Assessment of Students’ Changed Spatial Ability Using Two Different Curriculum Approaches; Technical Drawing Compared to Innovative Product Design

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Introduction

Improving student performance on academic tasks in mathematics, science and engineering appears to occur when students’ spatial visualization skills have been improved. Studies have found improving spatial visualization can increase success in chemistry (Carter, et.al, 1987), reduce math anxiety (Maloney, et.al., 2011), improve calculus grades (Sorby, et.al., 2012), and increase retention and success in science and engineering curricula (Potter, et.al., 2006). Creativity in the sciences and engineering seems directly related to spatial visualization based on work by Kozhevnikov, et.al. (2013).

A widely used pathway to improve students’ spatial abilities employs three-dimensional software programs that enable a student to create an object and manipulate the object in real-time. Yet, studies seem to suggest that this approach is not always successful when spatial ability is tested using a standard spatial ability test. Work by Frey et.al. (2000) and Towle et.al. (2005) indicate that sole use of three-dimensional imaging software does not improve spatial ability in a significant way. Other work by Study et.al., (2011) and Veurink et.al, (2009) suggest that a mixed approach using hand drawing techniques and software may be more effective in increasing spatial abilities.

Finding an effective approach to improve spatial ability is considered an important research and pedagogical imperative for the profession of engineering. Research by Charyton et.al., (2011) explored the relationship between spatial visualization and creativity in engineering design tasks and found convergent validity between assessments for creativity and the Purdue Spatial Visualization Test-Rotations; this infers that improving spatial abilities may improve student creativity which, in turn, may help students meet today’s engineering challenges. Seminal work by Sheppard et.al., (2009) in Educating Engineers, Designing for the Future of the Field found design projects that could foster an “approximation to professional practice” were important to invoking a sense of real-world practice, improving teamwork and creativity but entered the curriculum too late to give students a sense of what professional practice entails. Therefore, increasing students’ spatial abilities in the context of design projects early in their academic career may be important for preparing students to enter practice with the mindset needed for the profession.

Study Purpose

This study attempts to determine to what degree a product design course involving creative real-world problem-solving, limited hand drawing, three-dimensional software modeling and building models improves students’ spatial ability compared to a traditional technical drawing class. The authors view this study as a pedagogical exploration that may establish an improved approach to significantly increase student’s spatial visualization capability and identify how changes are distributed over cohorts and genders.
Study Design

The Purdue Spatial Visualization Test – Rotations (PSVT-R) will be used to quantify a before-and-after change in student exposure to the course’s differing content and approach. The PSVT-R (Bodner and Guay, 1987)\(^{12}\) is used significantly in the literature as a standard test for spatial ability (Carter, et.al., 1987)\(^{1}\). The test utilizes a set of line drawings of an object that the test taker must manipulate mentally to arrive at a solution that mimics the rotations of an example object. Objects are not repeated and each question contains different example objects and test objects the student must manipulate mentally. The test is timed to prevent the test taker from analytically solving each problem; that is, draw in axes and determine the rotations needed to obtain the example object’s final orientation. The test is highly correlated to test takers scores on spatial tasks (Kovac, 1989)\(^{13}\) and has high construct validity (Branoff, 2000)\(^{14}\).

The PSVT-R was given to students before the beginning of each course and near the end of the semester. Data was gathered on student gender and class cohort at the time of testing. Only paired data sets (each student’s pre and post test score) are included in the final analysis to provide an overall assessment of change in spatial ability.

The two courses are referred to in this paper as MMAE 232 and CAE 100. The MMAE 232 course is the engineering design course and CAE 100 is the technical drawing course. Mechanical engineering and material science majors normally take MMAE 232 in their sophomore year. Civil engineering majors take CAE 100 in the freshmen or sophomore years, but many students take it when it fits easily in their curriculum plans.

MMAE 232 – Design for Innovation is a sophomore-level design course for mechanical engineers. It is the first in a series of three design courses. Although it is a sophomore level class, several juniors and seniors take the course, especially transfer students. Students take the second course in the series, which focuses on machine elements, in their junior year. The third and final design course is the capstone mechanical design course which students take their senior year.

The mechanical engineering department has taught Design for Innovation for three years, beginning in the fall of 2011. The course has three main objectives: 1) introduce design thinking and open-ended problem solving earlier in a student’s career, 2) teach technical writing, and 3) improve student use of three-dimensional CAD software.

Students begin the class with two-weeks of lecture on isometric hand-drawings, engineering drawings, and the basics of CAD software. Students use Autodesk Inventor for this class. Coupled with lectures are weekly 3-hour lab sections for the students to become familiar with the CAD software or work on their projects. In the lab sections, students follow a tutorial in a book (Autodesk Inventor Essentials by Thom Tremblay, Wiley Publishing). Instructors are present to help answer students’ questions. Coupled with this portion of the class are two individual assignments in which students must create part files, assembly files, and engineering drawings.

After the completion of the CAD assignments in the first three weeks, students form groups to focus on three open-ended design problems in which they must design and fabricate a device. In
the past two years, the problems have included a chair made entirely from foam-core board without any fasteners or glue, a trebuchet in which the main axle is made from ¼” diameter acrylic rod (this requires the students to perform stress and deflection analyses), and a bio-inspired robot fabricated using Arduino microprocessors and RC servos.

Each project focuses on a particular aspect of the design process. The chair represents sustainable design techniques such as light-weighting, whole-system design thinking, and lifecycle thinking. The trebuchet project encourages students to focus on the analysis portion of the design process, a step that many students overlook. The bio-inspired robot project introduces students to the bio-inspired design process, mechanism design, actuators, and mechatronics.

For each of the projects, students must create isometric sketches of their conceptual designs and engineering drawings of their final designs; as well as building the actual object and demonstrating that it works. Final grades are based on the quality of the technical communication as well as engineering drawings associated with each design phase.

CAE 100 – Introduction to Engineering Drawing and Design - is a freshmen level technical drawing class. Students who take this course may come from any cohort (freshmen, sophomore, junior or senior) since the class is not a pre-requisite for later courses. The text used in CAE 100 is Technical Drawing with Engineering Graphics, by Giesecke, et.al.,14th edition (2012)15. The course covers the basics of free-hand sketching and the use of instruments (triangles, t-squares and compass), lettering, isometric projection, orthographic projection, and two-dimensional drawings using scale. No computer software is used in this class.

CAE 100 spends a significant amount of time (almost a third of the semester) improving students’ free-hand sketching ability. Natural and mechanical objects are used as subjects of drawing. As students improve they are introduced to the basics of isometric drawing using hand drawing. This leads easily into perspective which is explored in the students’ collection of drawings. Instruments are introduced starting with lines, line thickness, lettering and the use of the compass.

Once orthographic perspective is introduced students perform orthographic hand drawing with simple objects. Measurement is introduced (types of measures, use of engineering and architectural scales) and related back to hand drawing of orthographic perspective of objects.

Use of the T-square and triangles are introduced in order to create orthographic drawings quickly and to proper scale. Continued practice with instruments and engineering objects give the students practice in creating accurate engineering drawings with appropriate dimensioning and are related to engineering drawings in various engineering disciplines. Grades in CAE 100 are based on completing a number of drawings and the quality of student’s orthographic drawings to meet industry standards.

General Results

The following tables show the overall data collected for both courses. Data are broken out into overall course scores on the PVST-R (out of 20 possible points) then by cohort and gender for CAE 100 and MMAE 232.
Table 1 shows results for the CAE 100 course. PSVT-R scores are means followed by standard deviation (SD). The column for increased and decreased scores is the number of such changes followed by the mean percentage change in PSVT-R score.

<table>
<thead>
<tr>
<th>CAE 100</th>
<th>Number of Students</th>
<th>PSVT-R Pretest score mean(SD)</th>
<th>PSVT-R Posttest score mean(SD)</th>
<th>Number of increased scores (mean percent increase)</th>
<th>Number of decreased scores (mean percent decrease)</th>
<th>Number of unchanged scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>All students</td>
<td>42</td>
<td>14.14(3.92)</td>
<td>15.69(2.78)</td>
<td>24(42%)</td>
<td>12(12%)</td>
<td>6(0%)</td>
</tr>
<tr>
<td>Freshmen</td>
<td>19</td>
<td>15.05(3.14)</td>
<td>15.79(2.99)</td>
<td>8(27%)</td>
<td>7(9%)</td>
<td>4(0%)</td>
</tr>
<tr>
<td>Sophomores</td>
<td>12</td>
<td>14.17(4.04)</td>
<td>16.67(2.41)</td>
<td>10(37%)</td>
<td>2(15%)</td>
<td>0(-)</td>
</tr>
<tr>
<td>Juniors</td>
<td>6</td>
<td>13.00(4.90)</td>
<td>14.33(2.16)</td>
<td>2(127%)</td>
<td>3(17%)</td>
<td>1(0%)</td>
</tr>
<tr>
<td>Seniors</td>
<td>5</td>
<td>12.00(5.15)</td>
<td>14.60(3.36)</td>
<td>4(42%)</td>
<td>0(-)</td>
<td>1(0%)</td>
</tr>
<tr>
<td>Males</td>
<td>31</td>
<td>14.65(3.83)</td>
<td>16.19(2.74)</td>
<td>18(37%)</td>
<td>10(11%)</td>
<td>3(0%)</td>
</tr>
<tr>
<td>Females</td>
<td>11</td>
<td>12.73(4.08)</td>
<td>14.27(2.59)</td>
<td>6(52%)</td>
<td>2(16%)</td>
<td>3(0%)</td>
</tr>
</tbody>
</table>

Table 2. General results for the MMAE 232 course.

<table>
<thead>
<tr>
<th>MMAE 232</th>
<th>Number of Students</th>
<th>PSVT-R Pretest score mean(SD)</th>
<th>PSVT-R Posttest score mean(SD)</th>
<th>Number of increased scores (mean percent increase)</th>
<th>Number of decreased scores (mean percent decrease)</th>
<th>Number of unchanged scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>All students</td>
<td>38</td>
<td>15.26(3.43)</td>
<td>16.10(2.76)</td>
<td>19(26%)</td>
<td>12(13%)</td>
<td>7(0%)</td>
</tr>
<tr>
<td>Sophomores</td>
<td>11</td>
<td>15.09(2.54)</td>
<td>16.54(2.46)</td>
<td>6(35%)</td>
<td>4(15%)</td>
<td>1(0%)</td>
</tr>
<tr>
<td>Juniors</td>
<td>18</td>
<td>15.66(4.10)</td>
<td>16.00(3.26)</td>
<td>9(18%)</td>
<td>6(12%)</td>
<td>3(0%)</td>
</tr>
<tr>
<td>Seniors</td>
<td>9</td>
<td>14.66(3.12)</td>
<td>15.77(2.16)</td>
<td>4(25%)</td>
<td>2(11)</td>
<td>3(0%)</td>
</tr>
<tr>
<td>Males</td>
<td>33</td>
<td>15.12(3.48)</td>
<td>16.09(2.91)</td>
<td>16(28%)</td>
<td>10(13%)</td>
<td>7(0%)</td>
</tr>
<tr>
<td>Females</td>
<td>5</td>
<td>16.20(3.19)</td>
<td>16.20(1.64)</td>
<td>2(14%)</td>
<td>2(13%)</td>
<td>1(0%)</td>
</tr>
</tbody>
</table>

The general results show that the CAE 100 course had higher mean percentage increase in PSVT-R scores from pre to post test compared to the MMAE 232 course. Decreased and unchanged PSVT-R scores were similar for both groups.

The CAE 100 male students started with lower PSVT-R scores then the male MAE 232 scores which is consistent with previous discipline specific PSVT-R studies that showed that mechanical engineering students (the MMAE 232 students) have a slightly higher PSVT-R scores then civil engineering students (Veurink, et.al., 2012)\(^16\). Interestingly the same study showed civil engineering females (CAE 100) should have PSVT-R scores similar to the MMAE 232 females, which is not the case for this study.
Analysis of Student Data

A statistical analysis was undertaken to determine if the differences within the CAE 100 and MMAE 232 overall score changes for cohorts and gender indicated any statistically significant changes.

A two-tailed T-test for paired data was performed for the CAE 100 course (all students). The calculation showed a significant difference in the scores for pre-test (m=14.14, SD=3.92) and post-test (m=15.69, SD=2.78) conditions; (t(41)=3.05, p=0.004). Cohen’s d statistic gave a value of 0.457 which makes the effect medium in scale (Cohen, 1988)\(^{17}\).

An examination of the CAE 100 cohorts (freshmen, sophomore, etc) showed no statistically significant difference in pre- and post-test scores for the freshman, junior or senior cohorts. The sophomore cohort did show a statistically significant change in scores from pre-test (m=14.17, SD=4.04) and post-test (m=16.67, SD=2.41) conditions; (t(11)=2.51, p=0.029). Cohen’s d statistic was 0.759 which is considered a medium to large change.

Gender differences for the CAE 100 course showed females did not have a statistically significant change in scores from pre- to post-test with the PSVT-R. Males did show a statistically significant change in scores from pre-test (m=14.65, SD=3.83) to post-test (m=16.19, SD=2.74) conditions; (t(30)=2.73, p=0.010). Cohen’s d was 0.459 which is considered a medium effect.

Performing a two-tailed T-test for paired data for the MMAE 232 course (all students) showed no statistically significant change in scores from pre- to post-test with the PSVT-R.

Examination of the MMAE 232 cohorts (sophomore, junior, and senior) also showed no statistically significant change from pre-to post-test scores for the PSVT-R within each cohort.

MMAE 232 gender grouping did show a statistically significant change from pre- to post-testing of the PSVT-R. MMAE 232 males showed a change from pre-test (m=15.12, SD=3.48) to post-test (m=16.09, SD=2.91) conditions; (t(32)=2.04, p=0.049). The Cohen’s d statistic was 0.302 considered a small to medium effect.

There were not enough female pairs in MMAE 232 class to perform a T-test for females only.

Discussion of Analysis

The statistically significant moderate to large change in PSVT-R scores for the CAE 100 class and lack of an equivalent change in the MMAE 232 course indicates the use of product design coupled with three-dimensional software and building prototypes is not as effective at increasing students’ spatial ability compared to a focused technical drawing curriculum.

Comparing the graded assignments of each course suggests to improve spatial ability student effort must be coupled with direct drawing assignments completed by all students to ensure an improvement in PSVT-R scores.
The CAE 100 course required each student to complete all drawing assignments for a grade while the MMAE 232 course utilized groups that handed in one set of drawings; potentially some students did not create drawings reducing the chance to improve their spatial visualization skills. Data was not collected on which students prepared drawings in MMAE 232 but faculty observation indicated that one student in each group accomplished most drawings handed in for assignments.

The analysis indicated that the CAE 100 sophomore cohort showed a significant change in PSVT-R scores over the course of the semester. The sophomores involved in the study were in four separate sections so it does not appear that the score improvement was related to grouping the students together. Further testing and background information would have to be accomplished with all CAE 100 cohorts to establish common variables that may have influenced the improvement in PSVT-R scores.

The percentage of students that showed no change or a decrease in PSVT-R scores for CAE 100 and MMAE 232 was 43% and 50% respectively. This sizable number suggests that some aspect of both courses is failing to influence students in a positive manner and should be explored to understand it as a confounding factor.

Study Limitations

Student perceptions of academic tasks were not assessed. This evidence, although anecdotal, would have provided a sense of; which assignments changed student perceptions of their spatial ability, did students in both classes receive the same number of impactful assignments, and whether the approach in either class was affecting the intended educational objectives.

The affect of maturation on student PSVT-R scores is unclear. The authors believe the data gathered for this study are not adequate to make a statement concerning maturation effects and highlight the need for such information in future work to account for potential influence. Psychological assessments related to maturation via student motivation or perseverance on tasks may provide a means to assess a relationship between maturation and the PVST-R.

Nearly half of the students in this study had no change or a decrease in PSVT-R scores regardless of the curriculum approach. The authors believe this statistic requires explanation. Unfortunately previous research does not appear to consider this aspect or provide explanations for its potentially confounding influence. The authors intend to examine this aspect in future work.

The amount of student-faculty engagement was not quantified for this effort. The quality and degree of student-faculty engagement could be a significant variable. The MMAE 232 classes were typically large (over 90 students) with limited time for the faculty member to interact with groups. In CAE 100 classes were typically smaller than 15 students to each faculty member but did not include group projects. It is possible this difference in engagement may have affected PSVT-R changes in both courses.
Conclusion

The use of a product design methodology coupled with hand drawing, three-dimensional software and prototyping of solutions had no statistically significant increase in PSVT-R scores. In contrast, a fairly traditional technical drawing class had a moderate to large significant increase in PSVT-R scores.

Future work with these two classes should assess student perceptions of what assignment aspects seem to improve their spatial ability, quantify student maturation and attempt to assess and equalize the degree of student-faculty engagement in both classes. With these additional factors controlled the results of the current pedagogical exploration can be quantified with known or measurable classroom or cohort attributes that may facilitate the transferability of successful practices to other institutions that want to increase student’s spatial visualization skills.


