Enhancing Visualization Skills-Improving Options aNd Success (EnViSIONS) of Engineering and Technology Students

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Abstract

Spatial visualization skills are vital to many careers and in particular to STEM fields. Materials have been developed at Michigan Technological University and Penn State Erie, The Behrend College to assess and develop spatial skills. The EnViSIONS (Enhancing Visualization Skills-Improving Options aNd Success) project is combining these materials and testing them with pre-college and college students at seven institutions: Michigan Tech, Penn State Behrend, Purdue University, University of Iowa, Virginia State University, Virginia Tech, and a "Project Lead the Way" course in south-central Arizona. By removing a barrier to success for students with low visualization skills, particularly women, the project leaders hope to improve the retention of these students in STEM disciplines and to enhance their success. This paper will give a brief overview of the implementations at the university level and the findings.

Introduction

Spatial skills have been shown to be important in a wide variety of careers. Nowhere is this more apparent than in engineering programs where graphics classes dealing with the representation of three dimensional objects are most often encountered in the very first semester, when students are also faced with the transition to college life. Along with motivation and adjustment issues, poor spatial skills often leave some students struggling with these first-year courses and can contribute to low grades and poor retention. Unfortunately, although verbal skills are a major focus of the entire K-12 curriculum, spatial skills (arguably the other half of the human cognitive apparatus) are not standard components of the K-12 curriculum. Therefore, it is understandable that the average first-year student has little knowledge of the component spatial skills and even less understanding that these skills can and should be improved.

One major problem impacting the attempts of engineering programs to improve diversity is that women and some minorities have been shown to perform more poorly on some of the component spatial skills. For example, one of the most robust sex differences in cognitive abilities is the degree to which men outperform women on mental rotation tasks. On other spatial skills women are at a par with men, or even perform more strongly (e.g. spatial memory), but this is not widely known, so women also have to contend with the stereotype that men are better at these tasks. To overcome this stereotype and the discrepancy in spatial skills, Michigan Technological University and Penn State Erie, The Behrend College, developed materials focused on improving the spatial skills of the most vulnerable of populations: engineering students taking their first-year graphics course.

Early studies at Michigan Tech (Sorby, 2009) found that approximately 20% of the freshman engineering students score below 60% on the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Guay, 1977). Although women comprise about 20% of the students taking the test, they account for about 40% of those who fail the test. Since 1993, Michigan Tech has offered a spatial visualization course to engineering students who score below 60% on the PSVT:R. Students choosing to take the supplemental spatial visualization course have been found to have higher retention rates (particularly women) and grades and found it easier to learn 3-D solid modeling software than students not taking the course (Sorby, 2009).

Holliday-Darr and Blasko at Penn State Behrend found that low grades and retention were related to scores on tests of basic spatial abilities such as mental rotation (Blasko, Holliday-Darr, Mace, and Blasko-Drabik, 2004). They created the VIZ website (http://viz.bd.psu.edu/viz/) as a free and open portal for training, information, and dissemination of research involving mental imagery and spatial skills.

To build on the success of the Michigan Tech spatial visualization course and the VIZ website, seven universities across the United States have joined together through the EnViSIONS (Enhancing Visualization Skills--Improving Options aNd Success) project. The goal of the project is to demonstrate that the successful programs developed at Michigan Tech and Penn State Behrend to improve spatial visualization skills can be successfully integrated and transferred to other universities. The effectiveness of implementations targeting high school students are summarized in Blasko, Holliday-Darr and Kremer (2009) and Duff and Kellis (2009).

Partner Universities

The universities joining together to remove a barrier to success for university students with low visualization skills are Michigan Tech, Penn State Behrend, Purdue University, the University of Iowa, Virginia State University, and Virginia Tech. These universities form a diverse setting in which to test the Michigan Tech and Penn State Behrend materials and are further described below.

Michigan Tech is a public university located in Houghton, Michigan. Michigan Tech enrolls approximately 7000 students: 1000 graduate and 6000 undergraduate. Michigan Tech is home to five schools and colleges. The College of Engineering houses eight departments which offer a total of 12 different undergraduate degrees. During the Fall 2008 semester, 3300 undergraduate students were enrolled in the College of Engineering.

Penn State Behrend is one of twenty campuses offering undergraduate degrees at Pennsylvania State University. Penn State Behrend has an enrollment of 4400 students of which 4031 are full time undergraduates. Approximately 1100 of these students are enrolled in an engineering program. Penn State Behrend offers seven baccalaureate and three associate degree programs in engineering and engineering technology.

Purdue University is a mid-western land-grant institution located in West Lafayette, Indiana. The university had a total of 31,186 registered students on the West Lafayette campus during the Fall Semester of 2007 (Purdue University, 2007). Among those, 63 students were enrolled as Engineering and Technology Teacher Education (ETTE) majors.

The University of Iowa offers more than 100 areas of study and seven professional degrees housed in eleven colleges. Early fall enrollment figures for 2008-09 show a record total enrollment of 30,561 students: 20,824 undergraduate students, 5,254 graduate students, and 4,149 professional students. The College of Engineering is home to six departments and has a total enrollment of 1,640; comprised of 1,300 undergraduates, 123 master's students, and 212 doctoral candidates. Women make up 20% of the undergraduate student body (University of Iowa Quick Facts 2008).

Virginia State University is a historically black university (HBCU) located in Petersburg, Virginia. The total enrollment at the university is approximately 5,000 students with 94% self identifying as black. The Department of Engineering and Technology has two engineering and three engineering technology majors with a total enrollment that has remained steady at around 250 students during the period of this study (Virginia State University, 2008).

Virginia Tech is a large land grant public university located in southwest Virginia. The university offers undergraduate and graduate degrees in eight colleges. Total undergraduate enrollment is 23,000. Virginia Tech is a residential campus with almost all freshman students living on campus, and most upper-class students living within a five-mile radius. Approximately 25-30% of the undergraduate population is non-white. The College of Engineering at Virginia Tech is home to thirteen departments with a total undergraduate enrollment of approximately 5,800 (VT Factbook, 2008).

The EnViSIONS project participants met in the summer of 2007 to become familiar with the Michigan Tech course materials and the VIZ website and formulate a common assessment plan.

Each university began a unique implementation of the spatial visualization course in the 2007-2008 academic year. These implementations are described in Section IV.

Course Materials

Project participants were given the following course materials used at Michigan Tech: a spatial visualization workbook, software and teacher's resource guide, quizzes and lecture materials (power point slides and snap blocks).

Spatial Visualization Workbook. Since the Fall of 2000, the Michigan Tech spatial visualization course has been structured around the Introduction to 3D Spatial Visualization: An Active Approach workbook and software by Sorby and Wysocki (2003). An ordered list of module topics covered in the workbook is as follows:

1. Isometric Sketching
2. Orthographic Projection: Normal Surfaces
3. Flat Patterns
4. Rotation of Objects about a Single Axis
5. Rotation of Objects about Two or More Axes
6. Object Reflections and Symmetry
7. Cutting Planes and Cross Sections
8. Surfaces and Solids of Revolution
9. Combining Solids

In addition to the workbook, a supplemental module developed by Michigan Tech on the Orthographic Projection of Inclined and Curved Surfaces was distributed to all project participants. All participants used the workbook, in part or in whole and most universities also used the software.

VIZ Website. The Visualization Assessment and Training project (VIZ) was developed at Penn State Behrend beginning in 1999 to provide a web-based portal for assessment, training, and research on spatial performance (Blasko et al., 2004). Based on a large meta-analysis of existing research on spatial cognition (Voyer, Voyer, and Bryden, 1995), the VIZ site focused on three separable dimensions of spatial skills: 1) mental rotation (rotating blocks), 2) spatial visualization (paper folding) and 3) spatial perception (water-level task). A spatial working memory task (rotating letters) was added to the site later because working memory has been shown to be a critical part of spatial performance (Shah and Miyake, 1996).

The VIZ modules use animations and movies to illustrate key concepts. The site collects reaction time and accuracy data for each problem which is presented to the user for feedback at the end of each test. All but one of the EnViSIONS implementations used the VIZ site as homework, assessment, extra practice, or extra credit.

Lecture Materials. The Michigan Tech course typically begins with a 10 – 15 minute PowerPoint presentation and in-class activity which introduce the topic for the day. Michigan Tech also provides their students with 15 snap blocks which they can use to build 3-D structures. These blocks prove to be most useful when students create isometric sketches of coded plans and sketch object rotations. They are also somewhat useful when sketching object reflections. Some of the universities used the lecture materials, while some universities used the workbook software (Sorby and Wysocky, 2003) instead of the lecture materials. All but one of the universities used the snap blocks and several developed additional manipulatives. The various modes of implementation of visualization content at partner institutions are described in the next section.

Implementations of Spatial Curricula

Due to the diverse nature of the universities involved in the project, each university developed a unique plan to incorporate the Michigan Tech course and VIZ website into their curriculum beginning in the Fall of 2007.

Michigan Tech incorporated the VIZ website developed by Penn State Behrend into their existing course. Students were given the opportunity to earn extra credit points on quizzes by completing the tasks on the VIZ website. Michigan Tech also examined the impact of teaching the modules in an order that was different than the workbook (Hamlin, Veurink, and Sorby, 2008).

Penn State Behrend At the beginning of Fall 2007, a spatial assessment of all mechanical and plastics engineering technology students enrolled in Introduction to Graphics and Solid Modeling (EG T 120) was conducted using the VIZ website in conjunction with the PSVT:R. Students performing below the 60th percentile on the PSVT:R were invited to enroll in a supplemental class designed to improve their spatial skills.

EG T 120 is a three-credit first-year required course for all mechanical engineering technology and plastics engineering technology students. Historically, a large number of students have failed to complete this course successfully. Research beginning in 1996 demonstrated that high spatial skills predicted positive performance in this class and to a lesser extent predicted semester GPA. At that point, the faculty teaching the course began working to develop problems and hands-on activities (such as clay modeling) that specifically targeted the component spatial skills. By 1999, the mental rotation task was up and running on the VIZ website and this allowed testing of all incoming students. Now there was a way to assess spatial skills before the class began, and help convince those with lower spatial skills that these skills were both important and trainable.

In 2005, a one-credit supplemental course, Visualization and Spatial Development (EG T 097), was pilot tested in order to try to improve the skills of students with lower spatial skills. Due to scheduling overlap with other classes and the fact that the class was not required, a relatively small number of students completed the course.

In the Fall of 2007, twenty-nine EG T 120 students performed less than 60% on the PSVT:R task and were counseled to enroll in the one credit supplemental course, EG T 097A. Due to the course times conflicting with other required courses, students were allowed to participate in either the first or second hour, as their schedule permitted. Thirteen (3 females, 10 males) enrolled in EG T 097A. Four of the students were able to attend both hours, seven attended the first hour, and two attended the second hour. Participants that successfully completed 80% of the workbook modules received a 2 GB USB flash drive. In the Fall of 2008, 36 EG T 120 students performed below 60% on the PSVT:R, and sixteen of these students enrolled in the supplemental course. This time, students were allowed to enroll only if they could attend both hours of the two-hour session. Two of the students did not complete the course.

EG T 097A was a two hour class divided into two periods. During the first hour, students completed a series of visualization software modules, workbook problems and assessment surveys. The second hour focused on interactive training activities using games designed by previous undergraduate VIZ research teams, such as Shapes and Pizza Delivery (Figure 1), and manipulatives, such as modeling clay and 'glass' boxes.

Figure 1. *Students playing the Pizza Delivery game.*

EG T 097A covered all sections of the Sorby and Wysocky training software and all but one exercise (Combining Solids) in the workbook (Sorby and Wysocky, 2003). The order was designed to compliment EG T 120: cutting planes and cross sections, orthographic drawings, isometric drawing and coded plans, flat patterns, combining solids, surfaces and solids of revolution, object reflections and symmetry, rotation about one and two axes. Use of manipulatives, such as snap cubes, paper and scissors, Play-Doh, 3D axis, was encouraged. Successful students were asked to share their strategies with the group in class discussion.

Over the past three years, the Penn State Behrend VIZ undergraduate research team has focused on creating interactive activities (games) designed to improve spatial skills. For example, the Shapes game focuses on strengthening mental rotation and spatial visualization. Both versions of this game were played after the Isometric module was completed. Time Bomb builds on perspective taking and Pizza Delivery focuses on improving way-finding skills. These games were played after completing the Flat Pattern module. As with the workbook exercises, students who were successful were asked to share their strategies with the group in class discussion (Blasko, Holliday-Darr, and Trich Kremer, 2009)

Purdue University The participants involved in the Fall 2007study at Purdue University were pre-service Engineering and Technology Teacher Education (ETTE) students.

The spatial visualization curriculum was integrated as part of an existing course in the ETTE program. The course, Teaching Communications, included curriculum that covered several different types of communications such as video, audio, electronic, graphic, and technical communications. The spatial visualization curriculum was integrated into the pre-existing graphic and technical communication areas of the course. The EnViSIONS curriculum was implemented through the use of lectures, demonstrations, and hands-on exercises in the Sorby and Wysocky workbook (2003). Self-directed learning through supporting materials such as the VIZ website and the interactive CD from the visualization workbook were given to participants to use as resources during the course of the project; however, participants were not required to use these supplemental materials.

Participants were first educated on the nature of the research project, their right to elect or reject participation, and of their rights as participants in the study. After choosing to participate, participants were given the PSVT:R, a subset of ten questions from the Mental Cutting test (CEEB, 1939), and the modified Lappan test (Lappan, 1981).

Lecture with demonstrations, class discussion, and hands-on activities was used to introduce each of the four modules that were covered in the course. The modules that were introduced were in the area of isometric projection, orthographic projection, flat pattern, and rotational graphics. After being introduced to the curriculum through the lecture, participants were assigned the corresponding workbook exercises to complete during lab time and as homework—the exercises were completed in a self-directed manner. The EnViSIONS materials were covered in one condensed seminar setting that was followed by a laboratory period. The ETTE students took the workbook home and spent additional time out of class to complete all exercises. After completing the modules and module evaluations, participants were then given the same PSVT:R, Mental Cutting, and Lappan tests as a means of post-assessment.

Of the 22 ETTE students enrolled in Teaching Communications Course, 14 chose to participate in the research project. Five (36%) of the participants were freshmen, six (43%) were sophomores, three (21%) were juniors, and no seniors were participants in the study. In addition, all participants were classified as traditional Caucasian-American students ranging from 18 to 24 years of age. Furthermore, 13 of the participants were male and one participant was a female. All participants were concurrently enrolled in an average of three Science, Technology, Engineering, or Mathematics (STEM) courses at the university; however, only three participants (21%) were in a concurrent math course at the time of the study (K.S. Harris, L.V. Harris, and M.A. Sadowski, 2009).

The participants involved in the Fall 2008 study at Purdue University were 69 engineering technology and industrial design students who were participating in the CGT 116 (Geometric Modeling for Visualization & Communication) class. 23 additional students in the class did not participate in all portions of the study and were excluded from the data analysis.

The spatial visualization curriculum was integrated into an existing CGT 116 course offered as a part of the required curriculum for Computer Graphics Technology and Industrial Design majors. The course included the EnViSIONS curriculum that was implemented through the use of PowerPoint presentations and lectures. An experimental group consisting of 15 students were additionally exposed to the VIZ website and hands-on exercises in the Sorby and Wysocky workbook (2003). Self-directed learning through supporting materials such as the VIZ website and the interactive CD from the visualization workbook were given to only those 15 participants to use as resources during the course of the project, and participants were required to use these supplemental materials during class and for homework.

Participants were first educated on the nature of the research project, their right to elect or reject participation, and of their rights as participants in the study. After choosing to participate, participants were given the PSVT:R, a subset of ten questions from the Mental Cutting test (CEEB, 1939), and the modified Lappan test (Lapppan, 1981).

Lecture with demonstrations, class discussion, and hands-on activities were used to introduce each of the four learning modules that were covered in the course to all students. The modules that were introduced addressed the topics of isometric projection, orthographic projection, flat pattern, and rotational graphics. After being introduced to the curriculum through the lecture, the experimental participants were assigned the corresponding workbook exercises to complete during lab time and as homework—the exercises were completed in a self-directed manner. At the end of the four modules, all participants were given the same PSVT:R, Mental Cutting, and Lappan tests as a means of post-assessment.

Of the 92 design and technology students enrolled in the course, 69 chose to participate in the research project. 46 (67%) of the participants were freshman, 12 (17%) were sophomores, and 10 (15%) were juniors. Furthermore, 57 (83%) of the participants were male and 12 (17%) participants were female (P.E. Connolly, L.V. Harris, M.A.Sadowski, 2009).

The University of Iowa gave 314 first-year students in the College of Engineering the PSVT:R to assess spatial skills. Students scoring at or below 60% were invited to participate in a pilot training course offered by the Women in Science and Engineering (WISE) Program. Of the 314 first-year engineering students who took the test, 48 (15.3%) scored below the 60% cut point used as an eligibility criteria for being invited to participate in the pilot training course. Of these 48, 22 (45.8%) were women and 26 (54.2%) were men.

An e-mail outlining the training course, including an invitation to participate, was sent to 44 potential participants. The letter outlined the expectations for those involved in the pilot training course as well as elucidating the benefits of participating.

Expectations:

- To attend all seven training sessions;
- To take three pre- and post-tests;
- To complete assigned work during each session;
- To complete an evaluation form for each session;
- To participate in a debriefing session at the end of the training; and
- To allow researchers to track their academic progress, retention, and major for up to six years.

Benefits:

- A $100 stipend upon completion of the course; and
- A copy of the workbook and CD used for the course (Sorby and Wysocki, 2003).

Of the 48 original students, four (2 male, 2 female) had left the University of Iowa after their first semester so were no longer eligible to participate. Several other students reported having changed their major to something other than engineering (or they anticipated doing so shortly) and saw no potential value in participating in the training, further decreasing the pool of potential participants.

Initially, fifteen (15) students expressed interest in participating in the training course, but only seven (7) attended the information session that followed the e-mail and participated in the training course. A breakdown of characteristics for the seven pilot training participants is as follows: all second-semester first-year students: 5 female, 2 male; 6 Caucasian, 1 African American; 6 engineering majors including 3 biomedical, 2 civil, and 1 undeclared; and 1 open major (participant had moved out of engineering and into liberal arts). On average, the seven participating students also reported being enrolled in 2.3 concurrent science, technology, or engineering courses and 1.9 concurrent math courses.

Training sessions took place between February 19 and March 11, 2008. The pilot training course consisted of seven sessions held twice a week for 90 minutes each. Each training session began with an opportunity for students to raise questions about material covered during the previous session that was not well understood. Next, the instructor introduced the module for the day and provided a brief overview of the exercises that would follow. After that, students started by working on the computer exercises found on the CD that accompanied the course workbook (Sorby and Wysocky, 2003), followed by at least 30 minutes of paper-and-pencil skill-building. The last 15 minutes of each session was reserved for a short debriefing of the materials presented that day and completion of an evaluation for that module. No homework was required for this course, but working outside of class on exercises accessed through the VIZ website was strongly recommended. During the first session, students were given fifteen snap blocks (manipulatives) to use throughout the training. They provided an excellent way to "build" actual three-dimensional structures while working on the same structure in a two-dimensional environment.

Five of the nine modules included in the workbook were used during this pilot training: Isometric Drawings & Coded Plans, Orthographic Drawings, Rotation of Objects about a Single Axis, Rotation of Objects about Two or More Axes, and Cutting Planes and Cross Sections. Exercises found on the VIZ website were used to complement each module as time permitted.

Students did not receive a grade or credit for attending the training sessions, owing to the fact that there was no mechanism in place for doing so (Brus and Boyle, 2009).

At Virginia State University, the EnViSIONS spatial visualization curriculum was incorporated into INTC 261, an already existing sophomore level engineering graphics course that is taken by students majoring in mechanical engineering technology, industrial technology, and manufacturing engineering. In the semesters used in this study, the class met two days a week. Visualization was addressed in the first class session and other topics, including CAD instruction, were in the second class session each week.

Workbook modules (Sorby and Wysocky, 2003) were completed in class by the students after an introductory lecture by the instructor. Use of the workbook software was not required for all modules but its use was encouraged, especially to individual students who were having problems with a particular module. The software was demonstrated in class, and most frequently used by students, on Modules 3, 6, and 7. The VIZ website was not used because in the initial implementation of the visualization curriculum, the class was taught in a computer lab that did not have internet access. During the Fall 2007 and Spring 2008 semesters, all modules in the workbook were completed in order. Due to a minor restructuring of the course, for the Fall 2008 semester, Modules 8 and 9 were completed first with the rest of the modules completed in order.

The students were given a grade of credit or no credit for completing each module and the completed modules were due at the beginning of the following visualization class session, although many students finished during the one hour and forty minute class. After a module was due, the answers were posted on Blackboard for the students to check their answers. The pre-test scores were not part of the overall grade in the course, but the post-tests were included in the course grade and visualization accounted for approximately 15% of the overall grade. The visualization portion of the grade included credit for completed modules, quizzes, and visualization components of the written exams. There are typically two written exams, two CAD practical exams, a final project, and a comprehensive final exam in the course.

Other topics taught in INTC 261 are 3D modeling techniques including wireframe, surface, CSG solid modeling, and parametric solid modeling. Dimensioning, tolerancing, file management, and drawing standards are also covered in the class. Students complete the majority of their CAD assignments using parametric modeling software such as Pro/ENGINEER or SolidWorks. There are also two assignments using a nonparametric modeler such as AutoCAD to demonstrate extrusions, revolutions, and Boolean operations using CSG modeling techniques. The final CAD project in the course is an assembly where students create the individual parts, the assembly, engineering drawings of all parts, and a basic animation showing a transition from exploded view to complete assembly.

The total number of Virginia State University students taking part in the study so far is 38 including: 9 students Fall 2007 semester, 13 students Spring 2008 semester, and 16 students Fall 2008 semester. The students in the study are those who enrolled in a section of INTC 261 where the spatial visualization curriculum was part of the course content. Students were not specifically recruited for enrollment as the course is required as part of the plan of study for the mechanical engineering technology and industrial technology majors and may be used as an elective in the manufacturing engineering major. Of the 38 total students taking part in the study, 97% self identify as black, 65% are sophomores, their average age is 19.8, and 13% are female. Sixty-eight percent of the students were concurrently enrolled in precalculus or college algebra at the time they were enrolled in the engineering graphics course (Study, 2009).

At Virginia Tech, the spatial visualization curriculum closely followed the content developed at Michigan Tech, which was implemented through a stand-alone, one-credit elective course in Engineering Education. This optional course targets first-year engineering students and also engineering-bound students who enter the university as University Studies students. The course is offered once a year in the fall semester and was first offered in Fall 2007.

The class meets once a week for 75 minutes throughout the 15-week semester. The general approach each week is the same. First, time is spent reviewing homework and answering questions related to the module covered in the previous week. Then material for the current module is introduced using a brief PowerPoint presentation with in-class exercises. Following that, students work through the visualization software for the module before leaving class. Students are expected to bring their own laptops/tablets to class each week, and they generally work through the visualization software independently or with minimal consultation with a neighbor. Homework is assigned from the workbook or, in the case of the inclined planes and single curved surfaces module, as a separate handout. Several exercises on the VIZ website are also assigned as out-of-class work, and these selections are linked to specific modules.

All nine modules in the textbook Introduction to 3D Spatial Visualization: An Active Approach (Sorby and Wysocky, 2003) are covered in order, with the supplemental materials on inclined and curved surfaces inserted between orthographic drawings (Module 2) and folding of flat patterns (Module 3). The paper folding exercises on the VIZ website are assigned with the flat patterns module of the text, the "Rotating Blocks" exercise is used with the text module on rotation of objects about a single axis, and the VIZ "Mental Rotations" exercises are used to supplement the text's Rotation of Objects about Two or More Axes module.

The visualization course is graded on an A-F basis, with fifty percent of the course grade based on class participation and homework. There are two hourly tests, each of which accounts for 15% of the semester grade, and a final exam that accounts for 20%. The first test covers materials from Modules 1 and 2 (isometric sketching and orthographic projections) and the supplemental materials on inclined and curved surfaces. The second test covers Modules 3, 4, and 5 (Flat Patterns, Rotations of Objects about a Single Axis, and Rotation of Objects about Two or more Axes). The final exam covers Modules 6, 7, 8, and 9 (Object Reflections and Symmetry, Cutting Planes and Cross Sections, Surfaces and Solids of Revolution, and Combining Solids) and the post-test evaluations discussed in the Assessment section below.

Throughout the semester, the students have access to several manipulatives that help impart visualization skills. During the first lecture, students are given a set of fifteen snap blocks to use for the semester. With these blocks, students create models of the objects they are asked to sketch. During the modules focusing on rotation, students are also provided with a paper handout to help them identify the proper axes and directions for requested object rotations. The handout consists of an x-z coordinate rose with the positive x-and z-axis labeled. An image of the rotation aid handout is provided in Figure 2. Students can place a snap-block model of an object in the first quadrant of the handout and then use the right hand rule to determine how to rotate the object. Both positive and negative rotations of any amount about the y-axis keep the base of the snap-cube object in the plane of the paper handout. Limited (90o) negative rotation about the x-axis or positive rotation about the z-axis is also easily accomplished/visualized without lifting the snap-cube object. During the module on cutting planes and cross-sections (Module 7), swimming pool "noodles" which have been cut to various lengths and then sectioned along bisecting cutting planes are used during the class as an aid to help students see how an object's features may appear elongated, shortened, or unaltered on the section created by the cutting plane (Knott and Kampe, 2009).

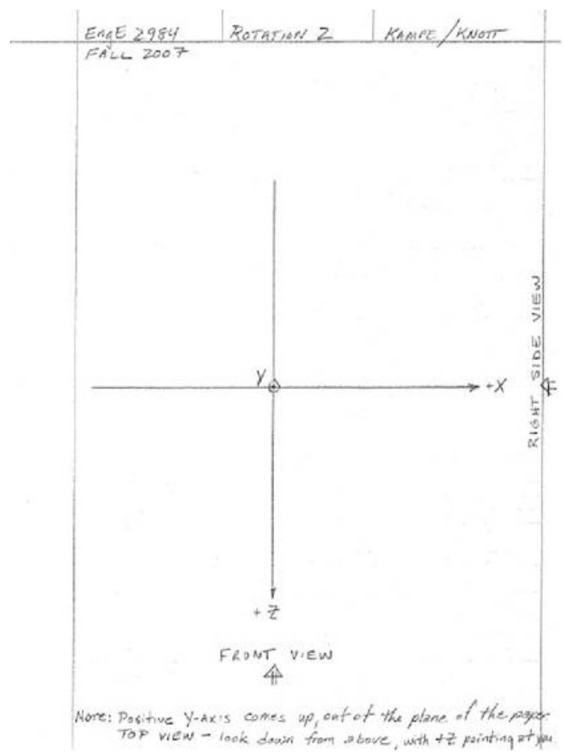

Figure 2: *Rotation Aid*

The implementations at each university are summarized in Table 1. Tables 2 and 3 summarize the students participating in the trainings. The results were combined for trainings that were offered multiple times. The number of students participating in this study at each school ranged from 7 to 116, with a total of 242 students at all universities. The implementations were primarily taken by freshman and sophomore students.

University	Type of course	Type of Student	Workbook Modules Covered	Use of VIZ Website
Michigan Tech	1 credit stand alone	Engineering	All plus inclined and curved surfaces	Yes
Penn State-Behrend	1 credit supplement to graphics & CAD course	Engineering technology	All	Yes
Purdue (Fall 07)	Part of existing Education course	Technology education	Isometrics orthographics flat patterns 1-axis rotations	Optional
Purdue (Fall 08)	Part of existing graphics & CAD course	Engineering technology	Isometrics orthographics flat patterns 1-axis rotations	Optional
University of Iowa	Optional training	Engineering	Isometrics orthographics rotations reflections symmetry cutting planes cross sections	Yes
Virginia State	3 credit ½ Envisions ½ CAD	Engineering technology	All	No
Virginia Tech	1 credit stand alone	Engineering & engineering bound	All plus inclined and curved surfaces	Yes

Table 1: *Implementations at Project Universities*

University	Term	#of Students	% Female	% Under-represented in Engineering[1]
Mich Tech	F07, F08	116	48%	51%
Penn State-Behrend	F07, F08	27	22%	22%
Purdue	F07	14	7%	7%
	F08	15	7%	7%
U of Iowa	S08	7	71%	71%
Virginia State	F07, S08, F08	38	13%	97%
Virginia Tech	F07, F08	25	32%	40%

[1] Underrepresented includes women and the following self-reported ethnic/racial identities: Black (non-hispanic), American Indian/Alaskan Native, and Latino/Latina (Hispanic).

Table 2: *Number of participants taking the spatial visualization trainings*

Underrepresented includes women and the following self-reported ethnic/racial identities: Black (non-hispanic), American Indian/Alaskan Native, and Latino/Latina (Hispanic).

University	Term	Grade Level	Concurrent (or Highest Completed) Math Level
Mich Tech	F07 & F08	First Year	6% College Algebra 49% Precalc 44% Calc1 or higher
Penn State-Behrend	F07 & F08	First Year	55% College Algebra or Precalc 44% Calc 1
Purdue	F07	36% Freshman 43% Sophomore 21% Junior	(36% Precalc 64% Calc 1 or higher)
Purdue	F08	73% First Year 27% Sophmore	(20% High School 40% Algebra 13% Precalc 27% Calc 1)
University of Iowa	S08	First Year	100% Calc1 or higher
Virginia State	F07, S08, & F08	10% Freshman 66% Sophomore 21% Junior 3% Senior	5% Algebra 79 % Precalc 16% Calc 1 or higher
Virginia Tech	F08	84% Freshmen 12% Sophomore	64% Calc 1 28% Calc 2 8% Linear Algebra

Table 3: *Grade level of students taking spatial visualization training*

Assessment

To determine the effectiveness of the implementations, all partners agreed to pre- and post-test students participating in the training using the same instruments. Also both students and instructors completed module evaluation forms.

Pre- and Post-testing. All universities agreed to measure student gains in spatial visualization skills with the following pre- and post-tests: 1) Purdue Spatial Visualization Test: Rotations (PSVT:R); 2) a subset of 10 questions from the Lappan Test (Lappan, 1981); and 3) a subset of 10 questions from the Mental Cutting Test (MCT) (CEEB, 1939).

An example problem from the PSVT:R is shown in Figure 3. This test requires that you identify a rotation of an object and apply that same rotation to a new object. This is a timed test in which students are given 20 minutes to complete 30 problems.

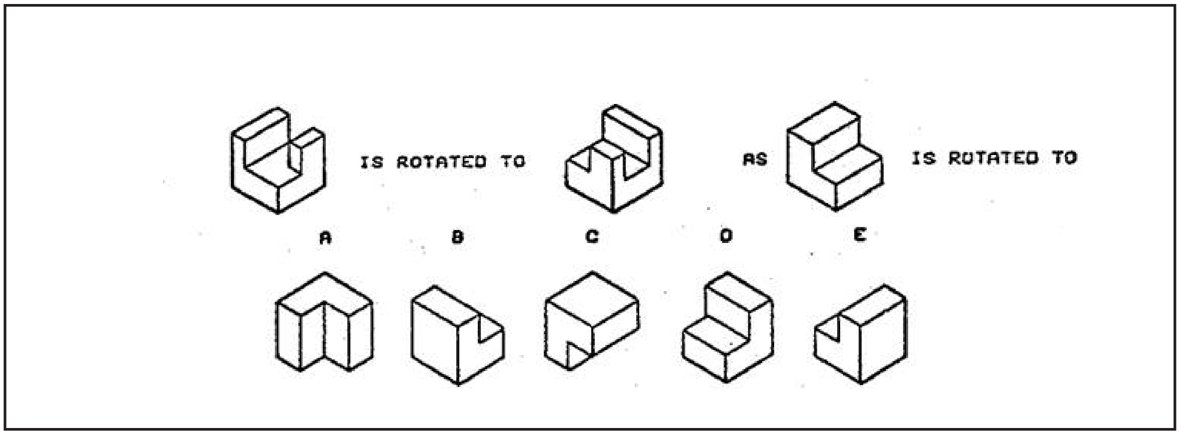

Figure 3: *Example problem from PSVT:R.*

A sample problem for the Lappan Test is shown in Figure 4. This test uses isometric sketches (3D representation) and orthographic views (2D representation) to assess how well different views of an object can be visualized. The questions often require a rotation of the object and that the object be represented in a dimension (2D or 3D) different from the given view. For example, an isometric sketch of the object may be given and identification of the back view (orthographic) required. Students were given eight minutes to complete the subset of ten questions.

You are given a picture of a building drawn from the FRONT-RIGHT corner. Find the BACK VIEW.

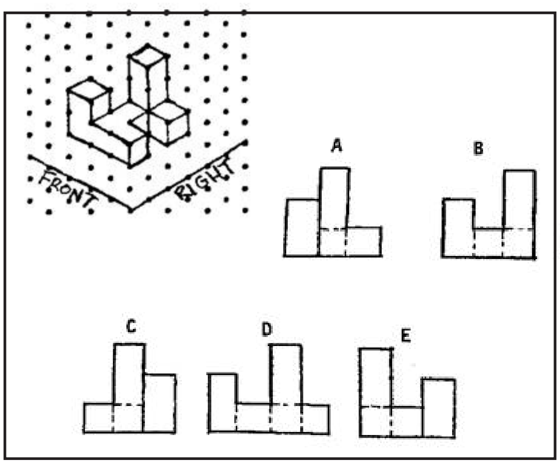

Figure 4: *Example problem from Lappan test.*

The Mental Cutting Test (example shown in Figure 5) is designed to measure how well the resulting cross-section of a three dimensional object cut by a plane can be visualized. This test is also timed; students were given eight minutes to complete the subtest of ten questions.

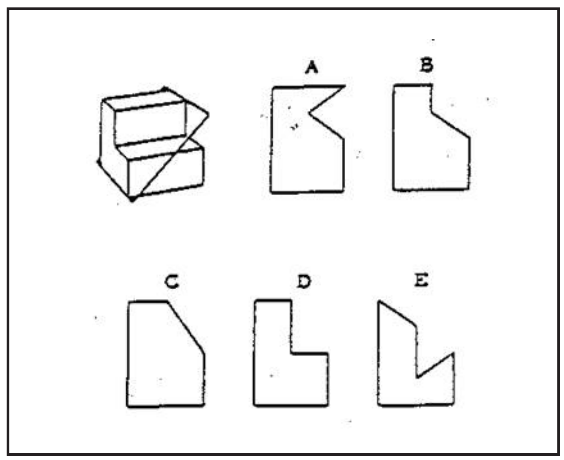

Figure 5: *Example problem from MCT.*

Module Evaluations. Students and instructors were asked to complete module evaluation forms after finishing each module. The student evaluation form is shown in Figure 6. The format of the instructor evaluation form was very similar to the student form. The evaluation questions were designed to quantify student and instructor attitudes regarding the quality and difficulty of the modules, how beneficial each component was to learning/instruction, and identify useful strategies and areas for improvement.

EVALUATION OF MODULE BY STUDENTS

Please take a few minutes to fill out this evaluation form. Your responses will help us arrange future materials to fit the needs of students.

Title of Module: ______________________

1. Overall, how would you rate the quality of this module?

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. The length of the module with respect to the activities was:

____too short

____appropriate

____too long

3. For my learning purposes, the overall level of this module was:

____too simple for my needs

____appropriate to my needs

____too advanced for my needs

4. Each of the following was beneficial to my understanding of the material*

a. Instruction (lecture and demonstration)

b. 3-D Spatial software

c. Workbook Problem Sets

d. VIZ website

e. Manipulatives (e.g., blocks)

f. Interaction with the instructor(s)/TA(s)

g. Interaction with other students

5. Suggest improvements for this module:

6. During this module I worked:

____alone

____in a group of 2

____in a group of 3

____in a group of 4 or more

7. Briefly describe the methods or strategies that were most helpful to you as you completed this module.

*Students were asked to rate the items in question 4 as:

____Not Applicable

____Strongly Disagree

____Disagree

____Agree

____Strongly Agree

Figure 6: *Student module evaluation form*

Results and Discussion

Pre- and Post-Tests. The average pre- and post-test scores and gains for the three evaluation instruments (PSVT:R, Lappan, and MCT) are shown in Tables 4-6. The average pre-test PSVT:R scores range from 47% to 70%. This range is consistent with the students targeted for the spatial skills training (<60% on PSVT:R or other diagnostic instrument) at most of the universities. The two groups that had an average PSVT:R score greater than 60% were the students at Purdue. The Technology Education students (Fall 2007) had an average pre-test score of 67%. These students were targeted to increase their awareness of the importance of developing spatial skills and to provide them with tools to use with their future students. The Engineering Technology and Industrial Design students (Fall 2008) had an even higher pre-test score of 70% which is not unexpected as the spatial visualization material was incorporated into a required course and was not specifically targeting students with low PSVT:R scores. The pre-test scores for the Virginia Tech students are also a little higher on the PSVT:R than the other schools. There were 4 students in Fall 2007 and 5 students in Fall 2008 that scored more than 60% on the PSVT:R. When these students were removed from the analysis the average scores were not altered significantly (within 3%). The Virginia Tech scores reported in Tables 4-6 are for all the students who completed the training. The gains observed on the PSVT:R, ranging from 13-25%, were statistically significant ($p<0.01$) and had a large effect size (d>=0.8) for all of the implementations, except the Fall 2008 Purdue students. It is important to note that the gains were statistically significant even for the schools covering only a portion of the workbook modules (Purdue Fall 2007 and University of Iowa students). At least one of the two modules on Rotations which are directly applicable to this evaluation instrument was covered by all the schools.

University	Term	Pre-Test	Post-Test	% Gain
Michigan Tech	F07, F08 n=111	52%	75%	23% $p<0.0005$ d=2.1
Penn State-Behrend	F07, F08 n=27	53%	69%	15% $p<0.0005$ d=1.2
Purdue	F07 n=14	67%	80%	13% $p<0.05$ d=0.7
	F08 n=15	70%	75%	5% $p<0.2$ d=0.6
Univ of Iowa	S08 n=7	48%	72%	25% $p<0.0005$ d=2.6
Virginia State	F07, S08, F08 n=38	47%	69%	22% $p<0.0005$ d=1.3
Virginia Tech	F07, F08 n=10	58%	77%	19% $p<0.0005$ d=1.3

Table 4: *PSVT:R Test Results*

The average pre-test scores on the Lappan Test, shown in Table 5, are more widespread and range from 45% to 77%. The Purdue students again had the highest average pre-test scores of 63% and 77%. The gains on the Lappan Test at the schools where all the modules were covered (16%-28%), were statistically significant and had a large effect size, with the exception Penn-State Behrend, where a medium effect size was found. Even though modules covering isometric and orthographic projections were used by the schools that covered a portion of the modules, the gains at Purdue (14% for Fall 2007 and 9% for Fall 2008) and the University of Iowa (10%) were not statistically significant.

University	Term	Pre-Test	Post-Test	% Gain
Michigan Tech	F07, F08 n=115	58%	75%	17% $p<0.0005$ d=0.8
Penn State-Behrend	F07, F08 n=25	48%	64%	16% $p<0.05$ d=0.7
Purdue	F07 n=14	63%	75%	14% $p<0.1$ d=0.5
	F08 n=15	77%	87%	9% $p<0.1$ d=0.6
Univ of Iowa	S08 n=7	59%	69%	10% $p>0.3$ d=0.4
Virginia State	F07, S08, F08 n=38	45%	62%	17% $p<0.0005$ d=0.9
Virginia Tech	F07, F08 n=10	56%	81%	28% $p<0.0005$ d=1.3

Table 5: *Lappan Test Results*

The results for the Mental Cutting Test are shown in Table 6. Pre-test scores on the Mental Cutting Test range from 34% to 59%; again the Purdue students have some of the highest scores. The gains for the schools that covered all the workbook modules and at the University of Iowa (15%-29%) were statistically significant and had large effect sizes. Students at the University of Iowa were trained on the topic the evaluation instrument tests: Cutting Planes and Cross Sections. It is not surprising that the Technology Education Students at Purdue (Fall 2007) did not show gains on the MCT since they were not trained on the module on Cutting Planes and Cross Sections. This suggests their training did not transfer to a mental cutting task. The Fall 2008 Purdue students covered the same modules as the Fall 2007 students but completed them over a four week period rather than a one week period. The Fall 2008 students also covered other graphics/CAD material during the four weeks they were completing the spatial visualization modules. These differences could explain why the Fall 2008 Purdue students had statistically significant gains on the MCT while the Fall 2007 students did not.

University	Term	Pre-Test	Post-Test	% Gain
Michigan Tech	F07, F08 n=115	44%	70%	26% p<0.0005 d=1.4
Penn State-Behrend	F07, F08 n=38	38%	57%	19% p<0.001 d=0.9
Purdue	F07 n=14	59%	60%	1% p>0.4 d=0.0
	F08 n=15	48%[1]	58%[1]	10% p<0.05 d=0.7
U of Iowa	S08 n=7	34%	60%	26% p<0.025 d=1.2
Virginia State	F07, S08, F08 n=38	41%	56%	15% p<0.0005 d=0.8
Virginia Tech	F07, F08 n=25	43%	72%	29% p<0.0005 d=1.6

Table 6: *Mental Cutting Test Results*

[1] The Purdue students in Fall 2008 took the full 25 question Mental Cutting Test.

Student Module Evaluations. Ratings of student responses on the module evaluation forms at Penn State Behrend, the University of Iowa, Virginia State University, and Virginia Tech were generally positive. Students at Virginia Tech typically rated the quality of the module as good to very good. Each of Modules 1, 2, 4, 7, and 9 (Isometric Drawings and Coded Plans, Orthographic Drawings, Rotations about a Single Axis, Cutting Planes and Cross Sections, and Combining Solids, respectively) did have one student rate the module only Fair. Table 7 shows similar responses were found at the University of Iowa (Brus and Boyle, 2009).

Overall, how would you rate the quality of this module?					
Rating	Module 1	Module 2	Module 4	Module 5	Module 7
Poor				1	
Fair			1		
Good		2	2	1	4
Very Good	6	4	3	4	2
Excellent	1	1	1	1	1
TOTAL	7	7	7	7	7

Table 7. *Participant rating of each module used in the pilot spatial visualization training course at the University of Iowa*

At Virginia Tech, at least 75% of the students felt the length was appropriate and at least 71% felt the level was appropriate for their needs. At least two students felt the level was too simple for their needs for each of Modules 1, 2, and 6, (Isometric Drawing and Coded Plans, Orthographic Drawings, and Object Reflections and Symmetry, respectively), while the supplemental inclined and curved surfaces module and Module 7 (Cutting Planes and Cross Sections) each had two students indicate that the level was too advanced (Knott and Kampe, 2009).

At Virginia State University, students consistently rated the quality of most modules as good or very good and generally thought the level was appropriate to their needs. Module 4, which dealt with rotation of objects about a single axis, was the module where students generally encountered the most difficulty. Seventy-five percent of the students thought Module 4 was too long, approximately 25% thought it was too difficult for their needs, and the overall quality of the module was only rated between fair and good.

Penn State Behrend students found the different aspects of the course "beneficial to their understanding/learning of the material." The following table shows the average response of the students. Each aspect was rated on a scale of: 1) strongly disagree to 4) strongly agree (Blasko et al., 2009).

Overall Course Rating	Mean	STD
Software	3.31	.48
Workbook	3.23	.44
Manipulatives / Activities	3.69	.48
Discussions	3.54	.52
Interaction with Instructor/TA	3.46	.51
Interaction with Other Students	3.54	.51

Table 8. *Means and standard deviations of ratings for the materials used in the Penn State Behrend class.*

Instructor Module Evaluations. Responses from the instructor module evaluations indicate the quality of most modules is very good to excellent. The modules on flat patterns, combining solids, and surfaces and solids of revolution were rated as being good. Instructors felt the length of the modules and their overall level was appropriate for their students' learning needs. Instructors were asked whether different activities were beneficial to their instruction of the course on a scale of 1– strongly disagree to 4 – strongly agree. Instructors strongly agreed or agreed that the workbook, software, and provided lecture materials were beneficial for all modules. They strongly agreed that manipulatives, primarily blocks, were beneficial for the instruction on isometric drawing, orthographic drawing, and rotations (Modules 1, 2, 4, and 5). Additionally, instructors agreed that the VIZ site was beneficial for flat patterns and rotations (Modules 3, 4, and 5).

Summary and Future Directions

Materials developed at Michigan Tech and Penn State Behrend to improve spatial skills have been successfully incorporated in various forms at six universities. Results indicate that improvement in the spatial skills of the participating students were statistically significant. It is encouraging that only a partial offering of the material also produces statistically significant improvements in spatial skills.

All the participating schools are continuing to offer the spatial visualization training with the exception of Iowa State University. Iowa State University did not offer the training in the 2008-2009 academic year because the engineering faculty involved in the project left the university. Most of the universities will track retention and course grades of students who took the spatial visualization curriculum to further examine the impact of the intervention. It is the project participants' hope that additional universities will adopt a spatial visualization curriculum which may in turn lead to a more diverse engineering workforce.

These results also prompt us to further explore the possibility of testing and training younger students, specifically those in middle and high school. Future projects will focus on developing a cadre of middle and high school teachers who understand the importance of and are trained in integrating spatial skill-building activities into the pre-college curriculum. It is hoped more universities will bring this curriculum into their education courses as Purdue did in their ETTE program.

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