AC 2012-2981: LESSONS LEARNED IN ENGAGING ENGINEERING STUDENTS BY IMPROVING THEIR SPATIAL VISUALIZATION SKILLS

Prof. Yaomin Dong, Kettering University

Yaomin Dong is Associate Professor of Mechanical Engineering at Kettering University. He received his Ph.D. in mechanical engineering at the University of Kentucky in 1998. Dong has extensive R&D experience in automotive industry and holds multiple patents. Dong's areas of expertise include metalforming processes, design with composite materials, and finite element analysis.

Lessons Learned in Engaging Engineering 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). The three main themes of the ENGAGE grant are Faculty Interaction, Everyday Engineering Examples, and Spatial Visualization. This paper presents lessons learned in an approach to improve students' spatial visualization skills for increased student success. The enhanced methodology includes three steps. The first is Pre-Test: the PSVT-R 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. The second step is Remediation: based on the results, all students who scored lower than 60% were required to take a spatial visualization course which was developed as one of the deliverables in the NSF-ENGAGE grant. The third step is Post-Test: by testing students' spatial visualization skills after the spatial visualization training, all the students who participated the training passed the post test. Further enhancements to the existing Engineering Graphics course have been made as lessons learned.

1. Introduction

As part of the professional development portion of the NSF – ENGAGE grant, the Kettering University ENGAGE team attended the ENGAGE conference in February 2010. A Plan of Attack in spatial visualization was developed. It includes five phases starting from Spring semester 2010. Currently at Kettering University, "Technical Graphical Communications (MECH-100)" is a core course for Mechanical Engineering (ME) students at freshman level. It is an elective 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. "PSVT:R" has been used university-wide for all science and engineering freshmen at Kettering University since Summer 2010.

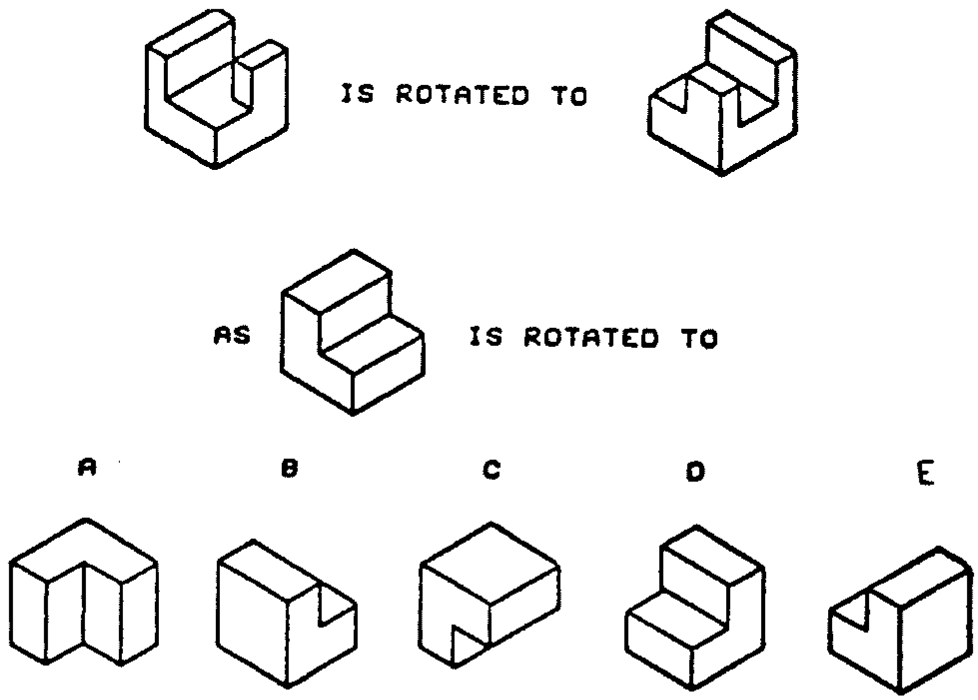

FIGURE 1 – PSVT:R MULTIPLE CHOICE QUESTION [8]

3. Pre-Test Results for University-wide Freshmen

A total of 221 freshmen took the "PSVT:R". Of these, 205 students (92.8% of total number of students) received a score of 60% or higher, which is considered acceptable. 16 students (or 7.2%) scored below 60% and needed improvement (Table 1.). As shown in Table 2, the average score of all students was 24.2 (80.7%). Gender breakdown indicated that women were, on average, somewhat less proficient at the spatial visualization skills. Female students averaged 70.7% in score compared 90.3% for male students. Approximately 9.6% of men needed improvement, compared to 35.3 % of women (Table 3.). This corresponds to the published literature.

Table 1: Total students who took PSVT:R

Total number of students	221
Score ≥ 60%	205 (92.8%)
Score < 60%	16 (7.2%)

Table 2: Average PSVT:R score

	Average Score
Overall	24.2 (80.7%)
Men	27.1 (90.3%)
Women	21.2 (70.7%)

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

	Men	**Women**
Total	187	34
Score ≥ 60%	169 (90.4%)	22 (64.7%)
Score < 60%	18 (9.6%)	12 (35.3%)

4. Spatial Visualization Training

Based on the Pre-Test results, all students who scored lower than 60% were required to take the spatial visualization training class. Since Mechanical Engineering students (approximately 60% of all engineering and science students) are required to take Engineering Graphics (MECH-100), it was decided to enhance MECH-100 course contents in line with this study. The first three weeks of MECH-100 are ramped up specifically for the spatial visualization training need. The Sorby workbook and software are used as for in-class exercises and quiz problems.

An overview of the topics covered in the MECH-100 class:

(1) Introduction to Fundamentals of Sketching
(2) Visualization and Spatial Representation
(3) Three Dimensional CAD Representations And Model Construction Processes
(4) Drawing Projections: Orthographic, Isometric, Sectional, Auxiliary Views
(5) Dimensioning, Geometric Dimensioning & Tolerancing
(6) Working Drawing Requirements
(7) Design Project

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 2 depicts a homework assignment on orthographic projection (given two views, sketch the third view and the isometric pictorial). FIGURE 3 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 4). 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.

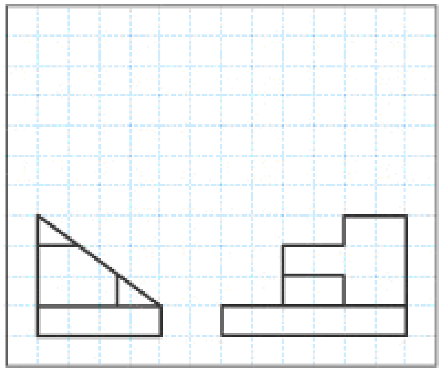

FIGURE 2 – ORTHOGRAPHIC PROJECTION (SKETCH THE THIRD VIEW AND THE ISOMETRIC PICTORIAL)

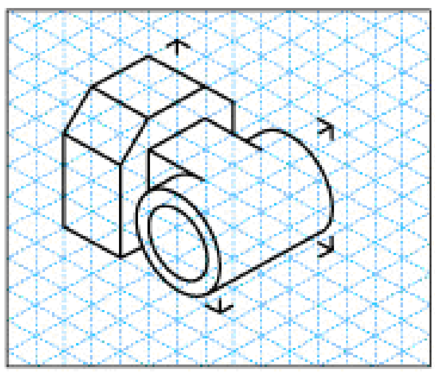

FIGURE 3 – ORTHOGRAPHIC PROJECTION (SKETCH THE TOP, FRONT, AND RIGHT-SIDED VIEWS)

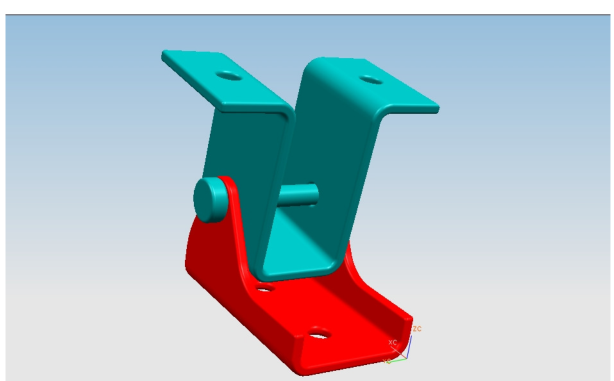

FIGURE 4 – AUTOMOTIVE DOOR HINGE ASSEMBLY

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 5 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.

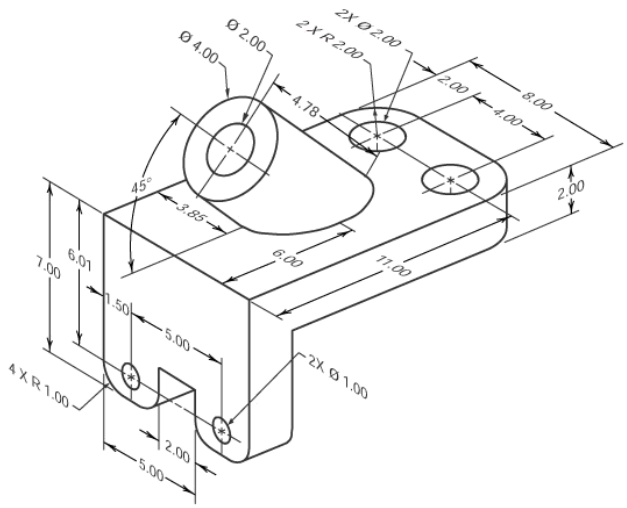

FIGURE 5 – GD&T AND DRAFTING PROBLEM

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 6 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 6 – impeller assembly (with exploded view)

Table 4 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) Four visualization quizzes are given in the first two weeks.
(4) 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.
(5) Dimensioning is moved from the 8th week to the 6th week so that students have the skill set to start the reverse engineering process.
(6) 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 4: Comparison of MECH-100 course outline before and after improvements

	Original	**New**
Week	Topics	Topics
1	Introduction to Fundamentals of Sketching Assignment 1	Introduction to Fundamentals of Sketching Assignment 1, Quizzes 1&2, *PSVT:R*, Sorby workbook problem solving *Term project discussion*
2	Visualization and Spatial Representation Assignment 2	Visualization and Spatial Representation Assignment 2, Quizzes 3&4, Sorby workbook problem solving
3	3D Computer Graphics Using NX Assignment 3, Quizzes 1-4	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

5. Post-Test Results

As shown in Table 1, 16 students scored below 60% and needed improvement. They were required to participate the three-week spatial visualization training outlined above. At the end of the training, they took the PSVT:R test. Table 5 shows the Post-test scores (75.2%) and comparison with the Pre-test scores (51.5%), an improvement of 23.7%. All these students passed the test.

Table 5: Results of PSVT:R Post-Test

Total number of students participated training	16
Pre-Test Score	51.5%
Post-Test Score	75.2%

6. 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 will not show true value.

7. Conclusions and Recommendations

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 three steps: first identifying students who should receive remediation in spatial visualization by PSVT:R Pre-Test for all engineering and science freshman students. Based on the Pre-Test results, all students who scored lower than 60% will be required to take a spatial visualization course. After the training course, all those students who failed the Pre-Test have passed the Post-Test. It is recommended that even earlier detection and remediation would be more helpful. Testing incoming engineering students and offering intervention before they arrive on campus and begin their foundational first year course would further increase student success.

8. References

[1] Sorby, S., "Educational research in developing 3-D spatial skills for engineering students", *International Journal of Science Education,* Vol. 31, No. 3, pp. 459-480, 2009.

[2] Sorby, S., "Gender differences in spatial reasoning skills and their effects on success and retention in engineering programs", http://www.eweek.org/site/News/Eweek/2006_marathon/BuildingSkills_2.ppt

.

[3] Pribyl, J.R. and G.M. Bodner, "Spatial ability and its role in organic chemistry: a study of four organic courses". *Journal of Research in Science Teaching*, 24: pp. 229-40, 1987.

[4] Bodner, G.M. and McMillen, T.L.B., "Cognitive restructuring as an early stage in problem solving". *Journal of Research in Science Teaching*, 23: pp. 727-37, 1986

[5] Smith, I. M., "Spatial ability-Its educational and social significance", University of London, 1964.

[6] Norman, K.L., "Spatial visualization - a gateway to computer-based technology", *Journal of Special Educational Technology, XII*(3), pp. 195-206, 1994
.

[7] Voyer, D., Voyer, S. & Bryden, M., "Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables", *Psychological Bulletin*, 117, pp. 250-270, 1995.

[8] Guay, R.B., "Purdue spatial visualization test: Rotations", West Lafayette, IN, Purdue Research Foundation, 1977.