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Abstract

Pictorial representation of three-dimensional objects has been one of the oldest forms of communication. Engineering graphics courses deal with the art of documenting three-dimensional objects in a two-dimensional format. Prior literature shows that graphics communication is a key skill for an engineer to possess. However, students in engineering graphics classrooms struggle to understand the concepts being taught due to a variety of reasons including poor visualization skills, limited class time, huge class sizes and unavailability of simple demonstrations. In order to address some of these issues, the instructors of the engineering graphics course at Tuskegee University, whose student population consists of predominantly underrepresented minorities, implemented a rapid feedback – resubmission cycle for students' homework. In one section of this course, the instructor provided rapid feedback on each of the homework submitted and allowed a resubmission of the same. During the resubmission, the students are expected to understand their mistakes in the original submission and correct those. They are awarded a maximum of 80% of the lost grade for the corrections. This cycle is supposed to give the students additional time to master the concept. As all these tasks depend upon their visualization skills, the resubmission cycle is expected to improve their said skill as well. This study uses Purdue Spatial Visualizations of Rotations test to measure the visualization skills of students. The results show some promising trends. The students who resubmitted their work frequently showed a greater improvement in their visualization skills compared to those who did not. While the class itself is helping students in developing some visualization skills, the rapid feedback and resubmission cycle provides an added advantage.

Introduction

This work aims to improve the spatial visualization skills of freshman mechanical engineering students enrolled in the freshman engineering graphics course at Tuskegee University, a university which serves underrepresented minorities, through the use of a rapid feedback and cycle. It is well known that retention rates in STEM programs for underrepresented minorities lags behind other groups[1]. Among contributing factors to this trend are the degree to which students are prepared in their K-12 studies, and resource limitations related to preparation[1]. In addition, many students, regardless of ethnic background often enter engineering programs without understanding what the expectations will be in their coursework. For example, in freshman engineering graphics, students often arrive with the perception that some students 'can draw', so they will be successful, and some 'cannot draw' and are thus doomed to be unsuccessful. For the new engineering student, the concept of spatial visualization is typically a new one; but once they learn to 'see' three dimensional objects in a two dimensional format, all students find that they can be very successful, regardless of their perceived drawing abilities. In order for this to happen, however, they require a lot of instruction,

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practice sketching and correction. We believe that by making this cycle as short as possible, students will be more engaged and motivated.

The hypothesis tested in this study is that the students who receive frequent feedback and the opportunity to resubmit their work achieve a greater improvement in their spatial visualization skills compared to those who do not. This was done by using two sections of the freshman engineering graphics course, one was a control and one was given the experimental treatment. The paper reports the motivation for this study, the experimental methods, a description of the categories with which students could resubmit their work, results and discussion from the data collected, study limitations, and finally we detail the significance of the study and the potential for further development.

Background and Motivation

Challenges in Developing Spatial Visualization Skills

Spatial visualization skill is an essential quality for being able to communicate graphically. It can be defined as the ability to mentally understand, visualize, rotate and manipulate geometric objects[2-5]. Literature shows that keen spatial visualization skills is an indicator of achievement in STEM fields[6]. These skills have been demonstrated as a key factor for the success in 84 careers[7]. In addition, a 2010 report on the role of women in STEM fields identifies that spatial visualization skills are important for the success of women students in STEM related fields[8]. The report also states that women and underrepresented minorities in STEM have comparatively lower spatial visualization skills.

Development of students' spatial visualization skills has been a major challenge in engineering graphics communications courses. This is a hard skill to acquire and the instructional methods being employed have a great effect on said skills[8]. This is the major reason for the recent interest in the research community on the methods to improve these skills and mental rotation abilities in students[2, 8-12]. For example, a recent study recommended the use of tangible models as an effective technique to develop visualization skills[13]. Similarly, Sorby developed a short course on spatial visualization skills which has proven to be effective in improving student GPAs in a wide range of STEM courses[12]. This study was conducted at Michigan Tech and the results showed that only 42% of students in engineering with low spatial visualization skills graduated in their major. However, after attending the short course, the retention rate of students with originally low spatial visualization skills increased to 64% (which is an increase of 52%). Currently the materials developed by Sorby[14] have been used widely in the United States[11].

There are multiple factors that influence the engineering graphics instruction at engineering departments. In most engineering schools, graphics is taught as a freshman course and they have comparatively huge class sizes. The unavailability of proper demonstrations and educational technologies to assist in graphics classrooms is a major factor of concern. Mainly the change of spatial dimension between 2-D and 3-D is a confusing factor for many students. When

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a spatial dimension change and visual rotations are together required to effectively visualize an object, it becomes a hard task for our students. The limited class time is another important factor as the instructor is unable to provide the immediate help that the students need. Since these courses are offered the first semester they attend a university, the students often are not mature enough to admit that they need additional help outside the classroom and approach the instructor for the same.

Purdue Spatial Visualizations of Rotations Test

The Purdue Visualizations Test[15] (PVT) was originally developed as a part of the Purdue Visualization Test Battery[16]. This is an instrument with 30 questions and tests students' ability to mentally rotate three-dimensional objects represented on a two-dimensional surface. Figure 1 shows an example of the tasks involved in PVT. A typical task provides an example of mental rotation and then directs the student to identify a similar rotation for a given object. The time limit for PVT is 20 minutes and students are required to complete all the tasks within this time. A student with an excellent SV skill can complete all the 30 tasks within the given 20 minutes, whereas one with very poor SV skill may struggle on the tasks.
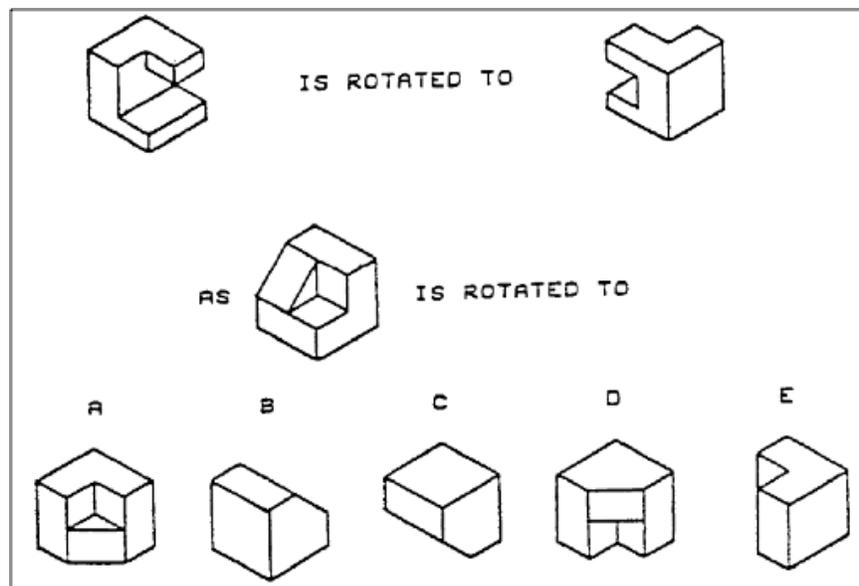

Figure 1. A sample task from Purdue Spatial Visualization of Rotations Test

Engineering Graphics Course at Tuskegee University

The engineering graphics course offered by the Mechanical Engineering Department at Tuskegee University is a part of the freshman design experience. This freshman design experience is currently structured as a two-semester sequence: engineering graphics in the first semester (Fall) and the freshman design course in the second semester (Spring). These courses meet once per week, and are taught in a laboratory format. The engineering graphics course

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meets for three hours, with one hour of lecture and two hours of laboratory practice time. The freshman design course meets for two hours. In the engineering graphics course, students learn the basic skills necessary for visual technical communications and spatial visualization. Topics include engineering sketching and drafting, orthographic projection of multi, sectional, and auxiliary views, dimensioning, tolerances (the first half of the semester), and solid modeling using the Computer Aided Design (CAD) tools (the rest of the semester). In a typical class, the instructor delivers a short lecture followed by a class activity based on the lecture. For example, in a class that teaches multi-view of objects, the class activity is to derive the multi-view for a given set of objects on an assignment sheet. The instructor helps the students during this activity. Once they complete the class activity, they are allowed to leave with a homework based on the same concept. Currently, there are two sections of this course offered in the Fall semester every year and each section contains around 30 students.

Formative Feedback & Repeated Learning Cycle Approaches

In education context, feedback is considered to be a crucial factor for student learning[17]. The effects of feedback on student learning are well researched over the past many decades[18-22]. When the feedback on someone's work is communicated to that person with the intention of improving his/her learning, that feedback is termed as "formative feedback"[23]. Literature identifies two types of formative feedback in education: directive and facilitative. In directive feedback[24], the instructor directly communicates the mistakes to the students and tells them what needs to be corrected. In facilitative feedback[24], the instructor only gives suggestions to the students so that they can identify the rest on their own and thus learn the material.

Existing literature proposes that the degree of learning in a course is a function of the ratio of the time spent on course materials to the actual time the students need to spend on the same[25]. In other words, for students to master concepts in a course, they need to spend sufficient amount of time on the course materials. Also, the more time students spend on learning a course material, the more is the chance that they learn it. The Mastery Approach was developed based on that principle. In this approach, students are required to master a concept before they can move to the next one[26-28]. After its development in 1970s, this method has been widely implemented at the primary and secondary level schools. The studies exploring its uses in higher education, especially in engineering, are very scarce. A recent paper suggests that the educators at Pennsylvania State University have adopted a variation of this technique for many of their engineering courses[29]. Their preliminary results show that this type of an approach might be beneficial in engineering courses.

Rapid Feedback and Resubmission Cycle

This paper deals with a study where a variation of the Mastery Approach was used for the freshman engineering graphics course at Tuskegee University. Here, the students were given multiple opportunities to score maximum points in their homework. Their initial submission is

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graded quickly and the feedback is returned in two days. This feedback is primarily facilitative in nature. If a student lost many points in their work, they are asked to schedule a personalized tutor session with the instructor about that concept. Then they are instructed to resubmit the work after correcting their mistakes. During the personalized sessions, the mistakes are not explicitly explained to the students. The instructor guides them in the right direction, so that they can figure out the mistakes themselves (facilitative approach). The students are awarded up to 80% of the points they lost on the original submission, depending on the correction.

While the existing literature suggests that directive feedback is more effective to reach at a correct answer[19, 22], this study assumes that facilitative feedback is more effective when students need to extend their learning to newer situations. Thus, in order to achieve better specialization skills, facilitative feedback is assumed to be more effective. Further, many researchers have shown the importance of a rapid feedback compared to a slower feedback [20, 30, 31].Combining these two aspects together, this study aims to identify the usefulness of rapid facilitative feedback on the spatial visualization skills of engineering graphics students.

Another aim of this technique is to provide the students sufficient time to learn engineering graphics concepts. Often, students loose points on their homework as they spend less time than required on those. The time required for each student varies depending upon their learning habits, background knowledge and a variety of other factors. The rapid feedback and resubmission cycle (referred to as "resubmission cycle" further) is expected to provide additional time for the students on their learning materials and homework. The study described in this paper aims to evaluate the effectiveness of said method.

Hypothesis:

Students who pass through the rapid feedback and resubmission cycle achieve a greater improvement in their spatial visualization skills compared to those who do not.

Method

Selection of Study Participants

This study was conducted at the two sections of the freshman engineering graphics class at Tuskegee University. One of the sections was used as a treatment class and the other one as control. Both sections were asked if they would like to participate in the study. If a student did not want to volunteer, his/her data were eliminated from the analysis. The opportunity to volunteer was presented by a person who was not an instructor of the course to avoid any bias. As an incentive, study participants were given extra points, regardless as to which section they were enrolled. These points were assessed *after* the final exam and the grades were tabulated. All study participants were at least eighteen years of age.

Procedure

As mentioned in the previous section, one of the classes was considered as the treatment class. In this class, after the students submit their homework, they received their feedback within the next two working days. They were told that they had a chance to resubmit the work, after correcting the mistakes in their original submission. Instead of stating the mistakes directly, the instructor pointed out the part containing the mistakes and asked the students to figure out those. If one student did very poorly in a homework (typically 60% score or less), he/she was instructed to meet the instructor during the office hours to discuss the homework further. The instructor helped those students to work through the mistakes during such sessions. All the students in this class were eligible to resubmit their work, regardless of the grade they received in the initial submission. They received a maximum of 80% of the grades they lost in the original submission, in return. All the resubmissions were due in the next class, after the feedback was given.

The feedback given to the students in the treatment class was targeted to improve their spatial visualization skills. In their homework, only the part that needs correction was indicated and the actual mistake was not clarified. The students were expected to explore the marked area and figure out the mistake with the help of their class notes. For poorly performing students, additional instructions were given during their meeting with the instructor. For example, if a student performed poorly in a homework to derive isometric views from the multi-views of an object, the instructor would use different physical models to illustrate the concept of transition from multi-views to isometric view and vice versa.

The students in the control class were not allowed to resubmit their homework. They received the feedback on their homework at a regular pace, typically in the next class (a week after the submission). Although the students were allowed to meet the instructor and discuss their mistakes during the office hours, they never received additional grades for such an extra effort. Though detailed records of these meetings were not kept, it was estimated that approximately 40% of the students met the instructor more than two times for additional help outside the classroom. In order to aid in the development of their spatial visualization skills, the feedback on their homework assignments were very detailed and the instructor provided them explanations of the areas where they needed to improve.

In order to avoid any ethical conflicts, a pre-planned grading plan was formulated for the two classes. In the control class, the grading was performed with the same standards as the previous semesters. In the treatment class, the grading was comparatively strict; i.e., a student would loose more points for a mistake in the treatment class in comparison with the same mistake in the control class. After resubmission, the student would be able to achieve approximately the same grade as a student in the control class. For example, if a student in the control class looses 1 point for a question worth 10 points (a grade of 9/10), another student in the treatment class would loose 5 points for the same mistake (an initial submission grade of 5/10). The student in the treatment class can resubmit their homework for maximum points of 9

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out of 10 in their resubmission (80% of 5 points lost). In the resubmission cycle, the students' understanding of the mistake was checked and the grading was very relaxed; i.e., if a student understands the mistakes and corrects it, he/she would obtain 80% of the points they lost in the original submission. This measure was employed to avoid any conflicts between the students with the same knowledge level in the two classes. This also ensured that the experiment was not affecting their final GPA in the class. Since the experiment design itself avoided any significant differences in the GPA's of students in the two classes, it was not used as a measure of the effectiveness of the treatment employed in the study.

Data Collection

The freshman engineering graphics course at Tuskegee University gives students the basic skills necessary for visual technical communications and spatial visualization. Topics include engineering sketching and drafting, orthographic projection of multi, sectional, and auxiliary views, dimensioning, tolerances, and solid modeling using the CAD tools. For the purpose of this study, data were collected from homework assignments and CAD labs that involved visualization and mental rotation of the objects. Since the course meets once per week, there were six such assignments; so, only those were considered for the analysis. These included assignments to convert isometric views to multiviews, multiviews to isometric views, coded plans to isometric views, multiviews to auxiliary views and to draw section views of objects. The data, once collected, were categorized by the percentage of resubmission (please refer to next section for more details). In addition, PVT was given as a pre- and post- test to the study to measure the improvement in their spatial visualization skills.

Categorization of the Data and Metrics for Measurement

Categories of Resubmissions

As the students got additional practice while they resubmitted their homework, it was assumed that the number of resubmissions constitutes a factor in the analysis. Within the experimental group, the students were allowed to resubmit all their homework during the semester. While all the students in the treatment class could resubmit their homework, the general trend showed that if a student scored more than 90% of the maximum possible score, he or she would not be interested in a resubmission. Keeping this in mind, it was assumed that a student was likely to resubmit only the ones with less than 90% score. Since the number of homework that a student would want to resubmit varied, the number of resubmissions was normalized with the number of homework that a student was likely to resubmit. This normalized measure is referred to as "percentage of resubmission" further in the paper.

$$Percentage\ Resubmission = \frac{\#\ homework\ resubmitted}{\#\ homework\ the\ student\ was\ likely\ to\ resubmit}\ x\ 100$$

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It is observed that the percentage of resubmission varied from 0 to 75% within the treatment class. Since it was suspected that the improvement in students' visualization skills could be influenced by the percentage of their resubmissions, this metric was divided in four different categories, as shown in Table 1. The analysis was performed within each of these categories.

Table 1. The definition of resubmission categories

Percentage Resubmission	Resubmission Category
No resubmissions	0
< 25 % resubmissions	1
25 – 50 % resubmissions	2
> 50 % resubmissions	3

Normalized Improvement Percentage

In this study, the spatial visualization skills of students were measured using the Purdue Visualizations of Rotations Test. This test was assigned to the students at the very first and last classes of the course (pre- and post- tests). The improvement in a student's score in the post test compared to that in the pre-test was used as a factor for analysis. However, if a student scored 90% in the first test, he/she could improve only 10% whereas another student with a pre-test score of 50% could improve another 50%. In order to eliminate this bias, the difference in pre- and post-test scores was normalized with the pre-test score. This metric is referred to as "normalized improvement percentage" further in this paper.

$$Normalized\ Improvement\ Percentage = \frac{(posttest\ score - pretest\ score)}{Pretest\ score} x\ 100$$

Results and Discussion

Al students in the treatment class were allowed to resubmit their homework. However, the number of resubmissions varied across the students. Table 2 shows the percentage of resubmissions of each student and their normalized percentage improvement in PVT. The table also provides the normalized percentage improvement for the control class. These data are used for further analysis as described in the subsections below.

Improvement in Visualization in Control and Treatment Classes

In order to understand the advantages of the resubmission cycle in a graphics classroom, it is essential to compare the performances of students who utilize this cycle to that of students who do not. The performance, in this study, was measured using their scores in the pre- and post-PVT, using the metrics explained in the previous section. Figure 2 shows the average normalized improvement percentage of the students in both the control and treatment classes. In order to eliminate any bias, the students who did not resubmit any homework in the treatment class were not included in this analysis. The trend in Figure 2 shows that the students in the treatment class

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who utilized their opportunities to resubmit their work performed better than the control group. However, this difference was found to be statistically insignificant. A t-test is used for the statistical analysis (t = 1.06, p = 0.14).

Table 2. Raw data showing the percentage resubmissions and the normalized percentage improvement in the PVT for all the participants

	Treatment class			Control class	
Student #	% Resubmissions	Normalized % improvement in PVT	Student #		Normalized % improvement in PVT
1	0.00	31.25	1		43.75
2	0.00	-6.25	2		20.00
3	0.00	0.00	3		-15.79
4	0.00	5.26	4		42.86
5*	0.33	-100.00	5		-100.00
6	0.67	36.36	6		0.00
7*	0.00	-100.00	7		72.73
8	0.33	36.84	8		71.43
9	0.60	33.33	9		0.00
10	0.33	50.00	10		12.50
11	0.25	18.18	11		-5.88
12	0.00	20.00	12		20.00
13	0.00	87.50	13		90.91
14	0.00	21.43	14		0.00
15	0.25	175.00	15		-100.00
16	0.00	50.00	16		5.56
17	0.00	-33.33	17		7.14
18	0.14	36.36	18		-100.00
19	0.14	15.38	19		325.00
20	0.00	37.50	20		128.57
21	0.00	72.73	21		-100.00
22	0.00	0.00	22		-100.00
23	0.17	100.00	23		20.00
24	0.00	-23.08	24		30.77
25	0.75	52.94	25		-25.00
26	0.00	111.11	26		366.67
27	0.00	0.00			
28	0.00	11.76			
29	0.17	50.00			
30	0.00	28.57			

* represents students who did not participate in the post survey
   data from these students are not considered for analysis

Though this comparison was statistically insignificant, it was clear that on average, a student in the treatment class performed better than the control class. The variance of the normalized improvement percentage showed a very high variance, which might contribute to the statistical insignificance. Further, the sample sizes were different by a significant amount

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(control: 26, treatment: 11). Although both classes had roughly the same number of students, only 11 students from the treatment class decided to use their resubmission opportunities.
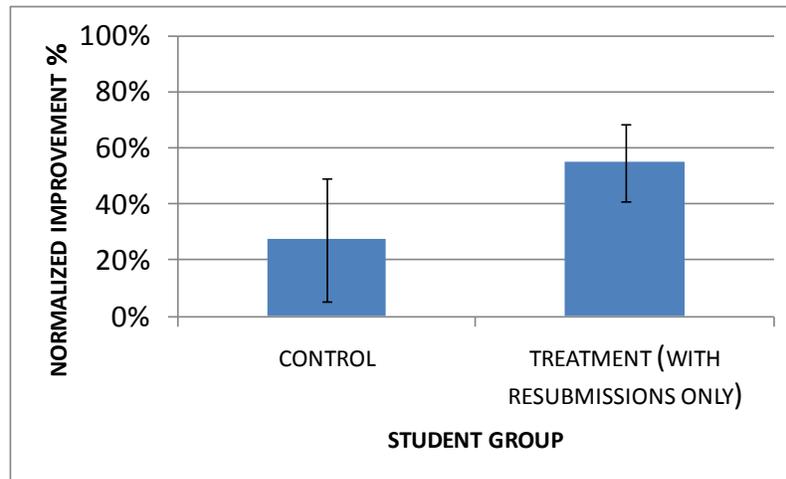

Figure 2. Comparison of normalized improvement percentage across the control and treatment groups. All error bars show (± 1) standard error

If the students in the control and treatment groups had significantly different visualization skills at the beginning of the study, it could offset the results. Hence the percentage scores of the participants in both groups were compared. The mean pre-test scores remained approximately the same (control = 47.3%; treatment: 47.2 %) across the two groups. Hence it was determined that the prior visualization skill was not a biasing factor in the analysis.

Within the treatment group in Figure 2, the students belonged to three different resubmission categories. Figure 3 shows the mean normalized improvement percentage across each category in comparison with the control group. On average, all the categories had a better performance compared to the control group. Again, these differences were not statistically significant.

Comparisons within the Treatment Class

As the students who resubmit their homework got additional feedback and practice on their work, it was assumed that the percentage of resubmissions could be a factor affecting their improvement in visualization. Figure 4 shows the mean percentage scores of each group in both the pre- and post- tests. For all categories, there was an increase in the percentage score in the test at the end of the semester. A paired sample t-test between the pre-test and post-test scores was conducted to verify this. The results of this analysis are shown in Table 3. As it is evident from the results, all the groups in the treatment class performed better in the post-test. This showed that the students might have better visualization abilities at the end of the course.
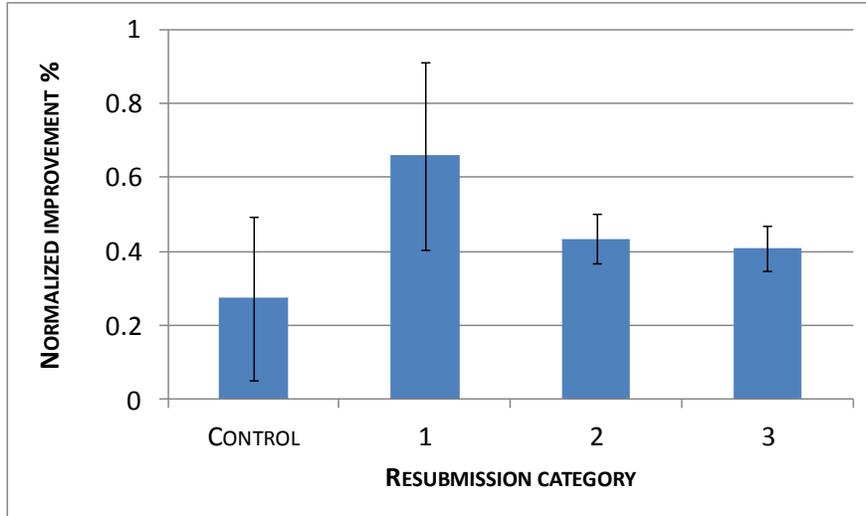
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Figure 3. The performance of various resubmission categories in the treatment class in comparison with the control class measured as normalized improvement percentage. All error bars show (± 1) standard error.
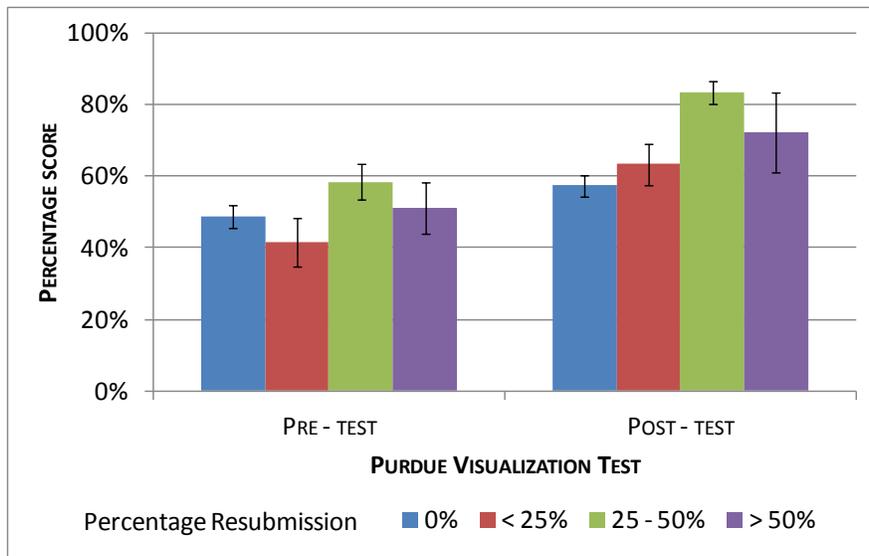

Figure 4. Comparison of pre- and post tests in various resubmission categories. All error bars show (± 1) standard error.

Table 3. Paired sample t-test results in various percentage resubmission groups

Percentage Resubmission	t-statistic	n	p
0 %	2.70	17	< 0.01[*]
< 25%	3.64	6	< 0.01[*]
25 – 50 %	15.00	2	0.02[*]
> 50%	4.35	3	0.02[*]

* Represents statistically significant comparisons at $\alpha = 0.05$

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The improvement in the visualization abilities of students in the treatment condition can be a composite effect – the effect of the course as a whole and the effect of the resubmission cycle. The significant improvement in the test score of students who do not resubmit their homework indicates that the course itself is helpful in improving the visualization skills of those students. A comparison between the students in this category and the students who resubmit their work (Resubmission categories 1, 2 and 3) can provide some insights about the additional improvement caused by the treatment. Figure 5 shows the comparison of mean normalized improvement percentage across all the resubmission categories. A single factor ANOVA showed that these categories did not vary significantly. However, the sample sizes in categories 2 and 3 were too low to obtain accurate comparison results.
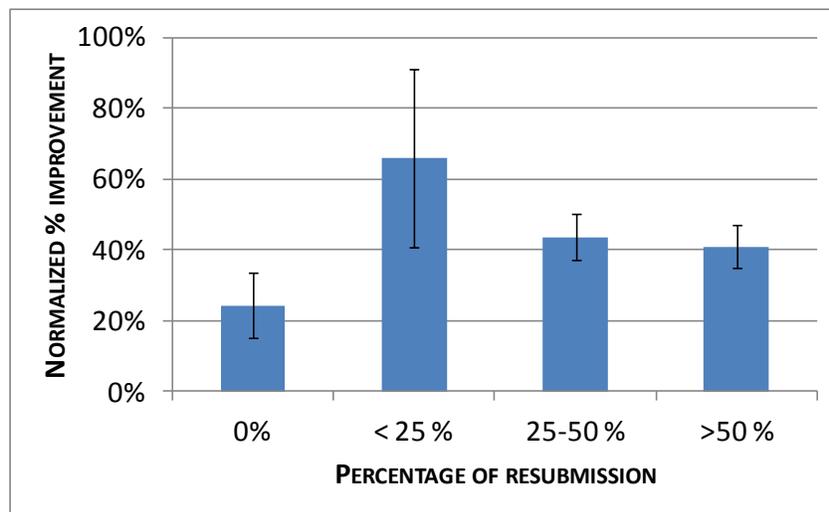

Figure 5. Mean normalized improvement percentage across various percentages of submission within the treatment class. Here the 0% submission represents the students in the treatment class who never used the resubmission cycle. All error bars show (± 1) standard error.

Another comparison was performed between the students who did not resubmit their homework and who resubmitted at least one (categories 1, 2 and 3 together). The comparison is shown in Figure 6. A t-test was performed on the normalized improvement percentage across the two groups. The results showed that these groups differed statistically ($t = 1.83$, $p = 0.04$). This indicated that the students who used the resubmission cycle had an additional advantage over those who did not.
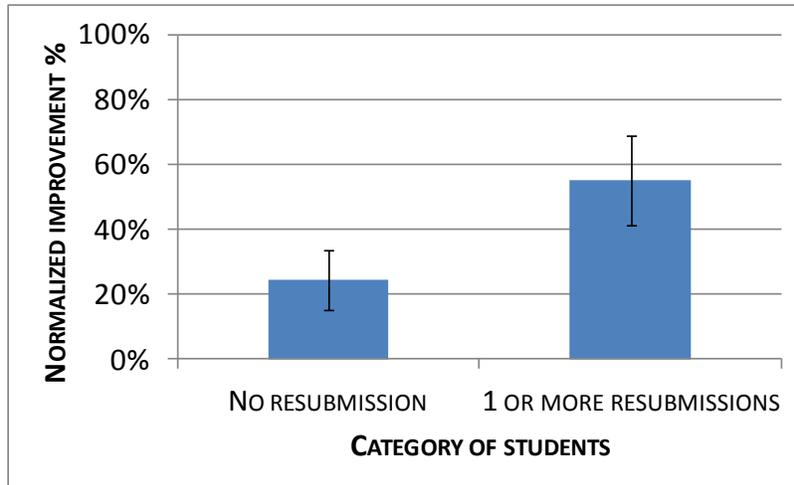
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Figure 6. Comparison of mean normalized improvement percentage between students who resubmitted and did not resubmit. All error bars show (± 1) standard error.

In summary, these results show promising trends. They show that as students get personalized rapid feedback from their instructor and put in an effort to understand and correct their mistakes, it gives them better results (measured as their visualization skills). As the lack of visualization skills is a critical problem that most graphics students face, these results provide a promising path forward.

Overall, the results support the hypothesis presented earlier. When students receive rapid feedback on their homework and resubmit their work, they receive additional training on that concept. The additional time they spend on the subject allows them to gain mastery on the subject. In a graphics course, spatial visualization skills are necessary to master most of the concepts. Hence, as students spend more time to master a concept, it contributes to an improvement in their spatial visualization skills. Though the sample size in some groups are small to derive any solid conclusions, the trends show that the spatial visualization skills of students can be influenced in a positive way using such rapid feedback-resubmission cycles.

From Figure 3 and Figure 5, it appears that as the number of resubmissions increases, the normalized percentage improvement shows a declining trend. Students who resubmitted less than 25% of their work eligible for submission appeared to have performed better in terms of the normalized percentage improvement, compared to those who submitted more than 25%. The current analysis cannot explain this trend and further investigation is needed on this trend.

An important matter of concern in this study was the lack of participation by a few students in the resubmission cycle. Two groups of students were observed to be reluctant to resubmit their work – students who perform really well in their first attempt and the students who consistently perform poorly throughout the course. While the first group's lack of participation is justified, the same from the second group was concerning. This group just wanted to get a pass

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grade in the course and was not interested in improving their grade. Many of them participated in the extra curricular activities offered by the university and considered their courses as a second priority. From the experience of the instructors, some of them blamed the lack of time for not resubmitting their work for a better grade. In future work, the authors intend to device better ways to improve the participation from said group.

Limitations of the Study

The main limitation of this study was the limited sample size. Although the treatment class had 28 students (2 students who did not participate in the post-test were excluded from the analysis), only 11 resubmitted their homework. When the resubmission categories were formed, category 2 and 3 (more than 25% resubmissions) had 2 and 3 students respectively. These sample sizes were not sufficient to provide accurate statistical comparisons. However, the results showed trends in the data that provided some useful insights for the future use of this technique.

The two class sections of this course were taught by two different instructors. Although the instructors coordinated to reduce any differences between the sections, it could still cause a bias in the results. However, this bias was not present in the comparisons where the resubmission category 0 within the treatment class was compared against the other categories in the same class. These results along with the results from control vs treatment comparison provided a few useful results regarding the efficacy of the treatment.

Conclusions

The primary aim of this study was to understand the effects of a rapid feedback – resubmission cycle in students' spatial visualization skills. In the resubmission cycle, the instructor provides a rapid feedback on the homework submitted by students. Many times, the instructor also helps the students to work through their problems. The students also get a chance to resubmit their homework for a maximum of 80% of the grades they lost in the original submission. This cycle allowed the students to work through their mistakes, correct the same and in the process, learn the concept more thoroughly. The improvement in the spatial visualization skills (measured by the Purdue Spatial Visualizations of Rotations Test) of the students who resubmitted their work frequently provided support for this argument. While it was difficult to draw solid conclusions due to the limited sample size in some categories, the results showed some promising trends. It can be inferred that if the instructor can spend some additional time with the students to help them work through their issues in a graphics class room and assist them in mastering each concept, the students can develop better visualization skills. In the future semesters, this technique will be implemented in both the sections of this course to help the students and collect additional data to support the arguments presented by this paper.

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