences in mean responses were generally more statistically significant between the lowest scoring and the highest scoring group.

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Table 4: Statistical significance of differences in mean questionnaire responses based on MCT Score

	Statistical significance of the difference in mean responses between groups 2 & 3	**Statistical significance of the difference in mean responses between groups 1 & 3**
Confidence in starting assignment	$p < 0.0005$	$p < 0.0005$
Ease in planning modeling approach	$p < 0.0005$	$p < 0.0005$
Time spent modeling part	$p = 0.001$	$p = 0.001$
Number of times starting over in creating model	$p = 0.01$	$p = 0.001$
Time spent creating engineering drawing	$p = 0.025$	$p < 0.0005$
Number of times starting over in creating engineering drawings	$p = 0.05$	$p = 0.005$
Ease of working with software	$p = 0.01$	$p = 0.025$
Was assignment difficult?	$p = 0.2$	$p = 0.1$
Amount of assistance required	$p = 0.2$	$p < 0.0005$
Ease in learning compared to teammates	$p = 0.005$	$p < 0.0005$
Ability to use software compared to teammates	$p = 0.005$	$p < 0.0005$

An identical comparison between mean responses for students with significantly low MCT scores, slightly low MCT scores, and above average MCT scores was made based on whether a student received solid modeling instruction before or after sketching instruction. Students with significantly low MCT scores had higher responses for all questions than students with above average MCT scores regardless of the order of instruction. However, there were greater differences in responses between the high and low MCT score groups when students received solid modeling instruction before sketching instruction. This indicates that the development of spatial visualization skills through sketching might improve a person's chance of success in learning 3-D modeling software and further makes the case for including sketching before modeling in graphics instruction.

Conclusions

This study concludes that a person's spatial ability does significantly influence his/her ability to learn and use 3-D solid modeling packages. Therefore, engineering graphics courses designed to improve spatial visualization skills should continue to be an important foundation topic in engineering education. In addition, because sketching plays an important role in developing 3-D spatial skills, practice in sketching should not be completely abandoned in an engineering graphics course, and sketching instruction should precede modeling instruction where feasible.

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