Enhancing Visualization Skills-Improving Options and Success (EnViSIONS): An Overview

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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 at seven institutions: Michigan Tech, Penn State Behrend, Purdue University, University of Iowa, Virginia State University, Virginia Tech University, 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 hopes to improve the retention and success rate of these students who go into STEM disciplines. This paper will give a brief overview of the project and its findings.

I. Introduction

Since 1993, Michigan Technological University has offered a spatial visualization course to students who score below 60% on the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Guay, 1977). Students choosing to take this 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 Erie, The Behrend College, found that low grades and retention were related to scores on tests of basic spatial abilities such as mental rotation (Blasko, et al., 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.

Seven universities across the United States (Arizona State University Polytechnic, The University of Iowa, Michigan Tech, Penn State Behrend, Purdue University, Virginia State University, and Virginia Tech) have joined together to build on the success of the Michigan Tech spatial visualization course and the VIZ website through the EnViSIONS (Enhancing Visualization Skills--Improving Options and Success) project. The goal of the project is to demonstrate 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.

Project participants met in the summer of 2007 to become familiar with the Michigan Tech course
material and the VIZ website. Participants developed individualized implementation plans and agreed on common evaluation instruments to measure the success of the project. Internal Review Board (IRB) issues related to the project were also discussed.

Each university applied for and received IRB approval in the summer and fall of 2007 and began implementation of the spatial visualization course as early as the summer of 2007. Each implementation is briefly described in Section III.

II. Course Materials

Project participants were given the following course materials used at Michigan Tech: a spatial visualization workbook, software and teacher’s resource guide by Sorby and Wysocki (2003), quizzes and lecture (power point slides and snap blocks) materials.

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 a portion of or the entire workbook. Most universities also used the software.

VIZ Website. The VIZ website contains the following tasks: 1) Mental Rotations, 2) Water Level, 3) Paper Folding, and 4) Spatial memory: Rotating Letters. 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. The VIZ site is further described in Blasko, Holliday-Darr, and Trich Kremer (2009). All but two of the 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 power point presentation and in-class activity which introduce the topic for the day. Some of the universities used the lecture materials, while some universities used the workbook software instead of the lecture materials.

III. 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 as early as the summer of 2007.

Michigan Tech incorporated the VIZ website developed by Penn State Behrend into the 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, et al., 2008).

Penn State Behrend offered two supplemental courses: a summer course that targeted minority and female high school juniors interested in STEM fields, and the other targeting first year Plastics Engineering
Technology (PLET) and Mechanical Engineering Technology (MET) students who scored poorly on the PSVT:R (Blasko et al., 2009).

**Purdue University** implemented the spatial visualization curriculum in two different venues: as a small part of a technology education course in the fall semester and as part of a summer transition program for freshman students in summer. The technology education course was taken by Technology Education majors and is described in detail by Harris, Harris, and Sadowski (2009). The summer transition program – Academic Boot Camp (ABC) – is predominantly attended by African-American students. The spatial curriculum was offered to ABC students enrolled in the College of Technology or the College of Science.

The **University of Iowa** offered a three-week pilot training course during their Spring 2008 semester to first-year engineering students who scored below 60% on the PSVT:R (Brus & Boyle, 2009).

**Virginia State University** incorporated the spatial visualization curriculum into an existing engineering graphics course taken by Industrial Technology, Mechanical Engineering Technology and Manufacturing Engineering students (Study, 2009). Half of the course consisted of the spatial visualization materials, while the other half covered CAD material using Pro/E or Solid Works.

**Virginia Tech** offered an optional 1-credit spatial visualization course targeting first year engineering and engineering-bound students during the fall semester. A diagnostic screening was offered to the target students to identify who could benefit from taking this course (Knott & Kampe, 2009).

Faculty at **Arizona State University** worked to incorporate the spatial visualization material into an “Introduction to Engineering Design” Project Lead the Way (PLTW) course at the Red Mountain High School in south-central Arizona (Duff & Kellis, 2009). Project Lead the Way is a National Science Foundation sponsored sequence of high school courses that introduces students to engineering during high school. The PLTW course meets daily, and the spatial visualization material was covered one day each week over two terms (for a total of eighteen weeks).

The implementations targeting high school students and college students are summarized in Tables 1 and 2, respectively. The number of students participating in this study at each school ranged from 7 to 42.

### Table 1: Implementations for high school students.

<table>
<thead>
<tr>
<th>University</th>
<th># of Students</th>
<th>Workbook Modules Covered</th>
<th>Use of VIZ Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penn State Behrend MCE-WISE</td>
<td>31</td>
<td>Isometrics orthographics rotations</td>
<td>Yes</td>
</tr>
<tr>
<td>Virginia State U - PLTW</td>
<td>29</td>
<td>All</td>
<td>No</td>
</tr>
</tbody>
</table>

### Table 2: Implementation for college students.

<table>
<thead>
<tr>
<th>University</th>
<th># of Students</th>
<th>Type of Student</th>
<th>Workbook Modules Covered</th>
<th>Use of VIZ Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan Tech</td>
<td>42</td>
<td>Engineering</td>
<td>All</td>
<td>Yes</td>
</tr>
<tr>
<td>Penn State-Behrend</td>
<td>13</td>
<td>Engineering technology</td>
<td>All</td>
<td>Yes</td>
</tr>
<tr>
<td>Purdue</td>
<td>14</td>
<td>Technology education</td>
<td>Isometrics orthographics rotations</td>
<td>Optional</td>
</tr>
<tr>
<td>University of Iowa</td>
<td>7</td>
<td>Engineering</td>
<td>Isometrics orthographics rotations reflections symmetry cutting planes cross sections</td>
<td>Yes</td>
</tr>
<tr>
<td>Virginia State</td>
<td>38</td>
<td>Engineering technology</td>
<td>All</td>
<td>No</td>
</tr>
<tr>
<td>Virginia Tech</td>
<td>11</td>
<td>Engineering &amp; engineering bound</td>
<td>All</td>
<td>Yes</td>
</tr>
</tbody>
</table>
IV. Assessment

To determine the effectiveness of the implementations, all partners agreed to pre- and post-test students participating in the training and complete module evaluation forms for students and instructors.

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 1. 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.

A sample problem for the Lappan Test is shown in Figure 2. This test uses isometric sketches (3D representation) and orthographic views (2D representation) to assess how well you can visualize different views of an object. The questions often require a rotation of the object and that you represent the object in a dimension (2D or 3D) different from the given view. For example, you may be given an isometric sketch of the object and asked to identify the back view (orthographic). Students were given 8 minutes to complete the subset of 10 questions.

The Mental Cutting Test (example shown in Figure 3) is designed to measure how well you can visualize the cutting of three dimensional objects. This test is also timed; students were given 8 minutes to complete the subset of 10 questions.

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

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Module Evaluations. Students and instructors were asked to complete module evaluation forms after finishing each module. The student evaluation form is shown in Figure 4. 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 Poor
   - [ ] 2 Fair
   - [ ] 3 Good
   - [ ] 4 Very Good
   - [ ] 5 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:
   - [ ] Instruction (lecture and demonstration)
   - [ ] 3-D Spatial software
   - [ ] Workbook Problem Sets
   - [ ] VIZ website
   - [ ] Manipulatives (e.g., blocks)
   - [ ] Interaction with the instructor(s)/TA(s)
   - [ ] 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 4: Student module evaluation form**

### V. Results and Discussion

#### Pre- and Post Tests.
In addition to Michigan Tech, there were four schools that covered all the workbook modules in their offerings: Penn State Erie (Blasko et al., 2009), Virginia State (Study, 2009), Virginia Tech (Knott & Kampe, 2009), and Red Mountain High School (Duff & Kellis, 2009). The average PSVT:R pretest scores for the schools covering all the workbook modules ranged from 45-60% except for the PLTW classes at Red Mountain High School which was much higher with an average of 81%. The range of pretest scores for the Lappan and MCT were more widespread, ranging from 33-71%. Gains on these tests (PSVT:R, Lappan, and MCT) were greater than 15% and were statistically significant (p<0.05), with the exception of the PSVT:R and Lappan tests for the PLTW course. These students had average gains of -1% and 9% on the PSVT:R and Lappan tests, respectively. 86% of the PLTW students scored above 60% on the PSVT:R pre-test, so it is not surprising there were no gains on the PSVT:R for these students.

There were several trainings that used a portion of the workbook modules. All of these offerings covered Isometric Drawings, Orthographic Drawings, and Rotations (Modules 1, 2, 4, and 5) at a minimum. Gains in spatial skills from these offerings are promising. There are statistically significant gains for the PSVT:R test for students in the Engineering and Technology Teacher Education program at Purdue (Harris et al., 2009) and the University of Iowa (Brus & Boyle, 2009). PSVT:R gains for the MCE-WISE students at Penn State Erie were not statistically significant; however, their gains on the Mental Rotation Task were statistically significant (Blasko et al., 2009).

**Instructor Module Evaluations.** Responses from the instructor module evaluations indicate that 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).

VI. Summary and Future Directions

Materials developed at Michigan Tech and Penn State Erie to improve spatial skills have been successfully incorporated in various forms at 6 universities and one Project Lead the Way course. Results indicate that in all but the PLTW offering improvement in the spatial skills of the participating students were statistically significant. It is also 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 spatial visualization training this year with the exception of Red Mountain High School’s Project Lead the Way offering. 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 course. 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.

VII. References


CEEB, Special Aptitude Test in Spatial Relations, (1939) College Entrance Examination Board, USA.


