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Impact of Changes in Course Methodologies on Improving 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 original model for improving spatial visualization skills adopted at Michigan Tech included a 3-credit (quarter system) course. The course met for two 1-hour lectures and one 2-hour computer lab per week over a 10-week period. In the new version of the course, students meet for one 2-hour session each week over a 15-week period of time. During each course session students work with multimedia software designed to improve their spatial skills and complete sketching exercises from a workbook. Less emphasis is now placed on lecture in our new course, however, sketching hand-held objects remains an integral part. This paper will examine results from the revised course and compare our 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.

Key Words: spatial visualization, remediation, gender differences

MSC 2000: 51N05

1. Introduction

It is well documented that spatial skills are critical to success in engineering and technological careers. It is further well-established that the spatial skills of women typically lag behind those of their male counterparts, thus presenting women with a barrier to success in the male-dominated field of engineering. 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 previous ICGG conferences

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[5, 6, 7]. Long-term assessment results from this course have shown that engineering students who initially failed the Purdue Spatial Visualization Test: Rotations (PSVT:R) [4] and who subsequently enrolled in the spatial skills course went on to perform better in their engineering graphics courses by a significant margin [8]. Further, for women with initially weak spatial skills, participation in this course led to a significantly higher retention rate in engineering over a six year period when compared to women with weak skills who did not participate in the course [9]. 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 [3]. 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.

2. Revised spatial skills course

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 are 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 beginning of the class, and a session of post-testing was included at the end. Further, three quizzes were distributed 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.

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 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 distributed, since there were no workbook pages that corresponded to that particular topic.

3. 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.

3.1. Pre-/Post-testing with spatial skills tests

One of the goals of the course is to improve the spatial skills of the students who enroll in it. To determine the level of improvement in spatial skills achieved by our students three instruments were administered as both pre- and post-tests

- the *Purdue Spatial Visualization Test: Rotations* (PSVT:R),
- the *Differential Aptitude Test: Space Relations* (DAT:SR) [1],
- and the *Mental Cutting Test* (MCT) [2].

Table 1: Spatial skills improvement 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 2: Spatial skills improvement from 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 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.

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 in part to the fact that the multimedia software can be used more effectively to illustrate cross-sections than a traditional lecture can.

3.2. Grades in follow-on courses

Another goal of the spatial skills course is 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 courses that first-year engineering students take. Figures 1–5 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. In the American system of grading, an "A" is the highest grade a person can earn, a "D" is the lowest passing grade, and "F" is a failing grade.

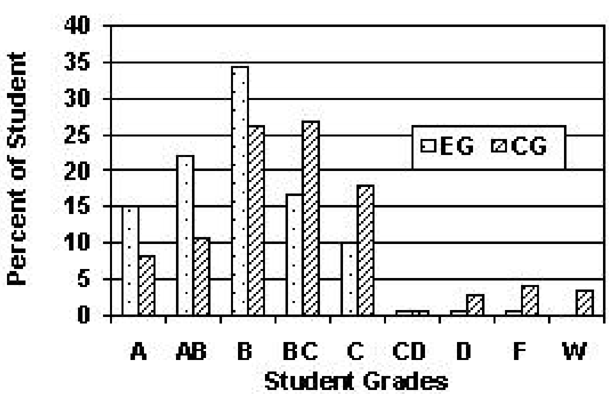

Figure 1: Student Grades in Engineering I

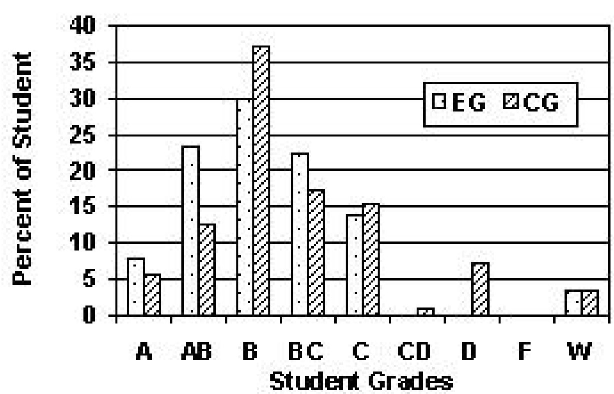

Figure 2: Student Grades in Engineering II

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. In America, GPAs are determined by assigning numbers to the letter grades as follows: A = 4.0, AB = 3.5, B = 3.0, BC = 2.5, etc. To compute the average GPA for this dataset, the number of A grades were multiplied by 4.0 and added to the number of AB grades multiplied by 3.5, and so on. The final sum was divided by the total number of grades assigned, or the total number of

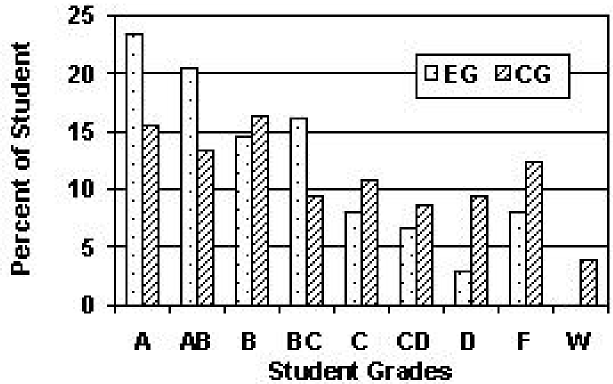

Figure 3: Student Grades in Calculus I

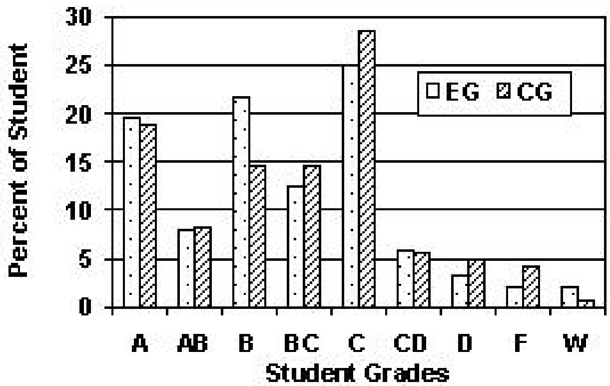

Figure 4: Student Grades in Chemistry I

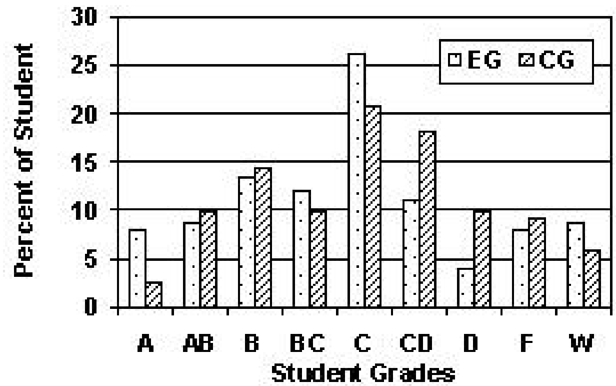

Figure 5: Student Grades in Physics I

students. 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

Table 3: 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	$p < 0.0005$

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.

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 determined for the GN102 students.

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.

3.3. 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. *Retention rates* are defined as the percentage of students who continued on with their educational program. For example, if 100 students began their studies in engineering in the fall of 2000, and 82 of these students were still enrolled in the fall of 2002, the retention rate for this group of students would be 82%. 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.

Table 4: Retention Rates for Students in the EG and CG

	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%

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 ($p < 0.0002$).

4. 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 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.

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