AC 2009-363: MEASURING AND ENHANCING SPATIAL VISUALIZATION IN ENGINEERING TECHNOLOGY STUDENTS

Patrick Connolly, Purdue University

La Verne Abe Harris, Purdue University

Mary Sadowski, Purdue University

Measuring and Enhancing Spatial Visualization in Engineering Technology Students

Introduction

One way engineering technology curricula aid in the preparation of future engineers and technologists is in the development of spatial visualization skills to better solve real world engineering design problems. This paper focuses on a recent study at Purdue University that was part of the National Science Foundation funded project: Enhancing Visualization Skills—Improving Options aNd Success (EnViSIONS). The purpose of the Envisions project is to disseminate and compare results for a course of remedial spatial visualization modules at seven major universities. The data will be collected and the impact of the modules or courses will be measured independently at all universities.

Four spatial ability modules were incorporated into one course at Purdue University: CGT 116, Geometric Modeling for Visualization & Communication, which is a core introductory computer graphics course that provides entry-level experiences in geometric modeling. As part of this course, students develop geometric analysis and modeling construction techniques and processes to produce accurate computer models for graphic visualization and communication.

One laboratory section of the course was the experimental group and had access to the remediation materials, including a workbook (Introduction to 3D Spatial Visualization: An Active Approach [1]) and practice website (VIZ; developed at Penn State Erie, The Behrend College [2]). Other laboratory sections made up the control group and did not have access to the additional materials. All students took the Purdue Spatial Visualization Test-Rotations, Mental Cutting Test [3], and the Modified Lappan Spatial Visualization Test [4] before the visualization modules were taught. Students then took these same tests at the end of the visualization modules. The pre- and post-assessment scores were compared to measured gains in spatial ability. Because past spatial visualization studies have found significant differences in scores when compared by gender [5-8], this construct would have been explored; however the number of females in this study was too small to provide significant insight.

Background Information

The EnViSIONS Project

The EnViSIONS Project is a collaborative effort by faculty at seven universities to examine, test, and report on efforts to enhance 3D spatial visualization skills through the use of educational modules and support resources. One primary focus of the research is to assist in the development of spatial skills in female students. Spatial skills are a key component for success in STEM related fields, where female participation is often underrepresented. The collaborators are pursuing a wide variety of research studies to further the body of knowledge in this area, as well as exploring technological resources for classroom and individual learning. This study is one component of this research effort. It is hoped that long-term results of this effort will impact K-16 educational programs and spatial skill assessment measures at many levels of standards-based testing.

Study Participants and Environment
The participants involved in this study were Computer Graphics Technology (CGT) and Industrial Design (ID) students at Purdue University. 92 students were enrolled in and completed the class during the fall semester of 2008. The number of participants who completed both pre- and posttest portions was 69. The majority of the participants were freshmen (n=46). The remainder of the participants were sophomores (n=12) and juniors (n=10). Participant academic majors were 47 Computer Graphics Technology majors and 21 Industrial Design majors. There was one non-traditional student who was auditing the class (no classification for status or major).There were 57 males and 12 females that participated in the study (see Tables 1 – 3).

Table 1. Participant Class Rank

Participant Class Rank (N=69)	**n**	**%**
Freshman	46	67
Sophomore	12	17
Junior	10	15
Senior	0	0
Audit	1	1

Table 2. Participant Academic Major

Participant Academic Major (N=69)	**n**	**%**
Computer Graphics Technology	47	68
Industrial Design	21	31
Audit	1	1

Table 3. Participant Gender

Participant Gender (N=69)	**n**	**%**
Female	12	17
Male	57	83

The Computer Graphics Technology 116 course an introductory engineering design graphics class that requires the students to plan, visualize, create, and manipulate 3D solid and surface models in several high-end parametric and NURBS-based computer graphics software packages. The students receive theory lectures and practical assignments involving sketching, 2D and 3D geometry applications, orthographic and pictorial imaging, the design process, creativity, and other related topics during a 16-week semester.

Spatial Visualization Curriculum Integration

In order to build on previous research from this project, four weeks of lectures and laboratory assignments from the spatial visualization curriculum were integrated as part of the CGT 116 class schedule. The four topics for these modules were isometric applications (sketching, axes, coded plans), orthographic applications (projection, sketching, orthographic to isometric transformations), flat patterns and developments, and rotation of objects. The content topics were coordinated with existing course content when possible, allowing for smooth incorporation of the

EnViSIONS modules. One laboratory section of the class (n=15) was chosen at random as the treatment group for this research. The remaining four laboratory sections of the class (n=54) were designated as the control group. The EnViSIONS modules were implemented through standard lectures and demonstrations, hands-on exercises, and self-directed learning. All of the students (treatment and control) were given the lecture material simultaneously during four sessions over the period of the research. The treatment group was provided with additional educational resources from a visualization workbook and interactive CD [1], and had access to the VIZ web site [2] to use as needed. The lectures and modules that were taught covered topics of isometric, orthographic, flat pattern, and rotational graphics interpretation and generation (See Figures 1-4). Lectures were facilitated through the use of PowerPoint® slides that were provided as part of the EnViSIONS project. After being introduced to the specific topic via the lecture, treatment group participants were assigned the corresponding laboratory modules and assignments to complete during lab time and as homework, in addition to the standard CGT 116 laboratory assignments involving 2D and 3D modeling in the CATIA software. The EnViSIONS practice/drill exercises, laboratory assignments, and homework assignments for the treatment group were taken from “Introduction to 3D Spatial Visualization: An Active Approach” [1], a workbook with resource software for visualization development. The control group participants did no additional exercises or assignments from the learning modules after receiving the lecture material, nor did they have access to the VIZ website. Their laboratory assignments involved the standard CGT 116 course assignments in CATIA modeling.

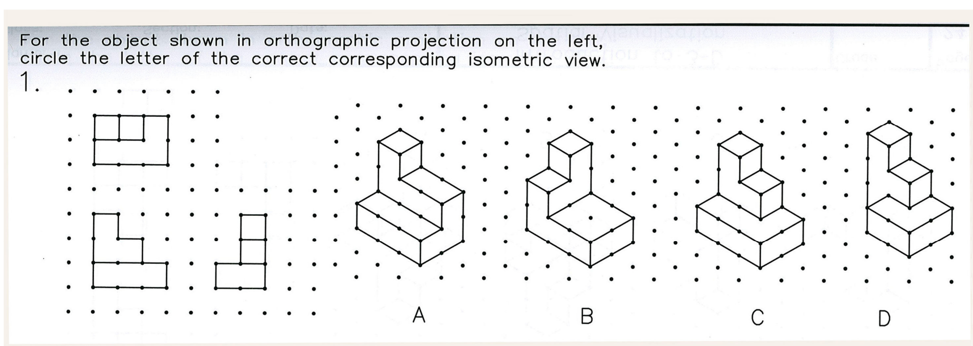

Figure 1. Orthographic Interpretation Example

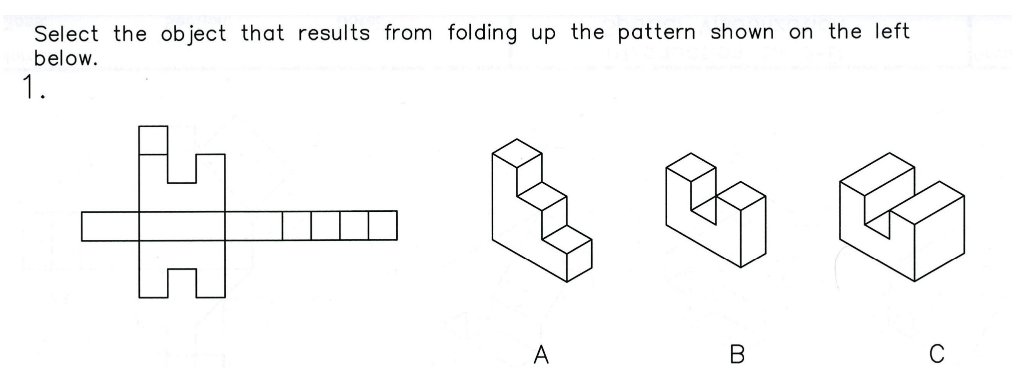

Figure 2. Flat Pattern Development Example

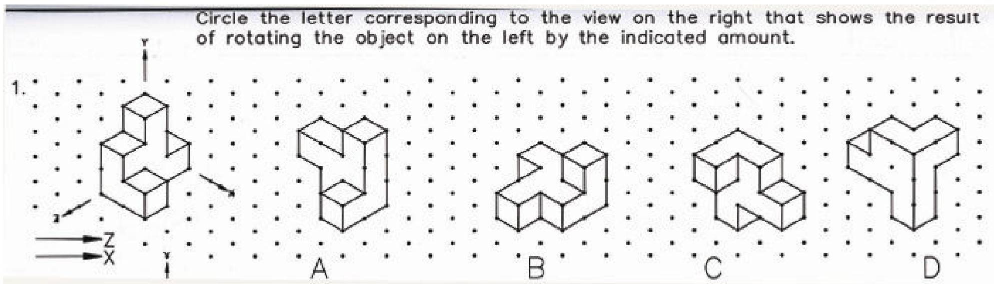

Figure 3. Rotations Example

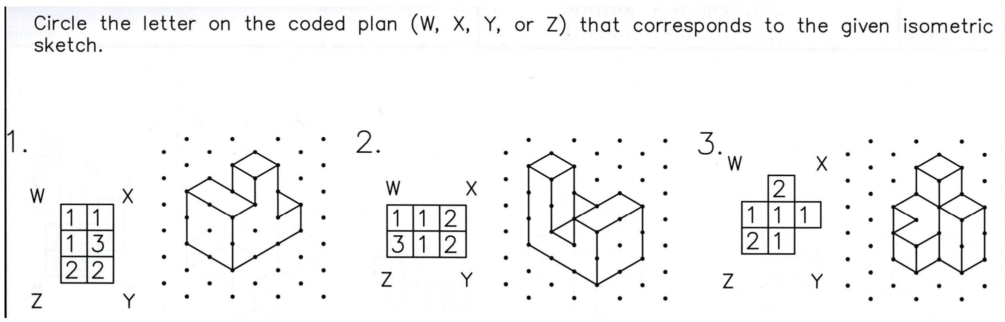

Figure 4. Orientations Example

Prior to the first EnViSIONS lecture and learning module, the students completed a pretest, which consisted of problems from the Purdue Spatial Visualization Test-Rotations (PSVT-R), the Mental Cutting Test (MCT), and the Modified Lappan Spatial Visualization Test (See Figures 5-7). These test instruments were chosen due to their acceptance as valid measures of spatial constructs and broad application in spatial visualization research over many years. The pretest was administered to establish base-line knowledge of the participants' spatial visualization skill.

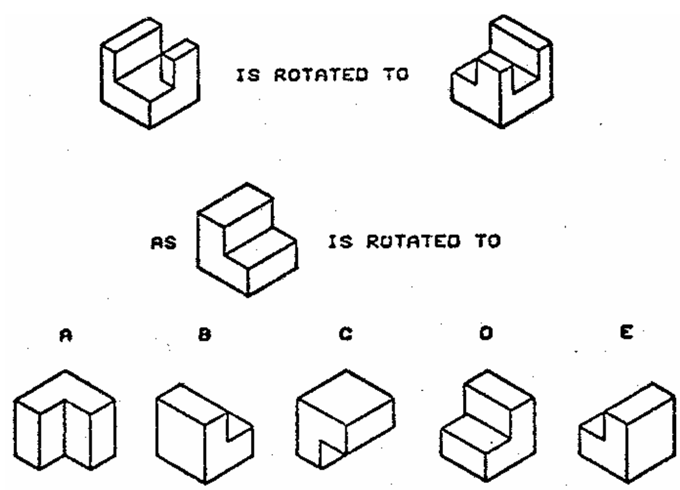

Figure 5. Purdue Spatial Visualization Test-Rotations Example

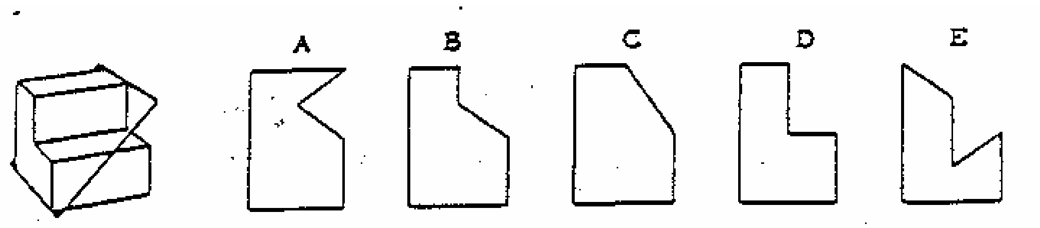

Figure 6. Mental Cutting Test Example

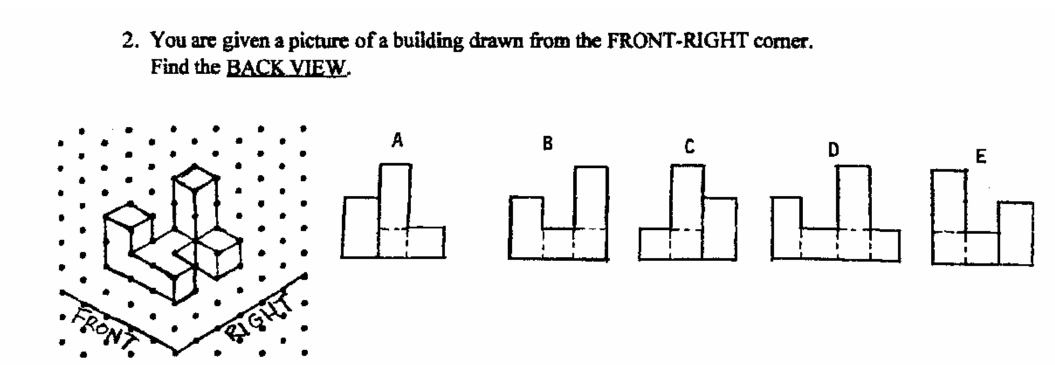

Figure 7. Modified Lappan Spatial Visualization Test Example

After completing the four instructional modules, participants again completed the same battery of spatial tests (PSVT-R, MCT, and Modified Lappan) as a posttest.

Results

The pre- and posttest evaluation scores were examined to see if there was participant improvement in areas of spatial ability after the modules were completed. Table 4 shows the mean scores for all participants from both the pretest and posttest. The mean pretest score of the Purdue Spatial Visualization Test-Rotations was 19.87 points out of 28.00 possible points. The mean posttest score was 21.45 out of 28.00 possible points, a mean score gain of 1.58. The mean pretest score of the Mental Cutting Test was 10.65 out of 25.00 possible points. The mean posttest score for the Mental Cutting Test was 12.64 out of 25.00, a mean increase of 1.99. Finally, the mean pretest score from the Modified Lappan Spatial Visualization Test was 7.42 out of 10.00 possible points, while the posttest score was 7.88 out of 10.00 possible, a mean gain of 0.46.

Table 4. Mean Pretest and Posttest Results

Test	**Mean pretest**	**Mean posttest**	**Mean Difference**
Purdue Spatial Visualization Test-Rotations	19.87	21.45	1.58
Mental Cutting Test	10.65	12.64	1.99
Modified Lappan Spatial Visualization Test	7.42	7.88	0.46

Table 5 shows the pretest and posttest results broken out by treatment and control group. The treatment group (n=15) showed improvement in all three tests from pretest to posttest. The mean pretest score for the Purdue Spatial Visualization Test-Rotations for this group was 21.07. The mean posttest score for the treatment group for the PSVT-R was 22.60, a mean score net gain of 1.53. The Mental Cutting Test results for the treatment group were 12.07 for the pretest mean, 14.47 for the mean posttest score, and a mean score gain of 2.40 from pretest to posttest. For the Modified Lappan Spatial Visualization Test, the pretest mean for the treatment group was 7.73, the posttest mean was 8.67, and the mean score gain was 0.94.

For the control group (n=54), there was also improvement in all three tests from pretest to posttest. The mean pretest score for the PSVT-R for the control group was 19.53. The mean posttest score for the control group for the PSVT-R was 21.13. This is a mean score increase of 1.60. The MCT results for the control group for the pretest mean were 10.26. The mean posttest score was12.13 for the control group, resulting in a mean score gain of 1.87 from pretest to posttest. For the Modified Lappan Spatial Visualization Test, the pretest mean for the control group was 7.33. The control group scored 7.67 on the Modified Lappan posttest mean. The mean score gain for the control group on the Modified Lappan test was 0.34.

Table 5. Mean Pretest and Posttest Results by Treatment Group

Group	**Test**	**Mean pretest**	**Mean posttest**	**Mean Difference**
Treatment (n=15)	Purdue Spatial Visualization Test-R	21.07	22.60	1.53
	Mental Cutting Test	12.07	14.47	2.40
	Modified Lappan Spatial Visualization Test	7.73	8.67	0.94
Control (n=54)	Purdue Spatial Visualization Test-R	19.53	21.13	1.60
	Mental Cutting Test	10.26	12.13	1.87
	Modified Lappan Spatial Visualization Test	7.33	7.67	0.34

Mean test results for all three test instruments showed increases for both control and treatment groups. Mean score improvements were slightly higher for the treatment group on the Mental Cutting Test and the Modified Lappan Spatial Visualization Test than for the control group. The mean score improvements for the control group were slightly higher than the treatment group for the Purdue Spatial Visualization Test-Rotations. In order to determine statistical significance, a paired samples t-test was conducted to determine if the difference in pre- and posttest scores from the Purdue Spatial Visualization Test-Rotations, Mental Cutting Test, and Modified Lappan Spatial Visualization Test were significant. For all participants, the results for all three test instruments were statistically significant at the .05 level (See Table 6). The treatment group showed statistical significance for the Mental Cutting Test and the Modified Lappan Spatial Visualization Test, but not for the Purdue Spatial Visualization Test-Rotations (See Table 7). Control Group t-test results were statistically significant at the .05 level for the Purdue Spatial Visualization Test-Rotations and the Mental Cutting Test, but were not statistically significant for the Modified Lappan Spatial Visualization Test (See Table 8).

Table 6. All Participants t-test Results

Test	**t**	**df**	**p**
Purdue Spatial Visualization Test-Rotations	2.79	67	0.007
Mental Cutting Test	5.41	68	<0.0001
Modified Lappan Spatial Visualization Test	2.57	68	0.012

Table 7. Treatment Group t-test Results

Test	t	df	p
Purdue Spatial Visualization Test-Rotations	1.36	14	0.195
Mental Cutting Test	3.52	14	0.003
Modified Lappan Spatial Visualization Test	2.29	14	0.038

Table8. Control Group t-test Results

Test	t	df	p
Purdue Spatial Visualization Test-Rotations	2.42	52	0.019
Mental Cutting Test	4.34	52	<0.0001
Modified Lappan Spatial Visualization Test	1.67	52	0.101

Comparing the mean differences between the treatment and the control group for each of the three tests resulted in no statistically significant differences.

Conclusions and Recommendations

Pre- and posttest differences for the participants as a whole, and for both the treatment and control groups separately, showed statistical improvement as measured by some of the test instruments. The treatment group showed statistical improvement on the MCT and Modified Lappan tests, but not the PSVT-R. The control group did not show statistically significant improvement on the Modified Lappan test, but did show significant improvement on the PSVT-R and MCT. Since there was no statistical difference between the improvement shown by the two groups as measured by these instruments, it must be concluded that the treatment (lecture, laboratory assignments, and individual exercises) was not more effective in improving spatial ability than no treatment (lecture only). Although no difference between the two groups was seen, it is important to note that both groups showed statistical improvement in several areas. It is possible that there was positive impact from the EnViSIONS modules that were presented in lecture to all participants, and further research is recommended to examine this premise more deeply. It is also recommended that this study be replicated with a larger treatment group to ensure statistical power. Similarly, it is recommended that the study be revisited with a larger sample of female participants. There were only 12 females as part of this study (only one in the treatment group), and more representation is needed to effectively analyze gender differences in these data. The authors recommend a longer duration of treatment than what was used in this study, in order to allow participants more exposure to the learning modules and support materials. It is also recommended that the posttest be administered again at the conclusion of the course, to see if spatial skills are improved through other course activities, making the additional treatment modules unnecessary for this class. Finally, it is recommended that the study be replicated with more balance in participant numbers in the treatment and control groups, and more balance in pretest measured spatial ability between the control and treatment groups.

Bibliographic Information

1. Sorby, S., Wysocki, A. F., & Baartmans, B. (2003). *Introduction to 3D Visualization: An Active Approach. CD-ROM with workbook.* Clifton Park, NY: Thomson Delmar.
2. VIZ Visualization Assessment and Training (2005). Retrieved March 13, 2009 from: http://viz.bd.psu.edu/viz/
3. CEEB Special Aptitude Test in Spatial Relations (1939). College Entrance Examination Board, USA>
4. Lappan, G. (1981). *Middle Grades Mathematics Project, Spatial Visualization Test*, Michigan State University.
5. DeFries, J. C., Vandenberg, S. G., & McClearn, G. E. (1976). Genetics of Specific Cognitive Abilities. *Annual Review of Genetics, 10:* 179-207.
6. Leopold, C., Sorby, S. A., & Gorska, R. (1996). Gender Differences in 3-D Visualization Skills of Engineering Students. *Proceedings of the 7th International Conference on Engineering Computer Graphics and Descriptive Geometry.* Cracow, Poland.
7. Sorby, S. A. (2005). Assessment of a "New and Improved" Course for the Development of 3-D Spatial Skills. *Engineering Design Graphics Journal, 69*(3) 6-13.
8. Wynn, T. G., Tierson, F. D., & Palmer, C. T. (1996). Evolution of Sex Differences in Spatial Cognition, *Yearbook of Physical Anthropology,* 39: 11-42.