AC 2011-438: IMPLEMENTING ENGAGE STRATEGIES TO IMPROVE RETENTION: FOCUS ON SPATIAL SKILLS - ENGINEERING SCHOOLS DISCUSS SUCCESSES AND CHALLENGES

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Implementing *ENGAGE* Strategies to Improve Retention: Focus on Spatial Skills
Engineering Schools Discuss Successes and Challenges

I. Introduction

ENGAGE - Engaging Students in Engineering, (www.EngageEngineering.org) is a five-year Extension Services project funded by the National Science Foundation's Research on Gender in Science and Engineering program. Extension Services projects are modeled after the Cooperative Extension Service in Land Grant Institutions and are intended to extend proven, research-based strategies into science, technology, engineering and mathematics (STEM) education. The overarching goal of ENGAGE is to increase the capacity of engineering schools to retain undergraduate students by facilitating the implementation of three strategies to improve students' day-to-day classroom and educational experience.

The first cohort of 10 engineering schools is working to implement ENGAGE strategies in the freshmen and sophomore years when student attrition is highest. Engineering schools participating currently in ENGAGE include: Kettering University, Purdue University, Rose-Hulman Institute of Technology, Stevens Institute of Technology, The Ohio State University, The University of Texas at Austin, University of Louisville, University of Maryland, University of South Carolina and Virginia Tech. A second cohort of 10 schools has been selected to begin this work in 2011 and a third cohort of 10 schools will be identified in 2012. Although schools who are participating formally in ENGAGE are supported in their efforts in a variety of ways, ALL engineering schools have the ability and capacity to integrate ENGAGE methods into the undergraduate experience. It is our intention to extend and provide support to engineering schools who are interested in using ENGAGE strategies on their campus by continuing to offer technical assistance through webinars and conference presentations and enhancing resources available on www.EngageEngineering.org.

ENGAGE selected the following three strategies because research indicates that they improve retention of undergraduate engineering students, particularly women; and because they are enhancements rather than wholesale changes to the curriculum:

- **Spatial Visualization Skills:** Assess students' spatial visualization skills and implement proven teaching and learning strategies to improve students' spatial skills.

- **Everyday Examples in Engineering (E3^{s}):** Involve faculty who teach 1st and 2nd year courses in efforts to use and develop examples that are familiar and engaging to students to illustrate theoretical concepts.

- **Faculty- Student Interaction:** Involve engineering faculty who teach 1st and 2nd year courses in efforts that build faculty knowledge and skill to better engage and interact with undergraduate engineering students inside and outside of the classroom.

This paper will focus on the Spatial Visualization Skills strategy including: the research that serves as the foundation of each strategy; the experiences of ENGAGE schools who are working to integrate a student assessment and spatial skills training course on their campus; and the resources that are available to all schools, to support the implementation of a method to improve students' spatial skills.

II. The Research: Why Improve Students' Spatial Visualization Skills?

Spatial visualization is considered to be one of the seven human intelligences and has been a topic in educational research over the past century. Based on previous research, two distinct themes emerge: 1) well-developed 3-D spatial skills are critical to success in STEM fields, including engineering, mathematics, physics, chemistry, architecture, computer science, medicine, and dentistry[1,2,3,4,5,6], and 2) the 3-D spatial skills of women typically lag significantly behind those of their male counterparts. [7,8,9,10,11,12,13] Just as with any of the other human intelligences, there are some individuals who naturally possess excellent spatial abilities and some whose spatial skills are less than adequate. Unfortunately, most individuals whose spatial skills are weak tend to be women or from lower socio-economic groups. We have found that women who are otherwise outstanding students are often discouraged from STEM fields if they struggle with topics that are seemingly easy for their male colleagues. The important thing to remember about spatial skills is that they are skills and can be developed through practice, just like any other skill.

Several researchers have conducted studies to determine what type of pre-college activities tend to be present in those students who have well developed spatial skills.[14,15,16] Although each study has produced slightly different results, it seems that activities that require eye-to-hand coordination are those that help to develop these skills. Factors that have been found to be significant for students with well-developed spatial skills include: 1) playing with construction toys as a young child, 2) participating in classes such as shop, drafting, or mechanics as a middle school or secondary student, 3) playing 3-dimensional computer games, 4) participating in some types of sports, and 5) having well-developed mathematical skills.

Understanding the need for spatial skills training for some individuals, particularly women, Michigan Tech implemented a spatial skills course in 1993, developed with NSF funding, aimed at first-year engineering students. This course and the materials used in it have evolved significantly over more than a decade, and its implementation has been shown to have a significant positive impact on the success and retention of women engineering students. With further assistance from the NSF, multimedia software and a workbook have been developed that are suitable for use at many levels in the educational spectrum, including pre-college levels.

From 1993 through 2008 at Michigan Tech, first-year engineering students were given the Purdue Spatial Visualization Test: Rotations (PSVT:R) to determine their level of spatial ability during orientation.[17] Those who failed the PSVT:R were encouraged to enroll in the spatial skills course; some chose to do so, others did not. For purposes of data analysis, students who failed the PSVT:R and enrolled in the course were the experimental group (EG) and students who chose not to were the comparison group (CG). In one longitudinal study conducted in 2000, retention in engineering was 77% for women in the EG compared to 47% for women in the CG (difference in retention rates significant at $p<0.0001$). In another longitudinal study conducted in 2004, students in the EG outperformed students in the CG in a number of introductory engineering courses as shown in Table 1.

Table 1. Average GPAs for Students in EG and CG

Course	Average GPA EG	Average GPA CG	Significance of Difference of Means
Engineering 1	3.04	2.62	$p< 0.0005$
Engineering 2	2.94	2.71	p.0.001
Calculus 1	2.78	2.35	$p<0.001$
Chemistry1	2.70	2.56	$p<0.1$
Physics 1	2.25	2.02	$p<0.02$
Overall	3.00	2.64	$p< 0.0005$

The results obtained at Michigan Tech in terms of student performance, as measured by grades in foundational courses and through retention rates, demonstrate the importance of spatial skills for engineering success. Michigan Tech's experience was so compelling that beginning in 2009, all students who fail the PSVT:R during orientation are now required to enroll in the spatial skills course. Students who are not ready for calculus typically are required to enrol in precalculus before progressing in the engineering curriculum. Likewise students who are not ready for chemistry will take preparatory chemistry first. Providing students with the opportunity for spatial skill-building through an introductory course, may be just as important in terms of their overall success and achievement.

III. ENGAGE Schools Discuss Their Approach and Experience of Implementing Spatial Skills Visualization Assessment and Training

The first cohort of ENGAGE schools supported by the intellectual arguments, research, data and professional development provided by Dr. Sheryl Sorby at the ENGAGE Strategy Implementation Workshop in February 2010, developed their plans to assess students' spatial visualization skills and implement a training course. ENGAGE provided schools with a number of electronic resources (see Section IV), technical assistance, and a minigrant. Five schools including the University of Texas at Austin, The Ohio State University, University of South Carolina, University of Maryland, and the University of Louisville discuss their experience in the narrative that follows.

A. The University of Texas at Austin

Introduction

The ENGAGE team at The University of Texas at Austin initiated its first spatial visualization workshop series in fall semester of 2010. The team's long-term goal is to identify all first-year engineering students with low spatial visualization skills and to develop curricula and teaching infrastructure to improve their skills. Faced with the daunting task of adding a new course to the engineering curriculum in an era of diminishing teaching budgets, the team decided to begin the effort by inserting a series of workshops on spatial visualization skills into a pre-existing freshman seminar course, Undergraduate Studies (UGS) 001, also known as a First-Year Interest Group (FIG).

Approach

To identify high-risk groups and to streamline the implementation of the spatial visualization workshops in the first semester, the team targeted first year women, participating in FIGs organized by the Women in Engineering Program (WEP) at UT Austin. All first year women enrolled in FIGs were invited to take the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) prior to the start of the fall semester of 2010. Invitations were distributed in the form of email messages and letters sent to parents or guardians, describing the opportunity and the importance of strong spatial visualization skills for success in both engineering courses and professional engineering practice. Originally, a 60% threshold was established as a cut-off score, but after testing, the decision was made to invite a broader range of students into the workshops. Therefore, students who scored 67% or lower on the PSVT:R were invited to participate. Eighty-three (83) students took the test, out of a total of 88 students enrolled in the WEP FIGs. Eleven students earned a score below the threshold and another 16 were on the threshold; all were invited to participate. Of those students, 23 enrolled in the spatial visualization workshop. Enrollment was encouraged by awarding two $125 scholarships at the end of the semester, chosen randomly from the students who attended each seminar and completed pre- and post-seminar administrations of the PSVT:R.

Course Structure

The spatial visualization workshop consisted of a series of five interactive seminars, delivered as a subset of the parent WEP FIG courses. All students in the WEP FIGs met weekly, in sections of 20 to 25 students, for one hour seminars on topics such as study habits and engineering careers. The subset of FIG students who enrolled in the spatial visualization workshop replaced five of their weekly seminars with spatial visualization topics, for which they met as a separate group in a dedicated classroom. The spatial visualization workshop was organized by WEP staff and an engineering professor, and taught by two graduate engineering students. Students were organized into groups of 4-5 individuals according to their scores on the PSVT:R, with the lowest scoring students in the first group, the next lowest scoring students in the second group, and so on, to minimize the sense of frustration that an extremely low-scoring student might experience upon working with a student with a much higher score. (Pre-test PSVT:R scores ranged from approximately 40% to 70%). The means of organizing the groups was not revealed to the students.

The five interactive seminars covered the first five modules of the text, *Introduction to 3D Spatial Visualization: An Active Approach* [18] with one module covered during each weekly seminar. After experimenting with a lecture-heavy format, the instructors quickly converged to an interactive format for the seminars. Each seminar began with a 10-15 minute introduction to the topic from the graduate student instructors, complete with practical applications and motivating examples, such as topological maps and blueprints of engineered parts, to illustrate the importance of that particular skill. Then, students were encouraged to complete practice exercises in their workbooks during the rest of the 50 minute period. During that time, lunch was served (as an incentive for regular attendance), and students were encouraged to work together in groups and interact frequently with the graduate student instructors who wandered from group to group. Students were also encouraged to complete additional exercises as homework, preferably by working together in their assigned groups, and office hours were scheduled with the graduate student instructors.

Test Results and Outcomes
Of the 23 students who enrolled in the spatial visualization workshop, 22 students completed the course, and 17 participated in a post-seminar administration of the PSVT:R. The average pre-seminar score was 17. The average post-seminar score was 20. Some students raised their scores as much as 8 points (e.g., from a 13 to a 21). Students were surveyed anonymously for their assessments of the course and the instructors, and at least two-thirds of the students agreed that the course was valuable, well-organized, and well-taught, and almost all students (87%) agreed that the course met their expectations. Several students commented on the quality of the instruction and the usefulness of the course. For example, one student emailed the WEP office with the following comment: *I just wanted to tell you that seminar was amazing. You showed each and every step slowly so that everyone was catching up without a problem. It'll really help us all in the future. Thanks!*

On-Going Plans and Challenges
Based on the positive outcomes and student feedback from the pilot workshop, the team plans to expand the workshop series in order to reach more students, provide more in-depth training and skills development, and create a richer learning experience for students. In the spring semester of 2011, the workshop series will be expanded into a semester long General Engineering (GE) course entitled, "Spatial Visualization." The course will be offered on a pass/fail basis to 25 underrepresented students who are at risk of dropping out of the engineering school. At-risk students will be identified as those with low GPAs (2.0 or lower), who also earn low scores on the PSVT:R. The ENGAGE team will partner with the Cockrell School Student Affairs Office and the UT Austin's Equal Opportunity in Engineering Office (EOE) to identify and pre-test those students. The GE course will meet weekly for the entire semester. Students will be introduced to all of the modules in the text *Introduction to Spatial Visualization: An Active Approach*, along with several enrichment activities, such as a visit to the University's visualization lab, to stimulate the students' motivation and interest in engineering. Students who participate in the GE course (and the WEP FIGs) will be tracked over the next few years. Assessment of the programs will include GPA analysis, comparison to various cohorts of students (eg. in the workshops, not in the workshops, with low skills, with high skills), retention in engineering and other variables.

Additional future plans include incorporating PSVT:R testing into summer orientation to assess the spatial visualization skills of all incoming first year engineering students. Those with low spatial visualization skills will be invited (or required) to take the GE "Spatial Visualization " course that is currently being developed. This large-scale implementation takes time and resources to integrate into the university system and was not feasible for the first year of the project. However, the data already collected from the WEP FIGs and GE course, along with data documenting the success of the programs as they continue, will help drive the expanded implementation in subsequent years.

B. The Ohio State University

Introduction
The First-Year Engineering Program, as part of the Engineering Education Innovation Center at The Ohio State University, made plans in Spring 2010 to begin offering a course to develop

spatial visualization skills for incoming freshmen (ENG 180) scoring at or below 20 out of 30 questions on the Purdue Spatial Visualization Test – Rotations (PSVT:R). The course offered was a voluntary one-credit course. Based on preliminary work, The Ohio State University plans to continue, improve upon and expand this effort.

Background and Planning

The standard track of the First-Year Engineering Program offers a Fundamentals of Engineering course series (ENG 181 and 183), required of beginning engineering students. This course stresses hands-on laboratories, team-building, project management, graphical communications, computer-aided design, technical oral and written communications, design-build cornerstone projects, and problem solving and programming using MATLAB. Graphical communications including computer-aided design are stressed throughout the first course in the series (ENG 181) and through approximately half of the second course in the series (ENG 183). In addition, a version of this series featuring three courses more segregated by topic (ENG 185, 186, 187) is offered for transfer students, with ENG 186 focusing on graphical communications. The PSVT:R is already administered to all ENG 181 and ENG 186 students as an online pre-test and post test through "Carmen", the University's learning management system by Desire2Learn. It is automatically graded and posted to students' Carmen grade records online. In addition, Ohio State is currently on a quarter system, but is converting to a semester system by Summer 2012. Currently, ENG 181 is offered during Autumn and Winter Quarters, while ENG 183 is offered during Winter and Spring Quarters.

Due to the unique circumstances described above, a multiphase approach was initiated:

(1) A pilot version of ENG 180 was offered in the summer to students concurrently taking a graphical communications course for transfers (ENG 186). The ENG 186 PSVT:R pre-test and post test were used for screening and to assess gains.

(2) A more widely-offered version of ENG 180 was available in Autumn 2010 to incoming freshmen scheduled to take the first standard Fundamentals of Engineering course (ENG 181) in Winter 2011 to avoid concurrence and confounding during assessment between developmental and standard visualization course exposure. The ENG 181 PSVT:R pre-test taken in the Winter of 2011 was therefore used as an Autumn 2010 ENG 180 post test to gauge gains for students already taking a separate PSVT:R screening test for ENG 180 in order to avoid repetitive testing and to minimize learning of the test.

Procedures and Course Structure

The pre-test PSVT:R scores of ENG 186 students collected via Carmen were screened in Summer 2010. Students who scored at or below 20 of 30 questions were encouraged to enroll in ENG 180 concurrently to hone their spatial visualization skills.

For the Autumn 2010 offering of ENG 180, students were contacted in the summer via emails and postcards explaining the importance of spatial visualization skills to engineers, along with links and login instructions for an online version of the PSVT:R hosted by Dr. P.K. Imbrie at Purdue University. Students with threshold scores described above were contacted via email and encouraged to sign up for ENG 180 in Autumn 2010. Academic advisors were involved in the process and helped to encourage students to add the class to their existing schedules generated earlier in the summer during orientation.

The new ENG 180 spatial visualization development course was largely based on the lesson plans outlined by the workbook and software in *Introduction to 3D Spatial Visualization: An Active Approach.*[18] Students were also given a set of plastic, interlocking building blocks purchased online from EAIEducation.com as a tactile aid. These blocks, "Linking Cubes Plus", are unique in that unlike other similar products, cubes, isosceles right triangles, and quadrants are available for purchase and allow for more detailed depiction of objects in three dimensions. Additional support was provided through the depiction and rotation of objects in Autodesk Inventor, as well as through sketches on orthographic paper, isometric paper, and the classroom whiteboard. Summer sessions met twice per week for five weeks. Autumn sessions met once per week for ten weeks. Interactions with both the 11 students in the pilot offering and the 24 students in the Autumn offering were generally informal, typically beginning with a 10 minute introduction using the slides Dr. Sheryl Sorby made available on www.EngageEngineering.org. After working on up to two examples as a class, students were free to work with the software and the workbooks at their own pace with assistance from the instructor and graduate and undergraduate teaching associates.

Preliminary Test Results

Typically, students take the standard ENG 181 during each Autumn. However, only students expected to enroll in the standard ENG 181 course in Winter 2011 were solicited to take the PSVT:R for spatial skills screening, to avoid the concurrence of taking both ENG 180 and ENG 181 in the Autumn of 2010. This resulted in 328 students identified to take the PSVT:R in Summer 2010 for the Autumn 2010 offering of ENG 180. One-hundred fifty-five (155) of the 328 students took the test with a mean score of 21.5. Based on the threshold of scoring at or below 20 of 30 possible questions, 58 students were recommended to enroll in ENG 180 in Autumn 2010, and 24 students enrolled.

Summer ENG 180 pilot results involving 11 students concurrently enrolled in ENG 186, a graphical communications course for transfer students, are shown below. Complete Autumn ENG 180 results involving the 24 students who planned to take the Winter 2011 ENG 181, the standard fundamentals course which includes graphical communications topics, are not available as of this writing as students are currently enrolled in the course. However, initial screening results and enrollment rates for ENG 180 in Autumn 2010 are below.

Summer 2010 ENG 186 (includes ENG 180 students):		Summer 2010 ENG 180:	
(n= 66 students)		(n=11 students)	
PSVT:R Pre-test Mean:	23.3	PSVT:R Pre-test Mean:	14.1
PSVT:R Post test Mean:	24.8	PSVT:R Post test Mean:	20.3
PSVT:R Gain Mean*:	2.6	PSVT:R Gain Mean*:	6.8
Summer 2010 Screening for Autumn 2010 ENG 180:		Autumn 2010 ENG 180:	
(n=155 students)		(n=24 students)	
PSVT:R Pre-test Mean:	21.5	PSVT:R Pre-test Mean:	17.1

*(of those students who took the post test)

Students' comments from surveys and conversations about the course were unanimously positive. Students did request that the course not be offered concurrently, but rather as a preparatory course for standard graphical communications instruction. Complete results will be available once data processing and analysis is completed during Spring 2011.

On-Going Plans and Challenges

A full-scale offering of ENG 180 will be available to all eligible incoming freshmen engineering students as it becomes possible to screen students via the PSVT:R prior to orientation and advisor-assisted scheduling. This will allow students in need of spatial visualization skills assistance to intentionally delay scheduling their first Fundamentals of Engineering (ENG 181) course until Winter 2012. An additional positive aspect of this process is that students will have the opportunity to enroll in the standard graphical communications courses, benefitting from the experience of ENG 180 in the preceding Autumn of 2011.

In the future, ENG 180 will occur in Autumn 2011 and the first semester of 2012. Efforts are currently underway to standardize a local server-based PSVT:R screening test for incoming freshmen to take remotely prior to orientation, paralleling a similar process already in place for math placement. This will allow for a listing of test scores on advising reports so that incoming students can schedule ENG 180 during face-to-face meetings with academic advisors during orientation when they normally complete scheduling for their first term on campus. It is anticipated that this coordinated and more personal process will increase the number of students participating in the screening, increase the number of students recommended to enroll in ENG 180, and increase enrollment rates in the course.

Finally, the University plans to convert to a semester format in 2012. Consequently, the semester version of the Fundamentals of Engineering series is planned to feature graphical communications only in the second semester, allowing students needing to further develop their spatial visualization skills to take the semester version of ENG 180 in the first semester and hone their spatial skills without falling behind their peers.

C. University of South Carolina

Introduction

In these challenging economic times, mandating a new required course, or finding and allocating new or additional resources, even for a well documented, evidence based program, will generate resistance and have to overcome strong competition from other worthwhile projects. The University of South Carolina team realized, therefore, that dissemination and implementation of existing, research based tools, and potentially the development of new tools, would require a grassroots movement in our College. We needed to look at the skills of our own freshmen, try out the available tools for ourselves, and brainstorm activities that were feasible and within our immediate control; in other words, paint a local picture and tell our own story.

Our initial plan focused first on providing local evidence of our need to improve visualization skills. Much of our success thus far in this aspect of the project is due to the cooperation of our Assistant Dean of Academic Affairs for the College. With his help and support we become part of the orientation program for incoming freshmen and transfer students and we were able to test a college wide, multi-disciplinary sample. We administered a spatial visualization test to students in the summer of 2010 and plan to give the test again in the summer of 2011. This venue also gave us the opportunity to present the case for improving visualization skills to both students and their parents.

Pre-testing and Course Structure

During Summer 2010 freshman orientation, incoming students (both freshman and transfer) to the College of Engineering and Computing took the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R). The test is 30 questions about rotation of 3D objects, with a time limit of 20 minutes. A total of 406 students took the exam. The PSVT:R tests were graded and the results were given to the students during the orientation session. The incoming students were given the option to indicate interest in taking a no-credit Advanced Spatial Visualization (ASV) seminar to be offered during the fall 2010 semester. All students needing improvement (67) expressed an interest in taking the course.

Three weekly class times were set up for the Fall 2010 semester. Class format was ten minutes of lecture, in combination with software animation of concepts being discussed. Students then worked independently on visualization exercises on the computer or on next week's homework, and given feedback on their performance on last week's homework. There were no exams or testing, other than a second PSVT:R test.

The class used the workbook and software, *Introduction to 3D Spatial Visualization: An Active Approach*.[18] Students were assigned homework each week from the workbook. Exercises were of two formats: multiple-choice selection of a manipulated 3D object, or sketching a 3D object post-manipulation. Topics covered over the nine weeks were: isometric drawings and coded plans, orthographic drawings, flat patterns, rotation of objects about one or multiple axes, object reflections and symmetry, cutting planes and cross sections, surfaces and solids of revolution, and combining solids.

Test Results

As mentioned above, 406 students took the PSVT:R during orientation. Of these, 339 students got a score of 60% or higher, considered acceptable; and 67 students (or 16.5%) got a score below 60% (See Table 2). Gender breakdown indicates that women were, on average, somewhat less proficient at the rotation visualization. 14.6% of men needed improvement, compared to 28.1% of women. The average score of women (66.5%) was lower than of men (76.3%). Thirty-one (31) of the 406 students who were transfer students, not freshmen, scored lower than average (See Table 3).

Table 2: Total students who took PSVT:R in Summer 2010, and scores by gender

	Men	Women
Total	349	57
Score ≥ 60%	298	41
Score < 60%	51 (14.6%)	16 (28.1%)

Table 3: Average PSVT:R score from Summer 2010

	Average Score (All Students)	Average Score (Transfer Students)
Overall	74.9%	68.5%
Men	76.3%	70.1%
Women	66.5%	57.5%

All 67 students needing improvement were invited to participate in the ASV seminar. Although all students had indicated interest over the summer, only 17 students signed up for the class in Fall 2010. Ten students attended the first class. Four attended more than one of the sessions. Two students completed the course by consistently turning in homework, and also re-taking the PVST:R at the end of the course.

While not many students participated in the seminars, those who did showed a very significant improvement in performance. On the first PSVT:R, the scores were 53.3% and 50.0%. Scores after completing the ASV seminars were 83.3% for both students. In addition, each showed marked improvement in their Isometric sketching accuracy and ability.

On-Going Plans and Challenges

The curriculum used in the ASV seminar concentrated on skills which are frequently used in CAD (e.g., isometric views, rotation, reflection, Boolean operations). A sample of civil and mechanical engineering freshmen who took a CAD course in Fall 2010 will re-take the PVST:R in Spring 2011 to see if there has been any improvement in performance. If so, the CAD classes may be an excellent place to integrate spatial visualization instruction into the existing content. Incoming freshmen for the 2011-12 school year will be given the same PVST:R during Summer orientation to gather additional data about student skill level.

The most significant challenge faced in the USC implementation was low student participation in the ASV seminars. Among students who did, only two consistently attended class and completed homework assignments. While the post-testing scores showed significant improvement, it is difficult to make solid conclusions from only two data points. Also, a large-scale attempt to improve spatial visualization ability among students cannot be accomplished through voluntary participation.

D. University of Maryland

Introduction

The University of Maryland at College Park initiated a new and innovative education program – the Keystone Program in 2006. The Keystone program focuses on the first year and second year education to ensure that undergraduate students have an enriched, interactive and dynamic learning experience and to encourage the faculty to develop new and innovative teaching initiatives to forge a creative learning environment within the school of engineering. Integrating ENGAGE strategies within the Keystone program provided a sound rationale for moving forward.

Approach
The University of Maryland team decided to focus the first year effort on spatial visualization through the development of a new one-credit course. The target group was freshmen students, especially those students with low ability in spatial visualization skills. The following plan was implemented to accomplish our objective:

- Between March and April, we worked with a group of senior undergraduate students to study the 30 questions on the PSVT:R. Based on this review, we decided to create 12 questions for the on-line spatial visualization test used on our campus.* A freshman student is required to complete the questions within 10 minutes.
- The Admission Office sent a letter to each incoming student indicating that they would be taking the spatial visualization test during freshmen orientation.
- The Dean's Office sent letters to those students identified with low ability (below a score of 60) and encouraged them to register for ENES299A Spatial Visualization for Engineering Problem Solving. The course met on Mondays and Fridays from 4:00 – 5:40 from August 30, 2010 – November 5, 2010.

Course Structure
The spatial skills course included the following three components: 1) students worked with the plastic and colored cubes to construct objects, and viewed those objects through different orientations; 2) students learned 2 CAD programs, ProE and SolidWorks; and 3) a set of lab instructions and lecture notes were developed and distributed in class. Students completed two lab reports, six homework assignments, took a mid-term exam and final exam on the last day of the 10 week class. The classroom was a computer equipped room with excellent teaching facilities.

Test Results
A total of 636 first year students took the spatial skills assessment test in July and August, 2010. Unfortunately, the entries did not record gender so we cannot compare test results among males and females. It is estimated that 138 women took the test because women made up 21.75% of the freshmen class.

By setting a threshold score of 60 points, the number of students identified with low ability was about 100 among the 636 students taken the test. Of the 100 students encouraged to take the course, 11 students (2 male and 9 female) registered for ENES299A. Five (5) students dropped the class after the first week, leaving 6 students (5 female and 1 male) remaining.

To test student spatial skills ability after the course, questions 1-10 from the PSVT:R were used as the first test, and questions 11-20 of the PSVT:R were used as the second test. Each student

*University of Maryland created their own pre-test based on the PSVT:R because they wanted an on-line test to give to their 636 students. P.K Imbrie, Purdue University offered ENGAGE schools the option of utilizing an online PSVT:R test that he and his team have been developing. Several schools took advantage of this unexpected but much appreciated opportunity since it provided flexibility in scheduling, relieved the burden of grading, and archives the results to be able to look at trends. This option was not available when University of Maryland administered the test to their students.

had 20 minutes to complete the 10 questions. The final test included all 30 questions from the PVST:R (See Table 4 for test results).

Table 4. Post-Test Results for Students Taking Spatial Skills Course ENES299A

	Test 1, 09/24/2010 10 Questions Taken from PVST:R	Test 2, 10/11/2010 10 Questions Taken from PVST:R	Test 3, 10/29/2010 30 Questions Taken from PVST:R
Student 1	8 correct, 2 incorrect	9 correct, 1 incorrect	25 correct, 5 incorrect
Student 2	7 correct, 3 incorrect	8 correct, 2 incorrect	26 correct, 4 incorrect
Student 3	8 correct, 2 incorrect	7 correct, 3 incorrect	29 correct, 1 incorrect
Student 4	8 correct, 2 incorrect	9 correct, 1 incorrect	26 correct, 4 incorrect
Student 5	10 correct	9 correct, 1 incorrect	28 correct, 2 incorrect
Student 6	10 correct	10 correct	30 correct
Average	0.85	0.87	0.93

In addition to students improving their spatial skills from 60% or below to an average of 93%, the general response from the 6 participating students was overwhelmingly positive. The University of Maryland has a unified evaluation system and several items on the evaluation speak to the success of the course:

- I learned a lot from this course: 100% strongly agree
- My ability to apply knowledge of engineering principles has improved as a result of taking this class (5 responses): 60% agree 40% strongly agree
- My ability to use computers to solve engineering problems has improved as a result of taking this class: 17% agree 83% strongly agree
- My ability to use the techniques, skills, and modern engineering tools has improved as a result of taking this class: 17% neutral 17% agree 67% strongly agree

One student wrote in summarizing her learning experience:

I have learned a lot from this spatial visualization course. It has had the greatest impact overall on my confidence. When I was just starting this course, I did not have much confidence in my ability to manipulate objects mentally, but I am now much more confident in my ability to do so. I have improved by using the building blocks to build objects and then rotate them physically, but have largely improved from practicing building objects on the software Pro-Engineer. I can now look at different objects in orthogonal views and I know how to construct them on the computer software.

On-Going Plans and Challenges

The primary challenge faced in the implementation of the spatial skills course was low student participation. The University of Maryland team plans to work on approaches to require the course or find more innovative ways to encourage students to participate since the results, albeit few data points, indicate that the effort should continue and expand.

The on-going and future activities associated with implementing the course are: 1) organize the teaching/learning documents developed in the fall semester; 2) work on creating the second version of the spatial visualization test, which will consist of 10 questions, 3) prepare the teaching /learning materials for Spring 2011 when ENES299A will be offered to freshmen and sophomore students who could benefit from the course as well; 4) collect test information by gender; and 5) identify strategies to increase the number of students who participate in the course.

E. University of Louisville

Introduction

The University of Louisville team, after attending the ENGAGE Strategy Implementation Workshop in February 2010, began implementation of a spatial visualization course in the Fall 2010 semester. In the planning meeting preceding the course development with the ENGAGE team, engineering school dean and associate dean, it was decided the course would have to be offered as a non-credit, volunteer-only course because of curriculum and accreditation constraints.

Approach

The spatial visualization course was announced and described to incoming freshmen in three ways: 1) a brief verbal announcement of the course offering was included in the summer orientation program given by the advising staff; 2) an email was sent to each freshman during the first week of classes including a link to an online PSVT:R; and 3) the course instructor spoke to all students in four *Introduction to Engineering* course sections during the second week of classes. The information provided to students included four basic points: 1) the ease and convenience of taking the online PSVT:R test; 2) the importance of spatial visualization skills in engineering; 3) the research indicating that attendance in the spatial visualization course could improve performance in several courses as well as improve GPA; and 4) that course materials would be provided at no charge. The course was titled *Spatial Visualization Study* because of the volunteer-only, non-credit status.

The University of Louisville was one of the first ENGAGE schools to use the online PSVT:R offered by Dr. P.K. Imbrie at Purdue University. Although all 360 freshmen were aware of the PSVT:R and Spatial Visualization course offering, only 55 students completed the online PSVT:R. Students received their test scores by email and based on performance, received one of three messages: 1) those scoring 3 or more points below the mean were *highly recommended* to attend the Spatial Visualization course; 2) those who scored within 2 points below the mean score were *recommended* to attend; and 3) those scoring more than 2 points above the mean were invited to attend.

Course Structure

The engineering graphics course, ENGR 150, is required for all freshmen and can be scheduled for fall, spring, or summer semesters. Therefore, students who attended the Spatial Visualization course included two groups: those who were currently taking engineering graphics (approximately 30%), and those who would take engineering graphics in a subsequent semester (approximately 70%). The spatial visualization class met on Friday afternoons from 1:00 until 2:15 beginning the third week of fall semester. Ten students attended the first class and 15 students attended the second class. Each student was given a copy of the text, *Introduction to 3D Spatial Visualization: An Active Approach*.[18]

Each class began with a 15-20 minute instructor-led demonstration utilizing the interactive CD provided with text, followed by students working individually on exercises in the workbooks. The instructor and one student teaching assistant were available to assist students as needed. Student exercises were not graded. Instead, students checked their own work after completing the exercises, utilizing the answer key posted in the back of the classroom. Although most of the students were able to complete the assigned pages during each class, some students had to complete the exercises as homework. The nine modules included in the workbook were completed in 12 classes.

The *Introduction to 3D Spatial Visualization* workbook and CD provides an excellent strategy for improving spatial visualization skills. The interactive CD makes presenting the material fun and easy. The workbook exercises are well structured with some simple and some very challenging modules interwoven. One very interesting feature is that students can use left-brain, deductive logic to solve the exercises as a process to develop their own spatial visualization skills—normally, a primarily right-brain capability. This feature provides an excellent means for poor visualizers to build their spatial visualization abilities.

Test Results and Outcomes

A total of 15 students participated at varying levels in the course, but only seven students completed the course. Most of those students concurrently taking engineering graphics dropped the Spatial Visualization course after the engineering graphics mid-term exam since the first half of engineering graphics emphasizes visualization. Despite the small number of students who attended, the Spatial Visualization course was a success in many ways.

The post-test scores indicate that the students benefited from the course. The online PSVT:R was offered at the end of the semester for all students who had taken the pre-test. Of the students who took the post-test, the score was 4.5 points (average) higher on the post-test for those who attended the Spatial Visualization course only. Interestingly, for pre-test students who took the engineering graphics course only, their post-test improvement was the same as for those attending only the Spatial Visualization course—4.5 points average higher. Details of the pre and post testing are presented below:

- 55 freshmen students took the PSVT:R pre test. The mean score was 21.88 of 30, or 72.9%. In order to preserve student anonymity, student names and gender information was not collected, only email addresses.
- 8 students took the PSVT:R post test. The mean score was 27.25, or 90.8%.

ENGR 150 Group

Six students completed the engineering graphics course, ENGR 150, but not the Spatial Visualization class. Pre test and post test scores for this group were as follows:

- Pre test mean score: 23 (76.6%)
- Post test mean score: 27.5 (91.7%)
- Increase: 4.5 (15.1%)

Spatial Visualization Class

- Two students of the 7 who completed the Spatial Visualization class also took the PSVT:R post test. Pre test and post test scores for the group were as follows:
- Pre test mean score: 22 (73.3%)
- Post test mean score: 26.5 (88.3%)
- Increase: 4.5 (15%)

The Spatial Visualization course was very well received by the attending students. An email was sent to the students after the course inviting them to comment on the course. Below are some of those responses.

I definitely believe that the Friday sessions improved my spatial visualization skills—I got a 22/30 on the PSVT before attending the sessions and a 29/30 after the sessions ended. I enjoyed doing most of the exercises. Some were easy and some were difficult. The easy ones ensured your understanding and the more difficult ones challenged you to apply the concepts that you just learned. It was very nice that the CD and the workbook were free, but they definitely would have been worth paying for if they had cost money. For this class being on a Friday, I think it's saying something that it was the class I most looked forward to going to.

I feel the course should be directed to students who do below a certain level on the initial spatial exam. Below that level, I believe students should be strongly encouraged to take the course in order to enhance their skills before moving on to a freshman level graphics course.

The Spatial Visualization class helped so much. I was never introduced to spatial visualization exercises before and as an aspiring engineer knew that I had to be familiar with this material. Most of the exercises were not difficult, but some truly required critical thinking. Most exercises were thought provoking and helped my visualization tenfold. I loved this class and it truly was my highlight of my Friday classes. I truly encourage anyone to take this class and believe in its benefits.

I feel the class is a great starting ground for students. I believe that class is a great asset to the Speed School Curriculum and would most benefit students before they take a graphics class, especially one incorporating programs such as Autocad and Solidworks.

On-Going Plans and Challenges

Although the fall 2010 Spatial Visualization course was successful and the class will be offered in Spring 2011, several things can and need to be improved:

- It is important to increase the number of students attending to about 30 (approximately 10% of the freshman class). University of Louisville plans to focus on students who can attend before taking engineering graphics. With the positive student response and the supporting test data, the goal is to make this course required for the lowest 20% scorers for fall 2012.
- University of Louisville plans to offer the online PSVT:R pre-test for freshman during Summer orientation. In this way, students with lower levels of spatial visualization skills will have a chance to schedule the Spatial Visualization course for fall and the engineering graphics course in spring or summer.

- Attendance was particularly low on the Fridays preceding a holiday or break. Although students did not report Friday afternoon as a problem, the course should be scheduled earlier or on another day.
- The workbook and CD will not be distributed to students until after the second class and only copies of the exercises will be used before then. Since this course is voluntary, several students attended the first class, acquired the text and then did not return to class, presumably or hopefully completing the exercises on their own. If the course becomes a requirement, students will be required to purchase the book.

IV. Resources for Engineering Schools Interested in Improving Students' Spatial Skills

In addition to the considerable body of research recognizing the need for well-developed spatial skills for students studying engineering, ENGAGE developed a number of resources to support engineering schools interested in developing a program to assess and improve students' spatial skills. These resources are described briefly below and are available at no cost at www.EngageEngineering.org.

- Spatial Visualization Skills Research Brief: The paper highlights compelling data that provides justification to support a spatial skills development program. There are several other papers on the ENGAGE website that offer full studies and more thorough documentation of the data relating to spatial skills and academic success.
- *Spatial Visualization Skills Can Be Developed Through* Practice: This handout was developed for parents and students to understand the factors that contribute to a lower level of skill in spatial visualization and why the course is beneficial. The information addresses a lack of experience rather than a lack of ability.
- Lecture Notes for Spatial Skills Course Modules: Since many of the ENGAGE Schools used the text, *Introduction to 3D Spatial Visualization: An Active Approach*[18], the authors provided power point presentations developed to introduce each of the 9 modules of the curriculum that professors could adapt for their own use.
- Spatial Skills Webinar and PPT: The recording of the webinar that Sheryl Sorby delivered on January 27th, 2011 is available along with the power point presentation.

V. Lessons Learned and Next Steps

ENGAGE schools were successful in their effort to begin implementing a spatial skills assessment plan and training course. Faculty and staff who championed the initiative are enthusiastic about the potential outcomes and put in the effort necessary to launch the initiative. Given the positive preliminary data and students' responses, schools are planning to improve and expand their plan. An aspect that needs to be improved in the data collection process is that all schools will disaggregate the test and analysis data by gender, and ultimately race and ethnicity when the number of students increases.

One challenge that emerges for schools who are unable to require students with low ability in spatial skills to participate in a training course is the extremely low participation rate in voluntary courses. There is little doubt that requiring students to take a spatial skills course is the most successful method and schools are working to gather sufficient compelling data at the local level to make their case.

However, since this desirable option may not be possible for some schools in the immediate future, University of Texas at Austin's and The Ohio State University's experiences provide reason for optimism. In the case of UT, the use of incentives and a personalized approach was very effective in persuading students to attend a voluntary course, though their target group for this pilot effort was confined to first year women. It will be interesting to see if these creative strategies will be as effective with the larger and broader student body. OSU did not use incentives, but the instructor and advisors took a proactive role in encouraging students to enroll. This experience may suggest that persuading students to enroll in a spatial course may be more successful if students are persuaded by different people such as the department head, instructor, director of a minority or women in engineering program, coach or parent.

Finally, an opportunity that may remove some of the obstacles involved in implementing a required course may be close at hand. Plans are progressing for the workbook and CD that most schools are using, *Introduction to 3D Spatial Visualization,* to be available on-line. If students have access to the curriculum and the PSVT:R test on-line, this may provide schools with the scheduling flexibility and cost structure to facilitate the implementation of a required course or with the option of requiring all incoming freshmen to participate in testing and coursework prior to the start of school in the fall. ENGAGE is cautiously optimistic that this option will be ready for Fall 2011. In the meantime, lessons learned will be identified among all ENGAGE schools and posted on www.EngageEngineering.org as they become available.

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