AC 2011-546: ENGAGE ENGINEERING AND SCIENCE STUDENTS BY IMPROVING THEIR SPATIAL VISUALIZATION SKILLS

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Engage Engineering and Science Students by Improving Their Spatial Visualization Skills

Abstract

Research has shown that students with enhanced spatial visualization skills, the ability to see and think in 3-D, are more successful in engineering, technology, computer science, chemistry and mathematics courses. These skills can be developed with training and practice. Kettering University is one of the 10 selected schools in the NSF – ENGAGE Group (http://www.engageengineering.org/?page=6). The three main themes of the ENGAGE grant are Faculty Interaction, Everyday Engineering Examples, and Spatial Visualization. This paper presents an approach to improve students' spatial visualization skills for increased student success. The proposed methodology includes two steps: identifying students who should receive remediation in spatial visualization and improving the existing Engineering Graphics course offerings. An online test to assess students' spatial visualization skills created by Purdue University, a partner school in the ENGAGE project, was given to all engineering and science freshman students at Kettering University. Based on the results, all students who scored lower than 60% will be recommended to take a spatial visualization course which will be developed as one of the deliverables in the NSF-ENGAGE grant. In addition, by testing students' spatial visualization skills before and after the existing initial Engineering Graphics course, several improvements were implemented. The enhancements to the existing Engineering Graphics course are discussed.

1. Introduction

For the past 75 years, Kettering University has provided its students with top quality classroom instruction, state-of-the-art laboratory facilities and career-oriented work experience in industry. Kettering offers Bachelors Degree programs in engineering, science, mathematics, and management. Kettering students begin a unique five year cooperative education program in their freshmen year by alternating 12-week period of classroom studies with related work experience in over 600 corporate affiliates. The corporate sponsors of Kettering University students include over 600 other companies as well as the state and federal government. It is seen that the companies that sponsor Kettering University students represent a diverse cross section of U.S. industries. The changes that have been taking place in these industries and the needs and challenges they face are immediately reflected in Kettering University's classrooms as the students bring valuable experience after 24 weeks of work experience per year with their corporate sponsor. The students and the department of Mechanical Engineering are the focus of this study.

As part of the professional development portion of the grant, the Kettering University ENGAGE team attended the ENGAGE conference in February 2010. A Plan of Attack in spatial visualization was developed by Dr. Y. Dong, the Spatial Visualization Leader. It includes five phases starting from Spring semester 2010. Currently at Kettering, "Technical Graphical Communications (MECH-100)" is a core course for Mechanical Engineering (ME) students at freshman level. It is an elective or capstone course for students in other programs such as Industrial and Manufacturing Engineering (IME), Electrical and Computer Engineering (ECS), etc.

According to the studies by Sorby [1, 2], well-developed spatial skills have been shown to lead to success in many disciplines such as engineering, computer science, chemistry, and computer aided design. Significant studies on the relationship between spatial skills and chemical sciences were reported in the 1980s by Pribyl & Bodner [3] and Bodner & McMillan [4]. These research activities clearly showed that both spatial ability and gender can play a significant role in the success of students, particularly in entry-level classes such as general chemistry. They indicated that students with better spatial ability performed better on organic chemistry questions that require drawing of molecular representations in problem-solving process. As expected, students with higher spatial skills were more likely to create correct structural schemes than those with lower spatial skills. Earlier study by Smith [5] in 1964 showed that spatial skills play an important role in at least 84 different professions. For engineering related careers that require drawing and computer aided design, spatial skills and mental rotation abilities are particularly important [5 - 7].

2. Purdue Spatial Visualization Test: Rotations (PSVT:R)

PSVT:R test [8], developed by Guay in 1977, includes 30 questions about rotation of 3D objects with a time limit of 20 minutes, as shown in FIGURE 1. With this test, students are shown a criterion object and a view of the same object after undergoing a rotation in space. They are then shown a second object and asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. It was used in the MECH-100 class (freshmen) and MECH-210 class (Statics for sophomores) in Spring 2010, to compare

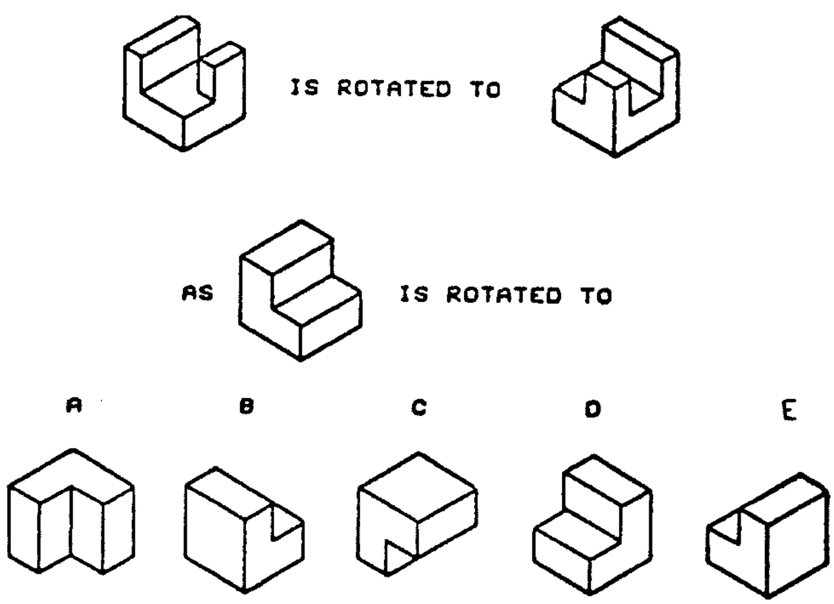

FIGURE 1 – PSVT:R MULTIPLE CHOICE QUESTION [8]

- Pre- and Post-MECH-100 class performance; and
- Freshman vs. sophomore performance

"PSVT:R" online test was launched university-wide for all science and engineering freshmen at Kettering University in Summer 2010.

2.1 Testing results for university-wide freshmen

A total of 119 freshmen took the "PSVT:R" online during Summer 2010. Of these, 102 students (85.7% of total number of students) received a score of 60% or higher, which is considered acceptable. 17 students (or 14.3%) scored below 60% and needed improvement (Table 1.). As shown in Table 2, the average score of all students was 23.2 (77.3%). Gender breakdown indicated that women were, on average, somewhat less proficient at the spatial visualization skills. Female students averaged 69.7% in score compared 89.3% for male students. Approximately 8.5% of men needed improvement, compared to 36.0 % of women (Table 3.). This corresponds to the published literature.

Table 1: Total students who took PSVT:R in Summer 2010

Total number of students	119
Score ≥ 60%	102 (85.7%)
Score < 60%	17 (14.3%)

Table 2: Average PSVT:R score from Summer 2010

	Average Score
Overall	23.2 (77.3%)
Men	26.8 (89.3%)
Women	20.9 (69.7%)

Table 3: Total students who took PSVT:R in Summer 2010, and scores by gender

	Men	**Women**
Total	94	25
Score ≥ 60%	86 (91.5%)	16 (74.0%)
Score < 60%	8 (8.5%)	9 (36.0%)

2.2 Testing results of pre- and post-MECH-100 class

Testing results of those who participated both pre- and post-MECH-100 are shown in FIGURE 2. As mentioned earlier, the "PSVT:R" test was used in Week 1 and Week 10 for the same class.

Pre-MECH-100 (week 1):	Average score:	23.35 (77.8%)
Post-MECH-100 (week 10):	Average score:	23.05 (76.8%)

It was found that students had very good spatial skills coming into MECH-100 classes (mainly ME freshmen) and the course did not improve their proficiency. The Post-MECH-100 scores dropped slightly from the initial testing. The hypothesis for this was that most students did not show significant interest due to final exams in week 10. Better results are expected if the post test was held no later than week 6.

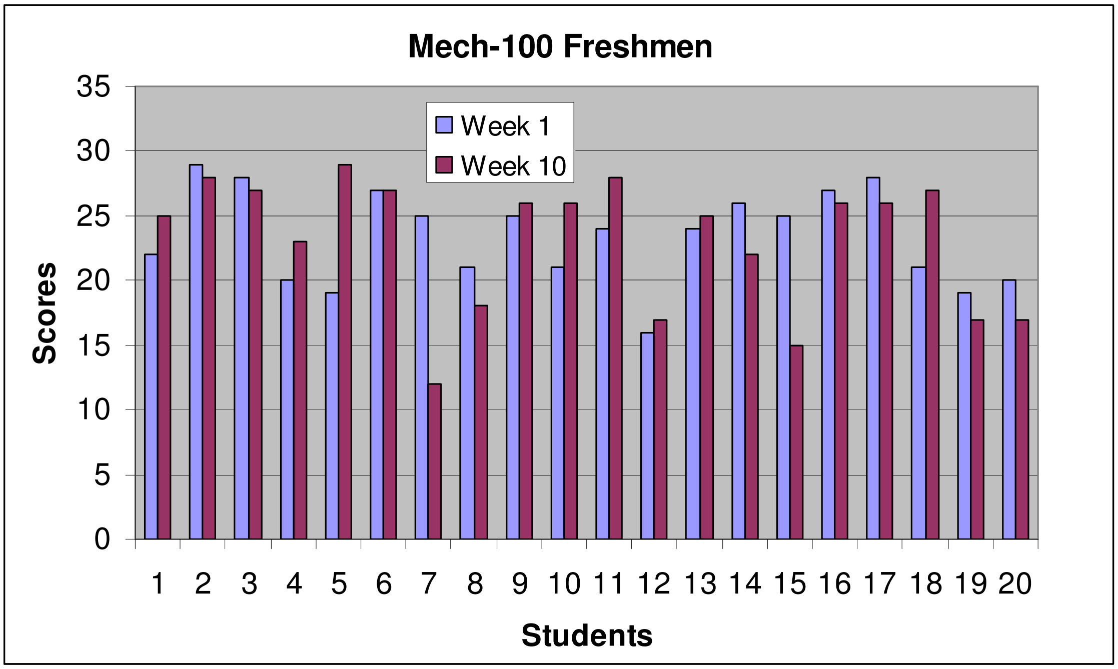

FIGURE 2 MECH-100 STUDENTS TESTING RESULTS

2.3 Testing results: freshmen vs. sophomores

As expected, the Statics (MECH-210) class students (mainly ME sophomores who have already taken MECH-100 classes) demonstrated very good spatial skills. Some lower scores represent non-ME students who have not taken MECH-100. These sophomores had an average score of 24.6 (82%), better than the MECH-100 freshmen class results. Therefore, this infers that the hypothesis for the decline in MECH-100 student scores was correct, and the timing of the tests should be altered to ensure that students have sufficient time to concentrate on the post test. Another strategy is to give class credit for both the pre and post tests to motivate students to do their best.

The gender break down for the sophomore spatial test results is provided in Table 4. Therefore significant improvement is shown in both male and female students after education. However, because spatial visualization skills is a known indicator of student success in STEM classes, remediation for low performing students could help student performance in first year classes. Because women students tend to have lower spatial visualization skills coming into college than male students, early intervention can be especially important to their success and retention in engineering programs.

Therefore, it is recommended that students be tested early and be provided remedial and supplemental education to increase their spatial visualization skills. Because of the transition away from home in the first year of college, it may be beneficial to test incoming students before they arrive on campus then offer online education for those students that score below satisfactory. In this way, students can increase their chances of success during the first year of mechanical engineering since the first year foundational courses include mathematics, chemistry and other courses where special visualization skills increase their success.

Table 4: Statics students' scores by gender

	Men	**Women**
Total	38	12
Score ≥ 60%	36 (94.7%)	10 (83.3%)
Score < 60%	2 (5.3%)	2 (16.7%)

3. Improvements Made to MECH-100

3.1 The course learning outcomes (CLOs)

The course learning outcomes of MECH-100 at Kettering University can be described as follows. Upon completion of the course students will be able to:

(1) Demonstrate the elements of 3D visualization and engineering sketching techniques
(2) Demonstrate the basic structure, content and terminology of engineering drawings.
(3) Demonstrate the techniques and processes of elementary solid modeling and visualization.
(4) Demonstrate the visual and written requirements associated with product realization.
(5) Use CAD, office, and web-based software to enable graphical project based communication.

3.2 An overview of the topics covered

(1) Introduction to Fundamentals of Sketching [1 Week]
(2) Introduction to Visualization and Spatial Representation [1 Week]
(3) Three Dimensional CAD Representations And Model Construction Processes [3 Weeks]
(4) Drawing Projections: Orthographic, Isometric, Sectional, Auxiliary [3 Weeks]
(5) Graphical and Written Requirements for Product Realization: Dimensioning, Geometric Dimensioning & Tolerancing, and Working Drawing Requirements [2 Weeks]
(6) Introduction to Web-Based and Office Software for Graphical Communication. [1 Week]

There are three class sessions per week of 120 minutes, two lecture hours and four laboratory hours. During the first two weeks of the 11-week MECH-100 course, students learn freehand sketching, multiview projections, and spatial visualization. From the third week, students start learning NX solid modeling, sketching, assembly modeling, drafting, and Geometric Dimensioning & Tolerancing (GD&T). FIGURE 3 depicts a homework assignment on orthographic projection (given two views, sketch the third view and the isometric pictorial). FIGURE 4 shows a homework assignment on "reverse" orthographic projection (given the isometric pictorial, sketch the top, front, and right-sided views). For the assembly, students are required to design an automotive door hinge mechanism including three components: the inner hinge, the outer hinge and the hinge pin (FIGURE 5). All parts in the assembly have to be mated properly, so that the outer hinge is allowed to rotate unobstructed around the hinge pin by at least 180 degrees.

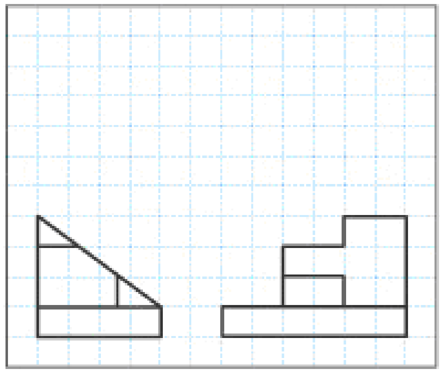

FIGURE 3 – ORTHOGRAPHIC PROJECTION (SKETCH THE THIRD VIEW AND THE ISOMETRIC PICTORIAL)

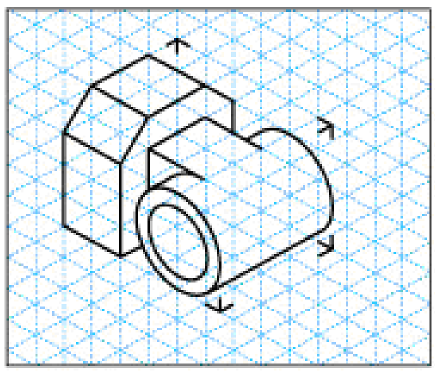

FIGURE 4 – ORTHOGRAPHIC PROJECTION (SKETCH THE TOP, FRONT, AND RIGHT-SIDED VIEWS)

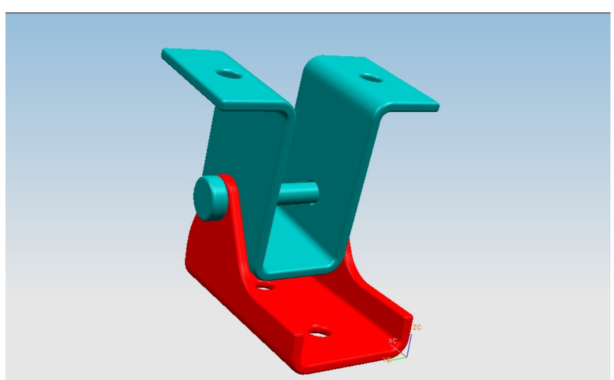

FIGURE 5 – AUTOMOTIVE DOOR HINGE ASSEMBLY

In the following weeks, the main focus is Dimensioning, Geometric Dimensioning & Tolerancing (GD&T). The fundamental techniques of GD&T are introduced. Students in the class design several parts with key dimensions given. FIGURE 6 shows an example of the homework in this topic. In this problem, the students are required to create the CAD model and then fully dimension the part in drafting application of NX software.

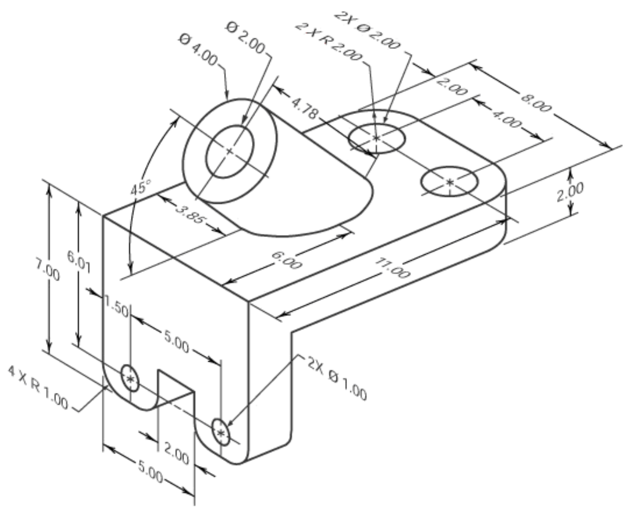

FIGURE 6 – GD&T AND DRAFTING PROBLEM

A student term project is assigned to the class and students work on it from the 7th week all the way to the 11th week. The project is the development of a final report based on the reverse engineering design of a common household / shop object. Students in MECH-100 are to separate into teams of minimum three and propose a project. Larger projects can pull more help from any of the other sections of engineering graphics. Proposals should include a minimum of five (5) different parts of ordinary difficulty per team member. FIGURE 7 shows an example of the student term project, an impeller assembly. The assembly includes the top and bottom housings, and the impeller shaft subassembly, the impeller blades, and a number of fasteners like bolts, nuts and washers.

FIGURE 7 – IMPELLER ASSEMBLY (WITH EXPLODED VIEW)

Projects will be graded on a nine-part system which includes the following areas and point values:

a)	MASTER GROUP PROPOSAL	5 PTS
b)	SKETCHING	10 PTS
c)	WRITTEN PRESENTATION	10 PTS
d)	ORAL PRESENTATION	10 PTS
e)	MODELING	20 PTS
f)	DETAILED DRAWINGS	20 PTS
g)	EXPLODED ASSEMBLY DRAWING	15 PTS
h)	PARTS LIST (BOM)	5 PTS
i)	PEER EVALUATION	5 PTS
	TOTAL	100 PTS

Deliverable 1) A one page written pre-proposal of the project idea and the proposed master group team members must be submitted by the second class period of 7th Week, and accepted by the third class period. See Deliverable 4) item 2).

Deliverable 2) Each master group must turn in **fully dimensioned** hand sketches and the one page written documentation by the first class period of 9th Week (See Items 1 and 2 in Deliverable 4 below). Sketches will be checked and returned. Both Deliverables 1 and 2 are to be revised, if necessary, and included in the final presentation.

Deliverable 3) Each master group will give a 5-8 minute presentation of their project during the final class period in week 11. **Attendance to the final presentation session is mandatory.** Peer assessment will be conducted during the presentations.
Furthermore, each team member will be expected to turn in a team member assessment document (to be distributed during 11th Week) separately from the report.

Deliverable 4) The master group is to submit one report. The final written report for the group should consist of, **at a minimum**:
(1) Dimensioned hand sketches including fits and tolerances.
(2) A one page written documentation including:
   a) The description of the object including number of parts along with a picture of the object or the object itself.
   b) Proposed master group team members names and sections also please indicate the name of the team leader
   c) The work (to be) performed by each
(3) The component solid drawings checked into each member's Home Account on U: drive in a folder marked "Final Project" by Wednesday, Week 10. These models should also be printed out for the final presentation.
(4) The 2-D layouts of each component with dimensions and tolerances printed out by Thursday, week 10.
(5) A completed exploded assembly drawing(s) of the project.
(6) A bill of materials. The BOM should include: a) part name, b) part number,

c) description, d) quantity needed, e) material(s) including density and f) any other pertinent information.
(7) One improvement you suggest for the product.
(8) Other extra credit avenues include: detail views, cutaway views, assembled assembly views, motion, any range of modeling not covered in class such as sheet metal, lips and grooves, rendering, families of parts, piping, weldments, etc.

3.3 Course enhancements

Table 5 shows the comparison before and after the enhancements to MECH-100 course outline. The following enhancements are summarized:

(1) PSVT:R test is given to every MECH-100 class at the first class serving as an assessment of their starting point in spatial visualization skills. This is a valuable pre-MECH-100 raw data.
(2) The term project is discussed in the 1st week, instead of the 7th week, to give the students a heads-up to start thinking their projects.
(3) Assembly design and modeling is moved from the 10th week to the 5th week. This will give the students the earlier assembly knowledge they need to work on the term project.
(4) Dimensioning is moved from the 8th week to the 6th week so that students have the skill set to start the reverse engineering process.
(5) PSVT:R test is given again in the 5th week to obtain post-MECH-100 testing results, since the major spatial visualization trainings are completed by the 5th week.

Table 5: Comparison of MECH-100 course outline before and after improvements

	Original	**New**
Week	Topics	Topics
1	Introduction to Fundamentals of Sketching Assignment 1, Quizzes 1&2	Introduction to Fundamentals of Sketching Assignment 1, Quizzes 1&2, *PSVT:R* *Term project discussion*
2	Visualization and Spatial Representation Assignment 2, Quizzes 3&4	Visualization and Spatial Representation Assignment 2, Quizzes 3&4
3	3D Computer Graphics Using NX Assignment 3	3D Computer Graphics Using NX Assignment 3
4	Fundamentals of Solid Modeling Using NX Assignment 4, Exam 1	Fundamentals of Solid Modeling Using NX Assignment 4, Exam 1
5	Advanced Surface Modeling Using NX Assignment 5	Advanced Surface Modeling Using NX *PSVT:R*, Assignment 5, *Assembly*
6	Sectional Views Assignment 6	*Dimensioning* Assignment 6
7	Auxiliary Views Term project starts, Assignment 7	Auxiliary Views Term project starts, Assignment 7
8	Dimensioning Assignment 8, Exam 2	Sectional Views Assignment 8, Exam 2
9	Geometric Dimensioning and Tolerancing Assignment 9	Geometric Dimensioning and Tolerancing Assignment 9
10	Assembly, Working Drawings Assignment 10	Working Drawings Assignment 10
11	Final project and presentation	Final project and presentation

4. Course Assessment Survey Questions

In addition to the direct assessment through the examinations described above, indirect assessment will also be utilized in the form of a survey. Systematic assessment will be carried out in order to obtain feedback from the students. These assessment results will help fine-tune the course down the road. The student survey will include specific questions regarding the content, tools, project, etc. and also general questions such as how and if the course materials are used at their co-op sponsor, and what they feel the scope of the course should be. We will also gather information such as what is their interest in the topic on a scale of 1-10, and the student's background.

4.1 Assessment techniques and tools

The Kettering University faculty has recently become acquainted with process education methodology through seminars facilitated by Pacific Crest. SII is a method of assessment articulated by Pacific Crest [9] which requires the assessor to focus on three main items: strengths, areas for improvement, and insights gained. *Strengths* identifies the ways in which a performance was commendable and of high quality. Each strength should include a statement as to why that particular strength was considered important and how the strength was produced. *Areas for improvement* identify the changes that can be made in the future to improve performance. *Improvements* should include the issues that caused any problems and mention how those changes can be implemented most effectively. *Insights* identify new and significant discoveries that were gained concerning the performance area. The authors have used the SII method on a regular basis in different courses to get feedback from the students.

4.2 Student course assessment questions

Following are the questions for indirect, qualitative assessment (such as for ABET) of student perception that will be used to complement the direct, quantitative assessment of knowledge and skills. This information will be used to continuously improve the course.

(1) Please rate your level of understanding of the fundamental skills of spatial visualization;
(2) Please rate your ability to apply the fundamental skills in engineering graphics;
(3) Please rate your ability to apply solid modeling techniques to engineering design;
(4) Please rate your ability to apply GD&T techniques to product design and development;
(5) How do you rate your ability to effectively communicate technical information in writing?
(6) How do you rate your teamwork skills?
(7) How do you rate your ability to make technical presentations?
(8) How do you rate your ability to be a self-grower with regard to life long learning?

In the survey a SII question will be asked in which the students will list their personal strengths, improvement areas and insights about their background knowledge of the course materials. This will provide the instructor with knowledge that can be used to customize the learning goals for each student.

The following SII questions will be used for additional post course assessment to facilitate continuous improvement, and validate the direct assessment:

(1) What are the three strengths of this course? Please explain.
(2) What are the top three things that you have learned?
(3) What are the three improvements for this course that would help you learn better?
(4) How can these improvements be made?
(5) What action plans can be put in place to help you learn more?
(6) What have you learned about your own learning process?
(7) Is there anything else you would like the instructor to know about the class?

5. Challenges and Lessons Learned

One difficulty we experienced at Kettering was immediate support from administration and IT, particularly the first time. It took a long time to approve the massive email list to all freshmen. It was also important that fellow faculty members buy into the strategy and support these ENGAGE activities. Even for the students, their enthusiasm changes in the scenario of mandatory vs. voluntary, with and without credit. The “PSVT:R” online version is a great tool to have, meanwhile there is no automated way to provide feedback to students who took the test. Each student needs to be notified individually to receive their test score.

The primary lesson learned, first and foremost, is to obtain support across the board – from the administration, the department to fellow faculty and staff. For students, make it mandatory, otherwise they will not take it seriously and the data won’t show true value.

6. Conclusions

Engineering has many gateway courses, such as calculus, chemistry, and physics. Engineering graphics may be a more significant gateway than these introductory math and science courses. Research shows that by developing and implementing a course to help students improve their ability to visualize in three dimensions, we can improve student success and retention. This paper documents an effort to improve students’ spatial visualization skills for increased student success. The proposed methodology includes two steps: first identifying students who should receive remediation in spatial visualization. Then enhancements of the existing Engineering Graphics course are proposed. An online test to assess students’ spatial visualization skills created by Purdue University was given to all engineering and science freshman students at Kettering University for quantitative assessment. Based on the results, all students who scored lower than 60% will be recommended to take a spatial visualization course. Several improvements were implemented to the existing Engineering Graphics course, however even earlier detection and remediation is recommended. Testing incoming engineering students and offering intervention before they arrive on campus and begin their foundational first year course would further increase student success. In addition it is recommended to also implement a student survey for qualitative assessment, outlined above, to complement the quantitative assessment completed in this study to further improve student’s special visualization skills which have been proven to directly correspond to student success in engineering.

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