Assessment of a "New and Improved" Course for the Development of 3-D Spatial Skills

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Abstract

Since 1993, Michigan Tech has offered a course aimed at improving the spatial skills of incoming engineering students who have a demonstrated weakness in ability as measured by the Purdue Spatial Visualization Test: Rotations (PSVT:R). In the fall of 2000, this course was altered dramatically in terms of both content and instructional delivery method. The modified course was described in detail in a paper presented at a previous EDGD annual conference. This paper will outline the changes made in the delivery of the course, examine results from the revised course, and compare findings with results from the previous version of the course. Particular attention will be paid to changes in success and retention rates among students with weak initial spatial skills.

Background

By one estimate there are at least 84 different careers for which spatial skills play an important role (Smith, 1964). For technical professions, such as engineering, spatial visualization skills and mental rotation abilities are especially important (Maier, 1994). Norman (1994), found that a person's spatial skill level was the most significant predictor of success in his/her ability to interact with and take advantage of the computer interface in performing database manipulations, and Sorby (2000) found that a person's spatial skills are related to his/her ability to effectively learn to use computer aided design software. Eyal and Tendick (2001) found that a person's spatial ability is related to his/her ability to effectively learn how to learn to use the modern-day laparoscopic equipment utilized throughout the medical profession. Tartre (1990) has suggested gender differences in spatial skills may be linked to math performance and indeed, when mental rotation ability was held constant in one study, gender differences in mathematical problem solving disappeared (Casey, Pezaris, & Nuttall, 1992).

Recognizing the importance of well-developed spatial skills for technological careers, the National Council of Teachers of Mathematics (NCTM) has included benchmarks regarding the development of spatial abilities within the Pre-college Mathematics Educational Standards (NCTM, 2000) and middle school mathematics education has been a focus of national interest due mainly to the results of the Third International Mathematics and Science Study, and state, national and local standards.

There is a great deal of evidence to suggest that the spatial skills of women lag significantly behind those of their male counterparts. Theories for the cause of these differences include the assertion that spatial ability is transmitted as a recessive characteristic on the X-chromosome (Stafford, 1972), that spatial ability is related to a male sex hormone (Hier & Crowley, 1982), or that environmental factors are the primary reasons for male-female differences in spatial skill levels (Fennema & Sherman, 1977). The truth most likely falls in the interaction of many factors. Because of media reports of research findings, as well as traditional stereotypes, both women and men in Western societies are usually convinced that women are naturally inferior in both mathematical and spatial performance (Jones et al., 1984). Stereotype threat theory (Spencer, Steele, & Quinn, 1999) suggests that performance may suffer if one is in a situation where the requirements of a task go against one's stereotypical role. Women in male-dominated professions do report feeling more threatened by negative stereotypes and also report thinking about changing their major more than males (Steele, James, & Barnett, 2002). This research suggests that female role models and mentors will be important to increasing gender diversity in STEM disciplines. Therefore it is critically important to increase the number of women entering and completing degrees in STEM fields.

The author has been involved in teaching a course (GN102) at Michigan Tech since 1993 aimed at improving the spatial skills of first-year engineering students. This 3-credit course (quarter system) was developed with funding from the National Science Foundation and was the topic of a paper published in the Engineering Design Graphics Journal (Sorby & Baartmans, 1996). Long-term assessment results from this course have shown that engineering students who initially failed the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Guay, 1977) and who subsequently enrolled in the spatial skills course went on to perform better in their engineering graphics courses by a significant margin (Sorby & Baartmans, 2000). Further, for women with initially weak spatial skills, those who participated in this course were retained in engineering at a significantly higher rate over a six year period when compared to women with weak skills who did not participate in the course (Sorby, 2001). It can not be stated definitively that participation in the spatial skills course resulted in higher retention rates; however, average GPAs in calculus and overall were not significantly different between the two groups under consideration and the only differences detected were 1) significantly higher graphics grades and 2) significantly higher retention rates. Despite these positive results, most engineering graphics faculty have been reluctant to institute a course such as this on their own campuses due to a perceived lack of time/resources.

In 1998, the author, along with two colleagues (Baartmans and Wysocki), received funding from the National Science Foundation to create multimedia software and a workbook for the development of spatial skills (Gerson, *et al.,* 2001). These products have been developed as stand-alone deliverables such that improvements in spatial skills can be accomplished with very little direct instruction delivered by a faculty member. About the time that the product development was complete, Michigan Tech converted from quarters to semesters. These two factors led to the development of a "new and improved" spatial skills course. The development of this new course (ENG1002) had two major goals: 1) significantly reduce the amount of time a faculty member must spend in the classroom for spatial skills remediation, and 2) maintain the level of improvement in spatial skills experienced by students in the earlier version of the course.

In order to achieve these twin goals, the first step was to critically examine the topics from GN102 to determine which were the most likely to have contributed to large gains in spatial skills, and which topics were dispensable. By examining the topics that were thought to be the most beneficial in developing spatial skills, we were also able to focus our software and workbook development activities to just nine modules. (Nine modules was deemed the maximum number that could be adequately supported with the available NSF funding.) Once this activity was complete, planning for the format and content of the new spatial skills course could begin.

The New Spatial Skills Course at Michigan Tech

One decision made early in the development process was that our new course would be a 1-credit course to meet for just one 2-hour lab session per week. (The previous 3-credit course met for two 1-hour lectures and one 2-hour computer lab per week.) The weekly session in this new course typically begins with a 10-20 minute "lecture" on the topic for the day. The students then spend the remainder of the session working through the multimedia software modules and completing assigned workbook pages. In this way, a faculty member was only required in the classroom for the initial few minutes of the class period and an undergraduate teaching assistant was hired to be present for the entire lab session as well as for grading for the class.

Since there were only nine software modules developed and there were 15 weeks in our semesters, the second decision that required attention was to determine what would take place in those weeks for which there was no software available. In order to assess the results from the instruction, a session of pre-testing was included at the begin-

GN102 (10-week quarter)	
Lecture	**Computer Lab**
1. Course Intro, Importance of Spatial Skills	Pre-Testing
2. Isometric Sketching	
3. Orthographic Projection-Normal Surfaces	Isometric Sketching
4. Inclined Surfaces	
5. Oblique Surfaces	Orthographic Projection
6. Single-Curved Surfaces	
7. Applications, Quiz #1	Pattern Folding
8. 2-D Patterns->3-D Objects	
9. Applications	3-D Coordinate Systems
10. 2-D and 3-D Coordinate Systems	
11. Applications	Translation and Scaling
12. Translation and Scaling, Quiz #2	
13. One-Step Rotations	Object Rotations
14. Two-Step Rotations	
15. Reflection and Symmetry	Object Reflections
16. Planes in 3-Space	
17. Cross-sections of solids,	Cross-Sections of Solids
18. Surfaces and Solids of Revolution, Quiz #3	
19. Combining Solids	Surfaces and Solids of Revolution
20. Post-Testing	

ENG 1002 (15-week semester)
1. Course Intro, Importance of Spatial Skills, Pre-Testing
2. Isometric Sketching
3. Orthographic Projection, Normal Surfaces
4. Inclined and Single-Curved Surfaces
5. Quiz #1, Architek Game
6. Pattern Folding
7. One-Step Rotations
8. Two-Step Rotations
9. Quiz #2, Babylon Cube Game
10. Reflection and Symmetry
11. Cross-Sections of Solids
12. Surfaces and Solids of Revolution
13. Quiz #3, Block by Block Game
14. Combining Solids
15. Post-Testing

Figure 1. Comparison of GN102 and ENG1002 Course Outlines

ning of the class, and a session of post-testing was included at the end. Further, three quizzes were distributed through the semester so that students would have feedback on a continual basis throughout the semester. This left one session unaccounted for. Since understanding and being able to visualize multiview projection is so important for success in engineering graphics and since there was only one software module developed for orthographic projection of normal surfaces, the decision was made to include one session of a "traditional" lecture on multiview projection involving inclined and single-curved surfaces. Figure 1 shows the comparison between the course outlines for GN102 and ENG1002.

For each session of the course (except for testing days), students were also assigned several workbook pages to be completed either during the lab time for the course or as homework. The workbook was also developed with funding from

GN102					
Test	n	Pre-test	Post-test	Gain	Significance
PSVT:R	186	50.5	76.9	26.4	p<0.0001
DAT:SR	99	62.3	78.3	16.0	p<0.0001
MCT	99	37.9	51.4	13.5	p<0.0001

Table 1. Spatial Skills Improvement from GN102

ENG1002					
Test	n	Pre-test	Post-test	Gain	Significance
PSVT:R	157	48.3	73.7	25.4	p<0.0001
DAT:SR	110	62.1	77.9	15.8	p<0.0001
MCT	109	34.8	52.6	17.8	p<0.0001

Table 2. Spatial Skills Improvement from ENG1002

the NSF grant and the assigned pages consisted of a combination of sketching and multiple choice problems. Most students who remained for the entire 2-hour lab period were able to complete all exercises in class. For the session on inclined and single-curved surfaces, a handout of assigned problems was compiled and distributed, since there were no workbook pages that corresponded to that particular topic.

Three games were identified that involved putting together 3-D spatial puzzles. These games were available from math instructional suppliers at a nominal cost and sufficient copies of the games were purchased for use in ENG1002. On quiz days, students in ENG1002 were divided into teams of two and given a copy of the game for the day. They spent the first 20 minutes of the class session working out the various puzzles for each game. They were told that they would receive one point of extra credit on their quiz for each puzzle they completed in the specified time period.

The first game, Architek Game, consists of several different 3-D shapes. There are varying levels of difficulty for the game depending on the ages of the players, but in the most advanced level, players are presented with a list of 3-D parts and with an isometric view of an object that can be created using those building blocks. Players must then construct the object from the basic parts. In the second game, Babylon Cube, there are eight puzzle pieces of different colors constructed from unit cubes glued together in various configurations. There are also two dice that have colors on their sides rather than numbers or dots. Players role the dice and remove the two puzzle pieces of the colors shown on the dice and then construct a 3 X 3 X 3 cube from the remaining puzzle pieces. In the third game, Block by Block, players are given seven puzzle pieces of various shapes that have been constructed out of unit cubes. A deck of cards contains shapes that players then construct from the building blocks.

Faculty Time Commitment

As stated previously, one of the major goals of this new course was a significant reduction of the amount of faculty time required for spatial skills remediation. In the previous incarnation of the course, GN102, an instructor was required for each of the one-hour lecture periods for a total contact time commitment of 20 hours over the quarter. A lab TA was hired for grading and to oversee the computer lab each week. The new semester version of the course, ENG1002, required far fewer contact hours on the part of the instructor. The total contact time for ENG1002 consisted of about 15 minutes for each of sessions 1, 2, 6-8, 10-12, and 14. Lecture times for sessions 3 and 4 were slightly longer (about 30 minutes each). Instructor involvement during quiz days and for pre-/post-testing sessions consisted of about five minutes at the beginning of each class to answer questions and to describe the procedure for the day. Thus, the total contact time spent in this version of the spatial skills remediation course was approximately 4 hours for the entire semester. Additional time was, of course, spent in preparing and grading the quizzes, but this time commitment was comparable to the quarter version of the course.

Course Assessment

Assessment of the effectiveness of the ENG1002 course took many forms. Scores on spatial skills tests were examined as were grades in follow-on courses. In addition, differences in retention rates, especially by gender, were examined to evaluate the course.

Pre-/Post-testing with Spatial Tests

One of the goals of each course was to improve the spatial skills of the students who enrolled in them. To determine the level of improvement in spatial skills achieved by our students, three instruments were administered as both pre- and

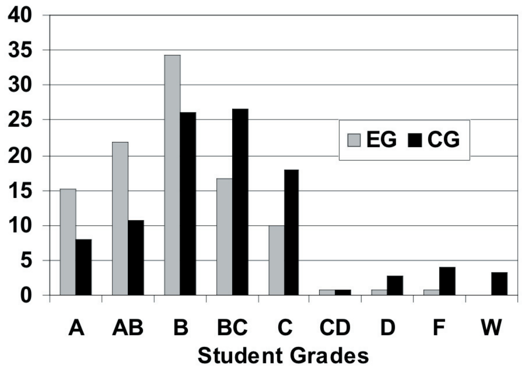

Figure 2. Student grades in Engineering I

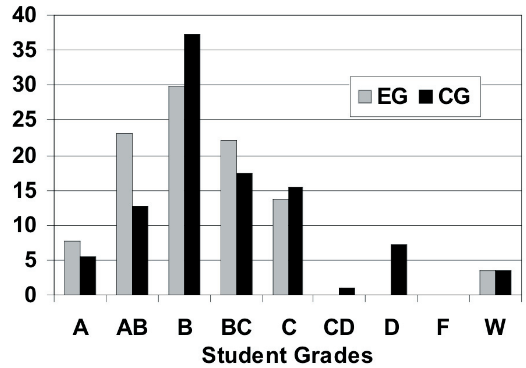

Figure 3. Student grades in Engineering II

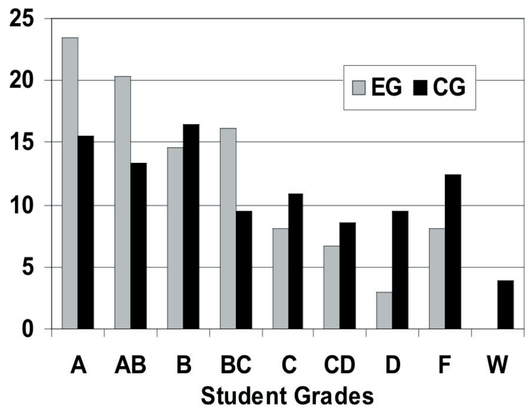

Figure 4. Student grades in Calculus I

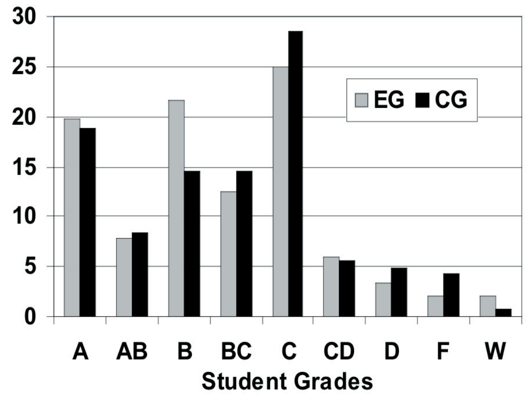

Figure 5. Student grades in Chemistry I

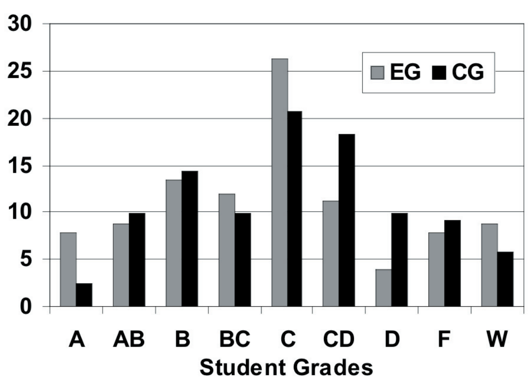

Figure 6. Student grades in Physics I

post-tests—the Purdue Spatial Visualization Test: Rotations (PSVT:R), the Differential Aptitude Test: Space Relations (DAT:SR) (Seashore, Bennett, & Wesman, 1973) and the Mental Cutting Test (MCT) (CEEB, 1939). Table 1 includes the data from seven years testing in our original course, GN102 (1993-99), and Table 2 includes data from three years testing in our new course, ENG1002 (2000-02). In these tables test scores are presented as average percent correct and significance was computed using a paired t-test.

The data presented in these tables indicate that the improvements in spatial skills for ENG1002 are similar to those obtained from GN102. In fact, improvements on the MCT for the new version of our course were better than those obtained for the original course (gain=17.8 vs. 13.5). This could be due to the fact that the multimedia software can be used more effectively to illustrate cross-sections than a traditional lecture can.

Grades in Follow-on Courses

Another goal of each spatial skills course was to improve the performance of students in their follow-on courses. For this analysis, the transcripts of all students who had failed the PSVT:R during freshman orientation for the years 2000-02 were obtained and sorted into two groups. The Experimental Group (EG) consisted of those students who had failed the PSVT:R and enrolled in ENG1002. The Comparison Group (CG) consisted of those students who failed the PSVT:R and did not enroll in ENG1002. Grades for these groups were determined for several introductory

Average GPAs for students in EG and CG			
Course	**Average GPA EG**	**Average GPA CG**	**Significance of Difference of Means**
Engineering I	3.04	2.62	p<0.0005
Engineering II	2.94	2.71	p<0.001
Calculus I	2.78	2.35	p<0.001
Chemistry I	2.70	2.56	p<0.1
Physics I	2.25	2.02	p<0.02
Overall	3.00	2.64	p<0.0005

Table 3. Average GPAs for students in EG and CG

courses that first-year engineering students take. Figures 2-6 show the grade distributions in five courses for the students in the EG compared to the students in the CG. The courses are Engineering I (a course in problem- solving and some graphics), Engineering II (a course in graphics and design with some computer programming), Calculus I, Physics I, and Chemistry I. A grade of "W" in a course typically indicates that a student struggled in a course and withdrew before its completion.

As can be seen from the data presented in these figures, the students in the EG generally earned a larger proportion of higher grades when compared to the students in the CG. Average Grade Point Averages (GPAs) were computed for each group for each course. Overall GPAs were also averaged for the students in the two groups. These data are presented in Table 3.

The data presented in Table 3 shows that the students in the EG generally had better grades than those in the CG. The difference in average GPA between the EG and the CG was highly significant for each of the engineering courses (where graphics is part of the coursework) and for the first calculus course. Differences in mean GPAs for Chemistry and Physics were not as significant. Overall GPAs for the EG was nearly one-half letter grade better than that of the CG, and the difference was highly significant. The large "n" for each group (~100) suggests that the differences were not merely coincidence; however, it could be that the EG (which was primarily self-selected) consisted of generally more motivated students than those in the CG.

For data collected between 1993 and 1998 for similarly defined groups (EG was students who participated in GN102 and CG consisted of students who failed the PSVT:R and did not take the course), differences in GPA were only detected for engineering graphics courses. For the GN102 students, the average graphics GPA for the EG was 2.93 and was 2.61 for the CG (p<0.0001 for the difference between means). Calculus GPAs were nearly identical between the two groups (2.38 for EG and 2.30 for CG) as were the overall GPAs (3.00 for EG and 2.98 for CG). Chemistry and Physics grades were not examined for the GN102 students.

	Women		**Men**	
	EG	**CG**	**EG**	**CG**
Enrolled	87	53	82	120
Retained	76	38	63	84
Retention Rate	87.4%	71.7%	76.8%	70.0%

Table 4. Retention Rates for Students in EG and CG

It is not clear whether the differences in mean GPAs were higher for the students in the EG because they were self-selected or whether improving 3-D spatial skills enabled the students to perform better in their follow-on courses. Further study of this phenomenon is required.

Retention Rates of Students

The transcripts of the students were obtained in December of 2003 for the students who failed the PSVT:R during orientation in 2000, 2001, and 2002. Student majors were noted as well as whether or not the students were still enrolled at Michigan Tech at that time. Table 4 includes the data for the students in both the EG and the CG by gender.

Statistical analysis was performed on the difference in retention rates between groups (difference in proportions). For the men, the difference in retention rate between the EG and the CG were not significant. The difference in retention rate for women was statistically significant (p=0.01). This data is comparable to that obtained for the GN102 students. For students in the original version of the course the retention rate for men in the EG was 75.3% and for men in the CG it was 69.0% (difference not significant). For women in the original group, the retention rate for the EG was 88.9% and it was 68.3% and the difference between retention rates for women was statistically significant (p<0.0002) (Sorby, 2001).

Conclusions

From the data presented in this paper it seems that our new semester course and multimedia software is as effective at improving spatial skills as measured by standardized testing instruments as was the quarter system course with traditional lectures. This comparable effectiveness was achieved with a significant reduction in contact time for the course instructor. Faculty contact time was reduced from 20 total hours over a 10-week quarter to around 4 total hours over a 15-week semester. As found with the quarter version of the course, students performed significantly better in their follow-on engineering courses and were retained in engineering at a higher rate than were their counterparts in the CG. Differences in retention rates for women in the EG were significantly higher than for women in the CG. It is unclear if the differences in retention and in performance in follow-on courses was due primarily to participation in ENG1002 or to some other factors. Further study of this phenomenon is required.

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