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Does Rapid Prototyping Improve Student Visualization Skills

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Introduction

Technical graphics permeates nearly every aspect of industry. Improving the ability of students to visualize the product depicted on a drawing in its' completed form is one of the primary purposes of design and drafting curricula. Various methods have emerged using prepared models, photographs, transparent boxes, and pictorials to illustrate what the drawing is intended to represent. It is common practice for students to work from these prepared examples in the production of both two-dimensional and three-dimensional drawings.

The advent of the rapid prototyping (RP) process gives educators and students the ability to model complex parts that have been very difficult, or impossible, to accomplish in the past. After the production of a three-dimensional CAD file, the prototype can now be produced in a relatively short time. This allows students to create, rather than simply copy, drawings and parts. It also parallels industrial practice in the idea, concept, drawings, prototype, and manufacturing cycle. This creative process is relegated to a relatively small portion of technical graphics textbooks and has therefore, not been seen as a priority in many teaching institutions.

Because the teaching of rapid prototyping is just beginning to be incorporated into the classroom, there is little previous research related to whether this process can increase students' visualization skills. Yet, visualization has been one of the most important skills in industrial development (Bertoline, 1997; Sartain, 1946). Jurrens (1998) believes that this lack of research is also partially due to a lack of standards, currently under development, for testing rapid prototyping technology.

Purpose

The purpose of this study was to determine if the use of rapid prototyping technology would improve student visualization skills. It was thought that rapid prototyping might be valuable due to its ability to show the students physical models, in addition to virtual models, of their 3-D designs, and thus increase the translation between abstract 2-D drawings and actual 3-D parts. In order to accomplish this, the following research questions were proposed for this study:

1. Will drawing an object in 3-D, and producing that part with a rapid prototyping system, improve visualization skills over those students without rapid prototyping experience?
2. Does the use of rapid prototyping as a means of improving visualization skills justify its cost?

The first question is relatively easy to quantify for a particular system. The second question depends heavily on the answer to the first research question in part due to the relative high cost of RP systems. If rapid prototyping does not significantly increase students' visualization skills, it would be difficult to justify the cost of an RP system based on this criteria.

To answer these questions, the null hyptothesis was formulated that stated there was no statistical difference in visualization scores between students who had rapid prototyping experience and those who did not. To this end, sixty-two students in Engineering Graphics, Computer Aided Drafting, and Technical and Computer Drafting courses at Southeast Missouri State University were tested during the Fall and Spring Semesters of 1997 and 1998. The testing occurred at the following levels of instruction:

1. No drafting instruction
2. Drafting instruction
3. Computer Aided Drafting instruction in 2-D and 3-D
4. Rapid Prototyping of a 3-D part

All students who completed the study went through levels one through three. Randomly selected sample of students from level three were required to complete level four. Visualization tests were given at various stages of instruction for comparison purposes.

Rapid Prototyping

Rapid prototyping (RP) can take many forms and names. Desktop Manufacturing, 3-D Printing, Stereo Lithography, and Automated Fabrication are just a few of the names used in this cutting edge field. The chief industrial use for this technology is to improve cycle times in bringing products to market. It does this primarily by verifying design changes quickly. A CAD designed part can be "made" in just a few hours with sufficient accuracy and strength to test for fit, form, and function (Rowe, 1998). Vendor literature quotes prices ranging from $7,000 to $350,000 or more. The system used in this study, a JP-5, was the lowest cost model. It is a Laminated Object Manufacturing (LOM) system. This means individual layers are automatically cut and manually assembled to produce the part. In this case, the layer material was self-adhesive paper available from the developer (Schoff Development Corporation).

While differences in materials, software, and methods make generalizing about Rapid Prototyping difficult, it can safely be said that most of the systems follow a certain sequence. This standard process in developing a part is as follows:

1. Develop a 3-D CAD model of the part desired.
2. Convert the CAD file to the standard *.STL format.
3. Import the *.STL file into the Rapid Prototyping Program specific for the machine involved.
4. Orient the part for easiest production.
5. Use the software to slice the part into horizontal layers.
6. Send the slice data to the Rapid Prototyping machine for production.
7. Remove the part several hours later, for the automatic assembly machines, or remove slices for manual assembly machines.

The time required for the entire process depends on many variables. Included in this list of variables are; part size, layer thickness, complexity, manufacturing method, and the materials used.

Standard, well-understood methods of measuring Rapid Prototyping's benefits are currently undergoing development at the National Institute of Standards and Technology (NIST) (Jurrens, 1998). Until these standards are promulgated, comparisons and reproducibility in experimental design are, at best, poor. Additionally, the wide variety of rapid prototyping methods, software, and documentation that is available makes comparisons among differing systems open to varying interpretation. Due to the wide diversity of the processes involved in differing RP systems, the data collected in this study may not be generalizable to other systems.

Methods

The study was limited to students enrolled in one of the researchers' classes. This restriction was intended to reduce variations in learning due to teaching styles and learning environment. This decision was made to conform to one of the portents of the **Representational Research methodology** which requires research to be conducted in situ. Only students attending and completing each class were included in the study. All students experienced consistant instruction, as much as possible. Tests, homework, and other assignments were identical between sections except where required by the study procedure.

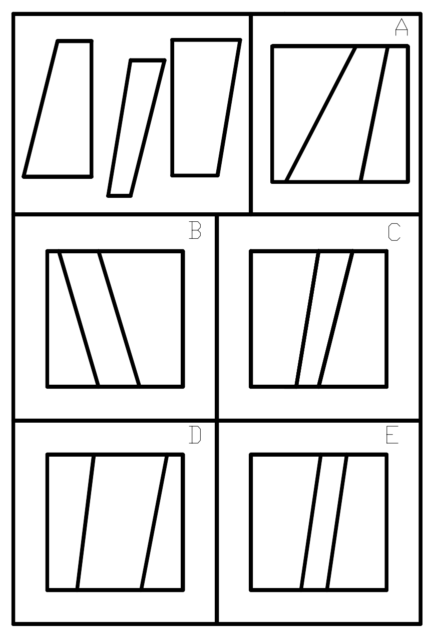
The study was not limited to Industrial Technology majors for two reasons. First, separating a sub-group from the class would have been technically difficult from a teaching standpoint. Second, this artificial division could have created a **Halo** effect due to the perceived "special treatment" on the part of the participants. Also, the validity of the study would have suffered due to the smaller N value.

Instrument

The Revised Minnesota Paper Form Board Test was used as the instrument for evaluating student performance in visualization (see Figure 1). This aptitude test is a well documented instrument with equivalent forms available for repetitive testing of the same sample group. Various reliabilities ranging from .85 to .91 have been reported (Rao, 1977; Lowman and Williams, 1987; Doran and Dietrich, 1980).

The validity of the test has been shown to have high multiple correlations with successful school to work performance in areas requiring visualization skills (Grimsley, 1944). This was articularly true in the drafting, printing, engineering, and inspection

Figure 1. Example, Similar to Revised Minnesota Paper Form Board Test



areas (Sartain, 1945; Grimsley, 1944; Crawford, 1942). These areas all exhibited correlation relationships greater than 0.40. In addition, extensive normative data exists for comparison purposes with both school and industrial groups (The Psychological Corporation, 1997).

Procedure

The pretest/posttest nature of this study indicated that Paired Difference Testing would best describe the data statistically (Brase, 1987). Students were tested for visualization skills at each of the following instructional levels:

1. No drafting instruction
2. Drafting instruction
3. Computer Aided Drafting instruction in 2-D and 3-D
4. Rapid Prototyping of 3-D part

Some students would complete instruction at level two while others would continue through level four. Due to this limitation, it was necessary to use different students at different levels of the study. In any case the difference in performance between steps is representative of one student's score, regardless of whether that particular student completed all the levels.

The first comparison involved students in two sections of TG120, Engineering Graphics. These students were all tested at the beginning and the end of the class. This corresponds to levels one and two above.

The second comparison involved all students continuing their education in TG126, Computer Aided Drafting. This group was tested at levels two and three above.

The last comparison involved students in two sections of TG126, Computer Aided Drafting. All students, in both sections, were given the same instruction until the last three weeks of the course when one randomly selected group worked with an exercise in 3-D CAD and in rapid prototyping the CAD part. The other group completed the 3-D CAD drawings used in the RP project but did not run the part. This corresponds to levels three and four above.

All of the students were informed that the testing was for comparison purposes with other groups and for determining teaching effectiveness within the class itself. It was emphasized that it had no effect on their grade. The results of the testing were made available to all students under a coded identification procedure within a week after each test was given. The students were also informed of average test scores in national testing of similar and dissimilar groups (Likert and Quasha, 1995). Alternate forms of the Minnesota Paper Forms Board Test, forms AA and BB, were used throughout the study. These forms are available from The Psychological Corporation in San Antonio, Texas.

While the study was originally designed only to evaluate whether Rapid Prototyping would increase visualization skills, it was necessary to eliminate or reduce the effect of as many variables as possible. The extended time period in this study allowed repetition with various groups for verification of results (Smith & Ragan, 1993). In addition, accuracy is improved if the researcher knows both the control and experimental group differences and this helps to correctly evaluate the results (Cook & Campbell, 1979). The extended time allowed for this study helped in both of these regards as well as increasing sample size.

Findings

The results of this study are summarized below. Several levels of testing are presented that are outside the original proposal, but are useful to understanding the results. These are divided according to the testing levels presented in the Introduction. These are:

1. No drafting instruction
2. Drafting instruction
3. Computer Aided Drafting instruction in 2-D and 3-D
4. Rapid Prototyping of 3-D part

Since paired difference testing was employed, the null hypothesis was that there was no statistical difference in visualization scores between the students who had rapid prototyping experience and those who did not. The research hypothesis was that the students who had rapid prototyping experience would score higher than those who did not. Since the students were randomly assigned into two groups, it is reasonable to say the two sampling distributions are independent (Brase & Brase, 1987). Small sample size in certain groups and limited time constraints dictated the use of the Student's *t* distribution instead of the *z* distribution.

A significant difference existed in visualization scores between students with no drafting experience and those with drafting experience. These differences are summarized in table 1.

Another increase in scores occurred when students underwent a period of instruction in 2-D and 3-D CAD. Whether this is due to increased drafting experience or is tied to the computer *per*

No Drafting (level one) Versus Drafting Instruction (level two)
Table 1. *Paired T-test and Confidence Interval*

Level	N	M	SD	SE Mean
1	34	44.91	8.28	1.42
2	34	49.72	7.54	1.29
Difference		-4.812	3.943	0.676

95% CI for mean difference: (-6.188, -3.436)

$t = -7.12$, $p < .05$

Since a t-value of 1.69 is the critical number, the null hypothesis, that the means are equal must be rejected. Therefore, the difference in the means is significant at the alpha equals .05 level.

se is uncertain. The differences are summarized in table 2.

Implications

The data supported the conclusion that the use of Rapid Prototyping in instruction did not significantly improve visualization skills in students. This implies that rapid prototyping should not be advocated as a tool to increase visualization skills for drafting students. The visualization tests did show a dramatic rise in scores as learning occurred at the other instructional levels tested as shown in Figure 2. These occurred at levels two (board drafting instruction) and three (2D and 3D computer aided drafting). Further use of the Rapid Prototyping system (level four) to produce the drawn object did not show an increase in visualization scores. Clearly the use of a Rapid Prototyping system as a means of improving visualization scores could not be justified.

It seems, therefore, that the costly nature of these machines precludes purchasing them on the basis of increasing students' visualization scores alone. However, a decision regarding the purchase of a rapid prototyping system should be based on the other potential benefits of these systems in the classroom. Some of the questions that must be asked are: Can the high costs be justified on the basis of simulating industrial practices; can the costs be shared with local industries; should universities be leaders in new technologies or followers always reflecting current industrial practices?

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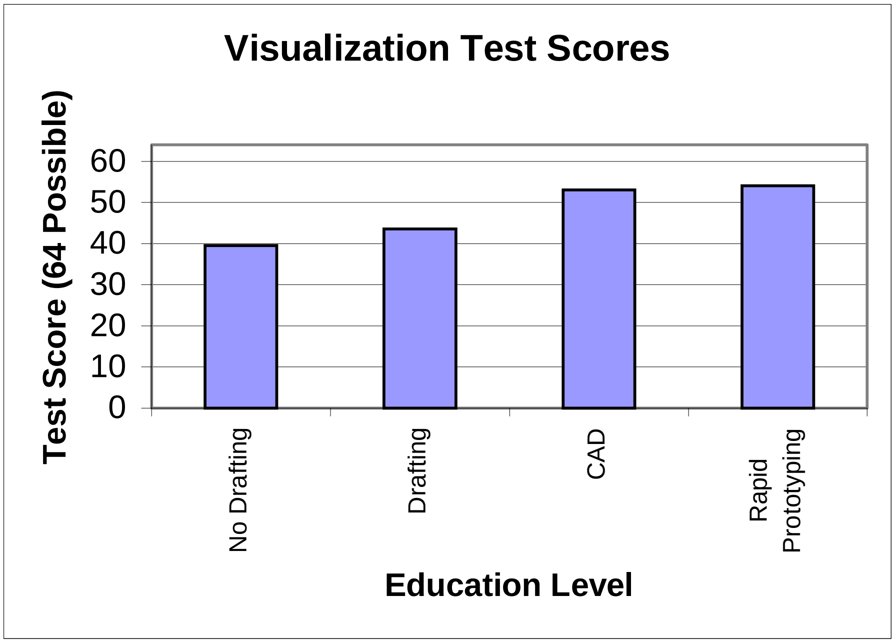
Figure 2. Visualization Test Scores



Drafting experience (level two) versus CAD instruction in 2-D and 3-D (level three)
Table 2. Paired T-test and Confidence Interval

Level	N	M	SD	SE Mean
2	17	48.47	5.70	1.38
3	17	51.94	5.14	1.25
Difference	-3.471	2.787	0.676	

95% CI for mean difference: (-4.903, -2.038)
t = -5.14, p < .05

Since a t-value of 1.69 is the critical number, the null hypothesis, that the means are equal must be rejected. Therefore the difference in the means is significant at the alpha equals .05 level.

Computer drafting experience (level three) versus Rapid Prototyping Simulation (level four)
Table 3. Paired T-test and Confidence Interval

Level	N	M	SD	SE Mean
3	17	50.98	9.02	2.19
4	17	51.60	9.40	2.28
Difference	-0.624	2.127	0.516	

95% CI for mean difference: (-1.717, 0.470)
t = -1.21, p < .05

Since a t-value of 1.69 is the critical number, the null hypothesis, that the means are equal must be accepted. Therefore, the difference in the means is insignificant at the alpha equals .05 level.

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