




ASEE | Engineering Design Graphics Division

# 68<sup>th</sup> Mid-Year Conference



## Web<sub>of</sub> Graphics



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# Web of Graphics

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Computer Graphics Technology  
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# Spatial Test Correlation in an Introductory Graphic Communications Course

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## **Abstract**

*With many spatial ability tests available for research, there is no consensus on which test(s) are preferred. A literature review produced a list of 24 tests that was used in a survey of EDGD members. The top three identified tests were the Mental Cutting Test (MCT), Mental Rotations Test (MRT), and Purdue Spatial Visualization Test: Visualization Rotations (PSVT: VR). Three sections of an introductory graphics course (N.C. State) provided spatial test scores from these tests for this research. This study examined correlations between the three identified tests and the recommendations for further research.*

## **Introduction**

Published articles on spatial abilities are found in the fields of psychology (Hetland, 2000), graphics education, and STEM areas (Connolly, Harris, & Sadowski, 2009). Wai, Lubinski, and Benbow (2009) studied efforts to identify and develop “personal attributes of scientists and engineers” and to foster their potential (p. 817). They identified spatial ability as a major contributor to success in STEM education and occupations. Spatial tests are used to measure this ability. Spatial literature in these areas was written from the researchers’ viewpoint regarding spatial ability definitions, spatial tests used, and conclusions drawn (Gorska & Sorby, 2008; Linn & Peterson, 1985).

## **Spatial Ability Research Background**

In the *Engineering Design Graphics Journal for 1936-1978* (EDGJ), there were six articles about visualization (spatial abilities). As published graphics research increased, EDGJ (1975-1996) listed many articles under visualization [spatial ability] and other associated headings (Sadowski, 1997). Miller (1996) discussed engineering graphics education history and visualization research (1920’s - 1990’s) and stated that the first published research article on visualization appeared in 1937. Hartman and Bertoline (2005) stated that “graphics and all that it encompasses is a unique body of knowledge that should be studied, practiced, and scientifically verified” (para. 20). Strong and Smith (2002) stated that “in industrial technology we utilize visualization in applications such as simulations, multi-media, modeling, and distance education” (p. 2). They added that “each person has their own unique visualization skills” (p. 2).

Students' spatial skills are based on their ability to mentally understand, visualize, and manipulate two-dimensional and three-dimensional physical objects or their pictorial representation (Adanez & Velasco, 2002; Miller & Bertoline, 1991). McArthur and Wellner (1996) discussed spatial ability test scores and suggested that tests are possibly incorrectly used to identify whether subjects have spatial abilities. Currently, with a large number of tests available for use in graphics education/spatial ability research, there is no consensus on which test(s) are preferred (Eliot & Smith, 1983). Therefore, a need existed to determine which spatial tests are used and preferred by graphics education researchers and if there is any statistical relationship between these tests.

### **Research Question**

Research articles in engineering design graphics encompass a variety of interests with many researchers using varied spatial ability tests in their analyses. Some areas were prior experience on spatial tests (Baenninger & Newcombe, 1989; Deno, 1995), spatial test modification (Branoff, 2000), student assessment (Connolly, Harris, & Sadowski, 2009; Sorby & Baartmans, 2000), and spatial ability development (Connolly, 2009; Gorska, 2005).

In order to determine preferred spatial ability tests, an Engineering Design Graphics Division (EDGD) member survey was conducted which identified three preferred spatial ability tests, (the MCT, the MRT, and the PSVT: VR). Given the discussion of the varied spatial ability tests available to graphic education researchers (Eliot & Smith, 1983; Eliot, 2000) and the different tests that have been used in the graphics education research, the research question investigated was:

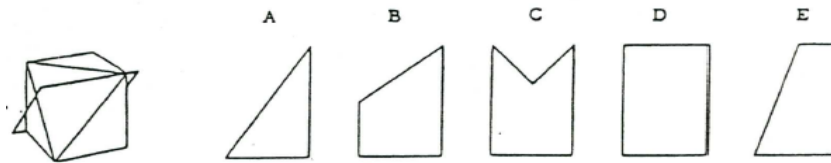
Are there any statistical correlations that exist between the three preferred spatial ability tests, MCT, MRT, and PSVT: VR?

This research studied student spatial ability in an introductory graphic communications course in engineering design graphics using the selected spatial ability tests. The research subjects were students in three spring semester (2012) GC 120 sections at North Carolina State University (N.C. State). Literature was located that utilized spatial ability tests that dealt with this research question.

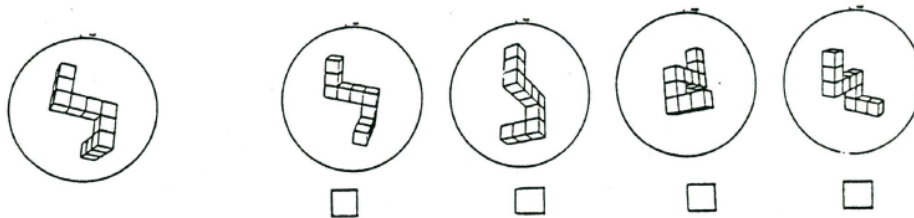
### **Methodology**

First, an EDGD preferred spatial ability test survey was developed. The survey was given to the 2011 EDGD membership via a listserv. In order to develop a listing of spatial tests, a review of articles from 1996 to the present in the graphics education field was conducted. This review shows that articles are predominantly published in journals from ASEE, the EDGD, and the *Journal for Geometry and Graphics* as well as conference proceedings from ASEE and EDGD

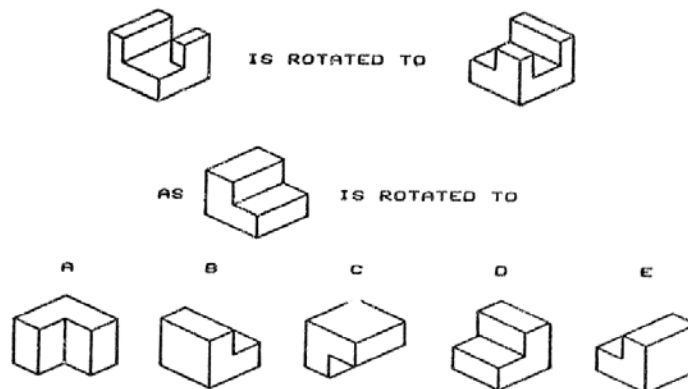
(Chin, 2004; Sadowski, 1997; Wladaver, 1978). These sources identified ten spatial ability tests from several principal (first writer) researchers that specifically utilized spatial ability tests and included their test research results. A review of the spatial ability tests available through the *Educational Testing Service* provided an additional listing of tests that graphics education researchers may use. A compilation of tests from these sources provided a final list of 24 spatial ability tests available for researchers. Through an online survey, EDGD members were asked to select their preferred tests from the list of 24. From the survey results, the top three preferred spatial ability tests were the Mental Cutting Test (MCT, Figure 1, developed by the College Entrance Examination Board in 1939), Mental Rotation Test by Vandenburg and Kuse (MRT, Figure 2, Vandenberg & Kuse 1978), and the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT: VR, Figure 3, Guay, 1977).



**Figure 1. Problem MCT Example**



**Figure 2. Problem MRT Example**



### Figure 3. Problem PSVT: VR Example

Three GC 120 sections were used in this study. Students in these sections signed an IRB consent form. Table 1 shows the design of a spatial ability testing sequence for each GC 120 section. Using this sequence, student pretest sensitization between the three tests was minimized preventing test data contamination.

Finally, test subjects were fully instructed on each test's requirements before the start of each test. Moodle™ course management software was used for test administration to all sections.

**Table 1. Testing Sequence**

| GC 120 Sections | MCT                          | MRT                          | PSVT: VR                     |
|-----------------|------------------------------|------------------------------|------------------------------|
| 00A             | administered 1 <sup>st</sup> | administered 2 <sup>nd</sup> | administered 3 <sup>rd</sup> |
| 00B             | administered 3 <sup>rd</sup> | administered 1 <sup>st</sup> | administered 2 <sup>nd</sup> |
| 00C             | administered 2 <sup>nd</sup> | administered 3 <sup>rd</sup> | administered 1 <sup>st</sup> |

### Data Results

The data was collected from three night sections (N = 100 participants) of GC 120. The specific data collected and analyzed was student test scores on each spatial ability test. Since each GC 120 section was a small convenience sample, non-parametric tests were used for all spatial ability test score analyses (Scales & Petlick, 2004). The level of significance used for all hypotheses testing was  $p \leq .05$ . Table 2 shows the statistical data for all three spatial ability tests.

**Table 2. Spatial Ability Test Statistics**

| Test    | N  | Tests Not Taken | Mean  | Median | Min  | Max | SD    |
|---------|----|-----------------|-------|--------|------|-----|-------|
| MCT     | 99 | 1               | 11.93 | 12.00  | 3.00 | 25  | 5.051 |
| MRT     | 99 | 1               | 27.97 | 30.00  | 2.00 | 40  | 9.357 |
| PSVT:VR | 98 | 2               | 21.43 | 22.00  | 0.00 | 30  | 6.236 |

### Internal Test Consistency

According to Gall, Gall, and Borg (2003), "internal consistency is an approach to estimating test score reliability [coefficient results] in which the individual items of the test are examined" (p. 197). Kuder-Richardson formulas K-R 20 can be used for this evaluation where test items are scored dichotomously (Richardson & Kuder, 1939). All spatial ability tests used in this study



were scored dichotomously; therefore, the K-R 20 formula was used in calculating internal consistency. The calculated K-R 20 coefficients are: MCT (.815), MRT (.868), and the PSVT: VR (.888).

### **Spatial Test Correlation Conclusions**

Sheskin (2004) presents the Spearman's rank-order correlation coefficient non-parametric test that uses rank ordered data for the correlation analysis between two sets of data. As discussed by Greene and D'Oliveira (1999), Spearman's non-parametric test is used for the correlation between a test subject's score on two different tests.

The null hypotheses,  $H_0: r_s = 0$ , (no correlation between each spatial ability test pair) for all combinations of spatial tests were rejected. The alternate hypotheses,  $H_1: r_s \neq 0$ , (there was positive correlation in this study) were accepted. The positive correlation results were  $H_1 \text{ MCT/MRT} : r_s = .351$ ,  $H_1 \text{ MCT/PSVT: VR} : r_s = .599$ , and  $H_1 \text{ MRT/PSVT: VR} : r_s = .647$ .

Suzuki, Shiina, Makino, Saito, and Jingu (1992) reported correlations between the MCT and the MRT of 0.43, 0.42, and 0.58 for studies at three universities which is similar to the correlation result found in this study (.351). Sorby (2000) reported a correlation from a 1999 study between the PSVT: VR and the MCT of 0.528 which is similar to the correlation result found in this study (.599). There were no research articles located reporting correlation between the MRT and PSVT: VR that could provide support for the correlation result found in this study.

These correlation results, although positive but varied in correlation strength (strength of linear association) relate to other reported correlation findings (Agresti & Finlay, 1997).

### **Future Research Recommendations**

The discussion on recommendations for further research is divided into two areas to provide additional investigation into these results: First, the EDGD online survey was a listing of 24 spatial tests included some tests that were only mentioned but not actually used in the reviewed graphic research literature. The listing of 24 tests could be reviewed and shortened to tests actually used in graphics education research for an EDGD membership re-evaluation of top preferences.

Given the discussion on Suzuki, Shiina, Makino, Saito, and Jingu's (1992) interpretation that the MCT evaluates some form of spatial ability, but they were unsure what characteristic the MCT was evaluating and this evaluation by extension may also apply to the MRT and the PSVT: VR. The literature review on spatial factors found evidence that the true spatial tests measurements may not be accurately known among graphics education researchers. An extensive review of the literature on spatial ability factors (such as visualization) should be undertaken to ensure that the factors evaluated by each spatial test is accurately known and not possibly surmised.

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# **Spatial Visualization Ability and Students' Ability to Model Objects from Engineering Assembly Drawing Information**

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## **Abstract**

*During the Spring 2013 semester a study was conducted in a junior-level constraint-based solid modeling course at North Carolina State University to verify the results of a similar study conducted in the Fall of 2012 in the same course. Students were administered the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) and the Mental Cutting Test (MCT) and then were asked to model the parts from information given in an assembly drawing. Relationships were examined between the PSVT:R, MCT, modeling test, final project, and final exam. This paper will present the results of this study.*

## **Introduction**

Several studies have been conducted to examine the usefulness of an engineering graphics literacy test (Branoff & Dobelis, 2012a, Branoff & Dobelis, 2012b, Branoff & Dobelis, 2012c). These studies revealed a positive relationship between this test (see Figure 1) and other measures in the course (e.g., final project and spatial visualization as measured by the PSVT:R). During the Fall 2012 semester, a study was conducted examining the relationship between the engineering graphics literacy test (modeling test) and spatial visualization – as measured by the PSVT:R (Guay, 1977) and the MCT (CEBE, 1939) (Branoff & Dobelis, 2013). There was a significant correlation between the modeling test and both measures of spatial visualization. There was also a significant correlation between the modeling test and the final project in the course. The purpose of the current study is to repeat the Fall 2012 study to verify the results.

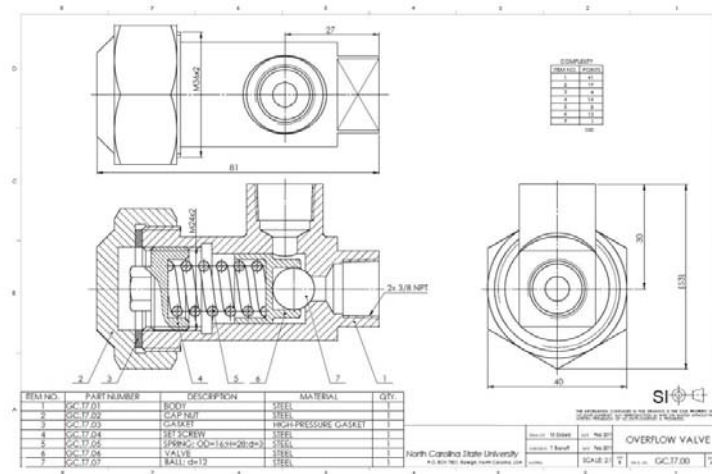


Figure 1. Example of the Modeling Test Drawing.

## Participants

During the Spring 2013 semester, twenty-eight students enrolled in a junior-level constraint-based modeling course participated in the study. Tables 1-3 summarize the demographic information of the students.

Table 1. Gender of Participants.

| Gender | Frequency | Percent |
|--------|-----------|---------|
| Female | 1         | 3.57%   |
| Male   | 27        | 96.43%  |
| TOTAL  | 28        | 100.00% |

Table 2. Academic Year of Participants.

| Year      | Frequency | Percent |
|-----------|-----------|---------|
| Sophomore | 1         | 3.58%   |
| Junior    | 10        | 35.71%  |
| Senior    | 17        | 60.71%  |
| TOTAL     | 28        | 100.00% |

Table 3. Academic Major of Participants.

| Major                                      | Frequency | Percent |
|--|-----------|---------|
| Computer Science                           | 1         | 3.57%   |
| Electrical Engineering                     | 1         | 3.57%   |
| Engineering Undesignated                   | 1         | 3.57%   |
| Industrial and Systems Engineering         | 1         | 3.57%   |
| Mechanical and/or Aerospace Engineering    | 10        | 35.71%  |
| Technology, Engineering & Design Education | 12        | 42.86%  |
| TDE – Graphic Communications               | 2         | 7.14%   |
| TOTAL                                      | 28        | 100.00% |

## Methodology

An activity was completed during the 17<sup>th</sup> class meeting of the semester to explain differences in U.S. and International drawing standards and to give students a chance to practice modeling objects from assembly drawing information. Students were shown how to interpret 3D parts from a 2D assembly drawing and were then given strategies for modeling the parts.

During the 20<sup>th</sup> class meeting students completed electronic versions of the PSVT:R and the MCT. Each test was set-up to terminate after 20 minutes. All students completed a modeling test during the 21<sup>st</sup> class period. This was the same modeling test that was administered in the previous studies (see Figure 1). Once the modeling test was completed, the researcher evaluated the students' models with the same evaluation rubric that was used in the previous studies.

## Analysis of Results

Figures 2-5 show scatterplots displaying relationships between the modeling test and the PSVT:R, MCT, final project, and final exam. Figure 6 shows the relationship between the PSVT:R and the MCT. Table 4 shows the descriptive statistics for the study.

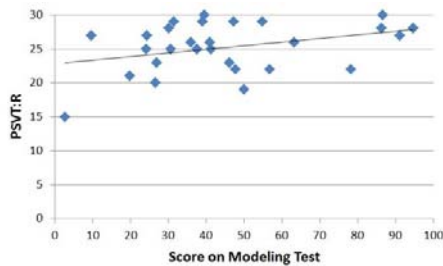


Figure 2. Modeling Test vs. PSVT:R.

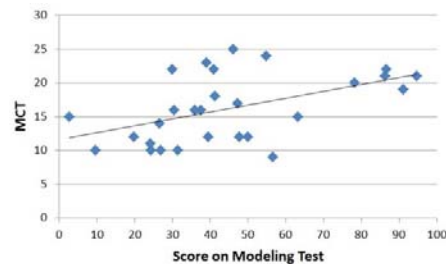


Figure 3. Modeling Test vs. MCT.

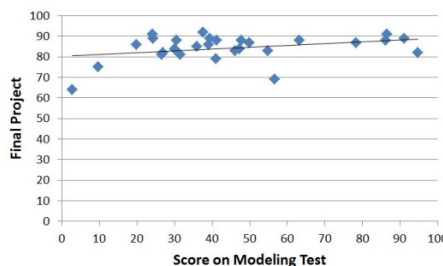


Figure 4. Modeling Test vs. Final Project.

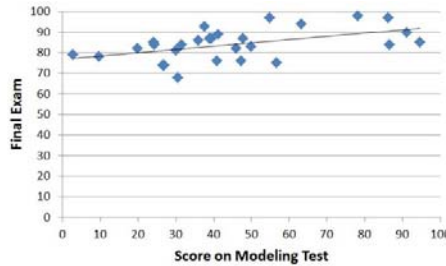


Figure 5. Modeling Test vs. Final Exam.

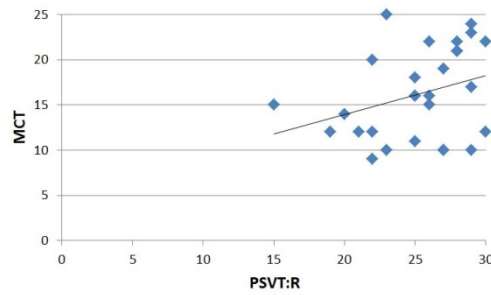


Figure 6. PSVT:R vs. MCT.

Table 4. Descriptive Statistics.

|               | N  | Range | Min.  | Max.  | Mean      |            | Std. Dev. | Variance |
|---------------|----|-------|-------|-------|-----------|------------|-----------|----------|
|               |    |       |       |       | Statistic | Std. Error |           |          |
| PSVT:R        | 28 | 15.00 | 15.00 | 30.00 | 25.21     | .70        | 3.69      | 13.58    |
| MCT           | 28 | 16.00 | 9.00  | 25.00 | 16.21     | .94        | 4.98      | 24.77    |
| Modeling Test | 28 | 91.97 | 2.71  | 94.68 | 45.11     | 4.57       | 24.18     | 584.86   |
| Final Project | 28 | 28.00 | 64.00 | 92.00 | 84.25     | 1.21       | 6.39      | 40.79    |
| Final Exam    | 28 | 30.00 | 68.00 | 98.00 | 84.11     | 1.43       | 7.58      | 57.50    |

Histograms were created to examine the shapes of the distributions of the data. These are shown in Figures 7-11.

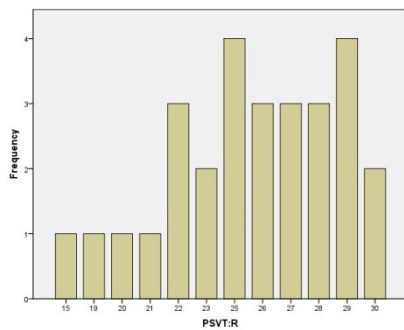


Figure 7. PSVT:R Histogram.

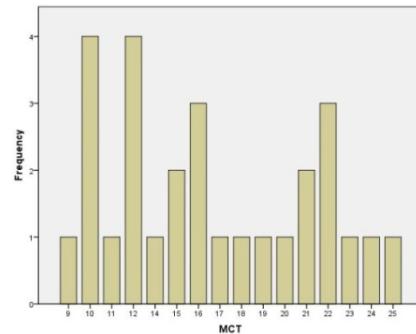


Figure 8. MCT Histogram.

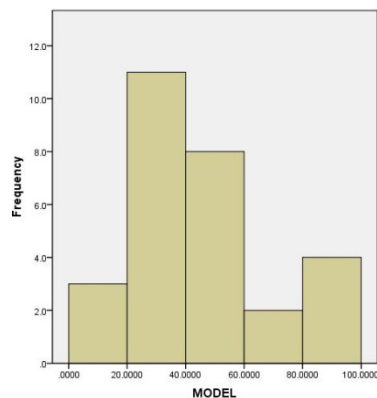


Figure 9. Modeling Test Histogram.

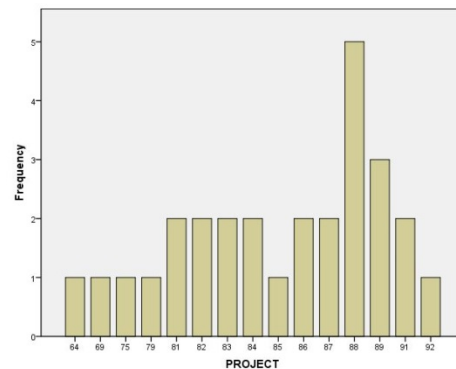


Figure 10. Final Project Histogram.



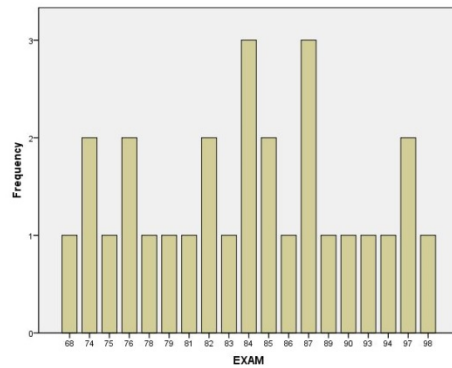


Figure 11. Final Exam Histogram.

The main research question for this study was “is student’s ability to interpret and model information from an assembly drawing related to their spatial visualization ability?” An additional research question was “how does this ability to read assembly drawings relate to other measures in the course (project and exam)?” Since the data do not meet assumptions for parametric tests (normal distributions, etc.), a non-parametric Spearman’s Rho was used to test the hypotheses. Table 5 displays the data for these analyses.

Table 5. Spearman’s Rho Correlations.

| Spearman's rho |                         | Modeling Test | PSVT:R | MCT   | Final Project | Final Exam |
|----------------|-------------------------|---------------|--------|-------|---------------|------------|
| Modeling Test  | Correlation Coefficient | 1.000         |        |       |               |            |
|                | Sig. (2-tailed)         | .             |        |       |               |            |
|                | N                       | 28            |        |       |               |            |
| PSVT:R         | Correlation Coefficient | .273          | 1.000  |       |               |            |
|                | Sig. (2-tailed)         | .160          | .      |       |               |            |
|                | N                       | 28            | 28     |       |               |            |
| MCT            | Correlation Coefficient | <b>.466*</b>  | .341   | 1.000 |               |            |
|                | Sig. (2-tailed)         | <b>.012</b>   | .076   | .     |               |            |
|                | N                       | 28            | 28     | 28    |               |            |
| Final Project  | Correlation Coefficient | .226          | .204   | .072  | 1.000         |            |
|                | Sig. (2-tailed)         | .248          | .298   | .717  | .             |            |
|                | N                       | 28            | 28     | 28    | 28            |            |
| Final Exam     | Correlation Coefficient | <b>.502**</b> | .282   | .324  | <b>.550**</b> | 1.000      |
|                | Sig. (2-tailed)         | <b>.007</b>   | .147   | .093  | <b>.002</b>   | .          |
|                | N                       | 28            | 28     | 28    | 28            | 28         |

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

The Spearman’s Rho analyses show significant correlations between scores on the modeling test and scores on the MCT ( $\rho = .466$ ,  $\alpha = .012$ ) and scores on the modeling test and scores on the

final exam ( $p = .502$ ,  $\alpha = .007$ ). The analyses did not reveal a significant correlation between the modeling test and the other measures (PSVT:R, final project, or the final exam).

## Discussion

The analyses revealed some interesting results. Some of these were consistent with previous studies, and others were not. There was a significant correlation between the modeling test and the MCT. This was consistent with the Fall 2012 study (Branoff & Dobelis, 2013). Students who scored high on the modeling test tended to score high on the MCT. There was not a significant correlation between the modeling test and the PSVT:R. This was not consistent with previous studies (Branoff & Dobelis, 2013; Branoff & Dobelis, 2012b). Examining the scatterplot for the modeling test vs. PSVT:R shows that the PSVT:R scores tended to be in the high range. As mentioned in the Fall 2012 study, the PSVT:R may not be a good discriminator of spatial ability, especially for students in a highly visual curriculum.

## Conclusions

This study confirmed the results from the Fall 2012 study that the MCT has a stronger relationship with modeling ability than the PSVT:R. The requirement of imagining the cross-sectional areas within the MCT is similar to the strategy required for modeling complex 3D parts. The PSVT:R concentrates more on mental rotations. Although this is required for modeling, it is not as important as defining cross-sectional geometry.

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# Impact of Spatial Training on “Non-rotators”

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## **Abstract**

*Rotational ability has been found to be a predictor of success in an engineering curriculum, and two main standardized tests are commonly used to measure rotational ability, the Purdue Spatial Visualization Test: Rotations, and the Vandenberg and Kuse Mental Rotations Test (MRT). A study of the MRT found certain problems on the test can be solved without the use of mental rotation, and test-takers that are successful on those problems on the test but not the ones requiring mental rotation were classified as non-rotators. This paper analyzes students participating in a spatial training course at Michigan Technological University to determine if some of the students can be considered non-rotators and if the spatial training course is successful in improving these students' rotational ability.*

## **Background**

Spatial visualization skills are important in many careers and mental rotation skills have been found to be particularly important to engineers. Several studies have found that skills of students with initially weak spatial skills can be developed through spatial training. Since 1993, a spatial training course has been offered for engineering freshmen at Michigan Technological University who score 60% or below on the Purdue Spatial Visualization Test: Rotations (PSVT:R). The one-credit fourteen-week course covers topics such as isometric and orthographic projections, reflections, cutting planes and cross sections, and object rotations. Instructors of this course have found a tremendous improvement in the spatial skills of the majority of the students taking the training. However, there are always a couple students each year who, although they do make significant gains in their spatial abilities, seem to struggle overall with the course material.

A common test to assess mental rotation skills is the Vandenburg and Kuse Mental Rotations Test (MRT) (1978). Geiser, Lehmann, and Eid (2006) found that not all items on the MRT-A (a 24 question version of the MRT redrawn by Peters, Laeng, et.al (1995)) need be solved by mental rotation, but can be solved by analytical strategies. Of the 24 questions on the MRT-A, the distractors (incorrect choices) for eight of the problems are different in shape than the target figure and can be solved correctly by comparing the shapes of the figures rather than using mental rotation.

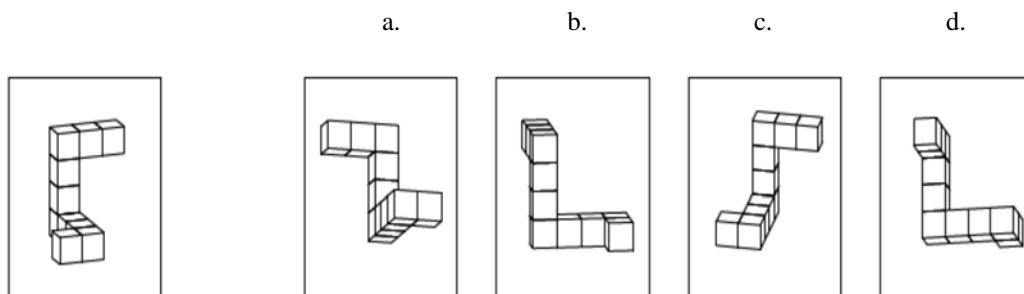
Through a multi-group latent class analysis of 1,695 German students taking the MRT-A, Geiser, Lehmann, and Eid found a class of participants who had high solution probabilities for these eight problems but low solution probabilities for the problems requiring mental rotation. They classified this group of participants as “non-rotators.” Of the 1,695 participants in the study, 13.2% of the participants fell in the non-rotator class for the first twelve items on the MRT-A, and 17.3% of the participants were classified as non-rotators on the second twelve items on the test. No studies have been performed to see if spatial training can improve the performance of the non-rotators on the MRT-A questions that require mental rotation.

### Purpose of Study

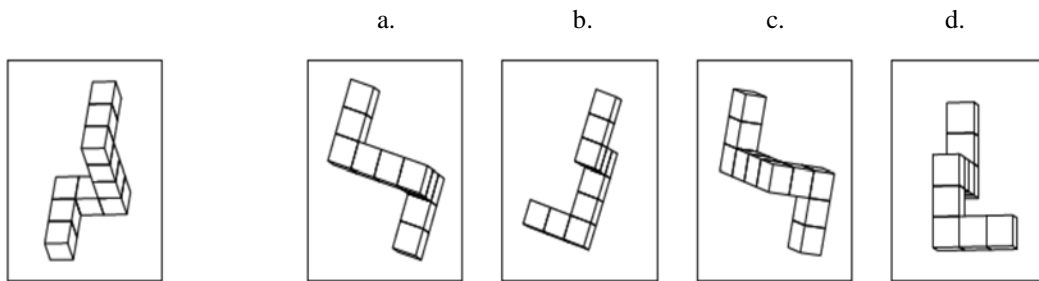
In order to determine if those students who improve, but still struggle in the spatial training course, are non-rotators, and to investigate if spatial training can improve the performance of non-rotators on the questions on the MRT-A that do require rotation, students in the Michigan Tech spatial training course have been given the MRT-A on the first and last day of the course since 2009. If the students who struggled in the spatial training course were indeed non-rotators, then it may be possible these students require a specialized spatial training approach.

### Method

On the first day of the spatial training class, the MRT-A was administered to all students in the class. Each item on the test shows an object, then students must choose which *two* of four possibilities are rotations of the original object. Example problems provided in the instructions for the test are shown in Figures 1 and 2 below. Note that in Figure 1 the distractors are mirror images of the target object, but in Figure 2, the distractors are different in shape than the target object. Those questions on the test where the distractors are different in shape than the target figure can be solved correctly by noticing this difference rather than using mental rotation.



**Figure 1: Example problem on MRT-A instructions that may require rotation**



**Figure 2: Example problem on MRT-A instructions that may not require rotation**

The 24-question test was administered in two parts. Students were given four minutes to complete the first twelve questions of the MRT-A, the twelve question test booklets were collected, and the next twelve questions were distributed. Students then had another four minutes to complete the second set of twelve questions on the test. Standard testing procedures call for answers to be indicated by putting an “X” across the two figures which are rotated versions of the target figure. However, the instructors asked students to indicate their results on an optical scanning form, rather than on the test booklet itself. The test is scored such that both correct figures must be correctly identified to score a point, for a maximum of 24 points possible. This same testing procedure was used on the last day of the 14-week class.

In order to determine if students could be classified as non-rotators at the beginning of the spatial training course, the success rate on attempted MRT-A questions not requiring rotation was compared to the success rate on those attempted that required rotation on the MRT-A pre-test. Success on attempted problems rather than all possible problems was compared as few students complete the twelve questions in the four minute time period and the non-rotation questions are not equally distributed among the twelve questions. Students were classified as non-rotators if they scored 25 percent or below on attempted questions requiring rotation (slightly better than chance), but had a higher success rate on attempted problems not requiring rotation. To determine if the spatial training course was effective at increasing students’ rotational abilities, pre- and post-test analyses were performed using both the MRT-A and the PSVT:R.

## Results

Table 1 below compares the success rate on attempted questions on the MRT-A pre-test for students classified as “rotators” and “non-rotators.” Although a success rate of 25% or below on attempted problems requiring rotation was the target criteria, one student who scored 27% on problems requiring rotation and 80% on problems not requiring rotation was also classified as a non-rotator due to the large difference in success rate between the two types of problems. Of the 459 students who took the MRT-A at the beginning of the spatial training course, 28 (6.1%) were determined to be non-rotators. The percentage of students classified in our study as non-rotators is

about half those classified as non-rotators in the Geiser, Lehmann, and Eid (2006) study. This is surprising as all students in this study scored 60% or below on the PSVT:R, while Geiser, Lehmann, and Eid sampled a general population of students; however, it could be that engineering attracts a large proportion of people with high spatial ability, so this could perhaps be a reason we observed fewer non-rotators. When the course instructors reviewed the names of the students classified as non-rotators through this analysis, some of the students appearing on the list were unexpected as they seemed to perform quite well in the spatial training course. Some, but not all, of the students that really struggled in the course were identified as non-rotators.

**Table 1: MRT-A Pre-test Analysis**

|              | Score for Attempted Problems not Requiring Rotation | Score for Attempted Problems Requiring Rotation | Overall Score out of 24 Possible Problems | Number of Students |
|--------------|---|---|---|--------------------|
| Rotators     | 84.1%   | 67.2%   | 12.5                                      | 431                |
| Non-rotators | 67.4%   | 16.8%   | 5.2                                       | 28                 |

Table 2 compares the MRT-A pre- and post-test results for the students identified as non-rotators on the pre-test. Students are listed on the table primarily in order from least improvement to most improvement on percentage correct of attempted rotator questions. From Table 2, it can be noted that:

- Students 9 through 27 all had gains of greater than 19% in their success rate.
- Students 9 through 27 with the exception of student 12 had success rates greater than 40% on attempted rotator problems.
- Student 8 had a success rate greater than 25% on attempted problems, but a smaller percentage gain on the post-test compared to the pre-test. A closer analysis of student 8 showed this student was correct on 3 out of 12 attempted rotator problems on the pre-test, but was correct on 6 out of 16 attempted problems on the post-test.
- Students 1 through 7 on Table 2 generally did not show the improvement students 8 through 27 did, and their score for the attempted rotator problems on the post-test was still below 25%.
- While students 8 through 28 showed significant improvement in their overall score and success rate on attempted rotator problems, they were still below the averages for all other students in the spatial training.

By comparing the pre- and post-test MRT-A results, it appears students 8 through 27 did shift from being non-rotators to becoming rotators, while students 1 through 7 did not. One of the students

identified as a non-rotator on the pre-test only attended the spatial training course sporadically and did not complete the post MRT-A and PSVT:R, so this student was removed from further analyses.

**Table 2: Comparison of Pre- and Post-Test Success on MRT-A**

| Student                                    | Pre-test Score out of 24 | Post-test Score out of 24 | Pre-test Score for Attempted Problems not Requiring Rotation | Post-test Score for Attempted Problems not Requiring Rotation | Pre-test Score for Attempted Problems Requiring Rotation | Post-test Score for Attempted Problems Requiring Rotation | Percent Improvement on Post-Test Attempted Problems Requiring Rotation |
|--|--------------------------|---------------------------|--|---|--|---|--|
| 1  | 4                        | 6                         | 37.5%  | 62.5%   | 8.3%   | 8.3%  | 0.0%   |
| 2  | 4                        | 7                         | 28.6%  | 62.5%   | 16.7%  | 14.3%   | -2.4%  |
| 3  | 6                        | 7                         | 37.5%  | 50.0%   | 18.8%  | 18.8%   | 0.0%   |
| 4  | 5                        | 8                         | 75.0%  | 83.3%   | 25.0%  | 25.0%   | 0.0%   |
| 5  | 5                        | 10                        | 75.0%  | 62.5%   | 25.0%  | 31.3%   | 6.3%   |
| 6  | 3                        | 7                         | 75.0%  | 50.0%   | 0.0%   | 18.8%   | 18.8%  |
| 7  | 3                        | 7                         | 75.0%  | 57.1%   | 0.0%   | 23.1%   | 23.1%  |
| 8  | 10                       | 12                        | 87.5%  | 75.0%   | 25.0%  | 37.5%   | 12.5%  |
| 9  | 4                        | 12                        | 66.7%  | 87.5%   | 22.2%  | 41.7%   | 19.4%  |
| 10   | 7                        | 10                        | 80.0%  | 25.0%   | 27.3%  | 50.0%   | 22.7%  |
| 11   | 9                        | 12                        | 85.7%  | 71.4%   | 23.1%  | 46.7%   | 23.6%  |
| 12   | 3                        | 7                         | 25.0%  | 25.0%   | 6.7%   | 31.3%   | 24.6%  |
| 13   | 5                        | 9                         | 60.0%  | 83.3%   | 25.0%  | 50.0%   | 25.0%  |
| 14   | 4                        | 12                        | 50.0%  | 50.0%   | 22.2%  | 50.0%   | 27.8%  |
| 15   | 4                        | 9                         | 50.0%  | 75.0%   | 25.0%  | 60.0%   | 35.0%  |
| 16   | 5                        | 10                        | 75.0%  | 100.0%  | 22.2%  | 60.0%   | 37.8%  |
| 17   | 6                        | 14                        | 62.5%  | 87.5%   | 8.3%   | 46.7%   | 38.3%  |
| 18   | 9                        | 16                        | 75.0%  | 100.0%  | 18.8%  | 60.0%   | 41.3%  |
| 19   | 5                        | 8                         | 100.0%   | 75.0%   | 12.5%  | 55.6%   | 43.1%  |
| 20   | 2                        | 12                        | 40.0%  | 50.0%   | 0.0%   | 50.0%   | 50.0%  |
| 21   | 5                        | 9                         | 100.0%   | 75.0%   | 25.0%  | 75.0%   | 50.0%  |
| 22   | 6                        | 19                        | 100.0%   | 75.0%   | 22.2%  | 81.3%   | 59.0%  |
| 23   | 4                        | 18                        | 37.5%  | 87.5%   | 6.7%   | 68.8%   | 62.1%  |
| 24   | 6                        | 14                        | 100.0%   | 100.0%  | 22.2%  | 88.9%   | 66.7%  |
| 25   | 10                       | 18                        | 100.0%   | 100.0%  | 23.1%  | 92.3%   | 69.2%  |
| 26   | 2                        | 17                        | 50.0%  | 62.5%   | 0.0%   | 75.0%   | 75.0%  |
| 27   | 6                        | 16                        | 100.0%   | 100.0%  | 18.2%  | 100.0%  | 81.8%  |
| Student 1 – 7 Average                      | 4.3                      | 7.4                       | 57.7%  | 61.1%   | 13.4%  | 19.9%   | 6.5%   |
| Student 8 – 27 Average                     | 5.6                      | 12.7                      | 72.2%  | 75.2%   | 17.8%  | 61.0%   | 43.2%  |
| All other students in the spatial training | 12.5 (n = 431)           | 16.5 (n = 416)            | 84.1%  | 86.4%   | 67.2%  | 72.9%   |  |

Table 2 also compares pre- and post-test success on attempted non-rotator questions. Some students were less successful on the non-rotator problems on the post-test than they were on the pre-test. This may be because these students attempted to use a different strategy (possibly a rotation strategy) on the post-test than they did on the pre-test. In comparing these groups of students it can be seen that:

- Students 8 – 27 had a 14.5% higher pre-test average and a 14.1% higher post-test average on the non-rotator questions than students 1 – 7.
- On the rotator questions, students 8 – 27 had a 4.4% higher pre-test average and a 41.1% higher post-test average than students 1 – 7. This may suggest that students 8 – 27 had initially better developed spatial skills (but not rotational skills) than students 1 – 7.

Pre- and post-test results on the PSVT:R are compared in Table 3 on the next page. Scores for student 1 are shown, but were not averaged with the remaining students as this student put forth little effort in the spatial training class and it appeared the post-test score for this student was skewing the results. Pre- and post-test scores were not found for student 7. Students 2 - 6 had the same average pre-test score on the PSVT:R as students 8 – 27. Unlike the MRT-A results, it appears that the spatial training helped students 2 - 6 almost as much as students 8 - 27 (students 8 - 27 had a PSVT:R post-test average only 1.7% higher than students 2 - 6). This may be due to the fact that the rotation content of the spatial training course is more similar to the rotation tasks performed on the PSVT:R than the MRT-A. In the training, students are asked to identify how an object is rotated or to perform a rotation of an object about one or more axes of a 3-D Cartesian coordinate system. Problems on the PSVT:R are rotated in this fashion also, while problems on the MRT-A are rotated in a more random fashion. Student familiarity with rotations about axes of a 3-D Cartesian coordinate system may have helped all non-rotators equally on the PSVT:R. It should be noted that both pre- and post-test averages of students 1 – 27 were below the averages for all other students in the spatial training course, indicating that the students initially identified as non-rotators did have more difficulty with rotations than the other students participating in the training.



**Table 3: Comparison of Pre- and Post-Test Success on PSVT:R**

| Student                                       | PSVT:R pre-test score out of<br>30 | PSVT:R post-test score out of<br>30 |
|---|------------------------------------|-------------------------------------|
| 1   | 17                                 | 5                                   |
| 2   | 12                                 | 16                                  |
| 3   | 12                                 | 20                                  |
| 4   | 18                                 | 22                                  |
| 5   | 13                                 | 17                                  |
| 6   | 16                                 | 23                                  |
| 7   |                                    |                                     |
| 8   | 3                                  | 16                                  |
| 9   | 12                                 | 23                                  |
| 10  | 17                                 | 26                                  |
| 11  | 12                                 | 20                                  |
| 12  | 14                                 | 19                                  |
| 13  | 17                                 | 14                                  |
| 14  | 14                                 | 14                                  |
| 15  | 13                                 | 23                                  |
| 16  | 18                                 | 13                                  |
| 17  | 17                                 | 21                                  |
| 18  | 16                                 | 24                                  |
| 19  | 16                                 | 27                                  |
| 20  | 14                                 | 22                                  |
| 21  | 18                                 | 22                                  |
| 22  |                                    | 24                                  |
| 23  | 15                                 | 22                                  |
| 24  | 13                                 | 18                                  |
| 25  | 13                                 | 19                                  |
| 26  | 11                                 | 16                                  |
| 27  | 16                                 | 19                                  |
| Student 2 – 6 average                         | 14.2                               | 19.6                                |
| Student 8 – 27 average                        | 14.2                               | 20.1                                |
| All other students in the<br>spatial training | 15.6<br>(n=436)                    | 22.8<br>(n= 419)                    |

## Conclusion

Students were classified as non-rotators if they scored 25% or below on attempted MRT-A questions requiring rotational strategies. Of the students in the spatial training, only 6.1% were classified as non-rotators. Additionally, the instructors were surprised that some of the students were identified as non-rotators as well as some of the students that were not labeled as such.

Spatial training appears to have helped a significant number of these non-rotators become rotators. On the MRT-A post-test, approximately 75% of the students initially classified as non-rotators improved their ability to rotate enough to no longer be considered non-rotators (their success rate on questions requiring rotational strategies improved to more than 25%). This indicates that there is a smaller group of students (25% of non-rotators, 1.5% of students trained) that did not significantly improve their rotational skills. However, it does appear that the spatial

training does help this small percent of students improve on rotation tasks tested on the PSVT:R nearly as well as the other non-rotators. While the spatial training improved most non-rotator's rotational skills, their skills are still below average for the students participating in the spatial training.

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# Developing Spatial Skills Among Middle School Students

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## **Abstract**

*Spatial skills have been the topic of educational research for decades and the importance of well-developed spatial skills to success in STEM fields is well-documented. Gender differences in spatial skills, especially in the area of mental rotation, have been observed in numerous studies. Helping students develop their 3-D spatial skills has been shown to lead to improvements in student success in engineering, particularly for women. Most of the research in spatial cognition conducted to date has been correlational in nature, i.e., spatial skills are correlated with success in engineering or other STEM fields. Graduates of STEM fields typically have highly developed spatial skills, but is this due to developing the skills over the course of study or is it due to “weeding out” of students with low spatial ability from these programs? Are high spatial individuals attracted to STEM disciplines? The answer to these questions is unknown but is likely a combination of these phenomena. The question remains: “If we help individuals develop their spatial skills at a sufficiently young age, can we increase their interest for STEM and their apparent willingness to choose STEM careers?” This paper describes an ongoing study that seeks to answer this question.*

## **Background**

Multimedia software and a workbook were developed by Sorby and Wysocki with funding from the National Science Foundation in 1998 (Gerson, et al, 2001). These materials have been the topic of several research studies since then and the primary findings from this body of work are (Sorby, 2001, Sorby, 2005, Sorby 2009, and Veurink & Sorby, 2011):

- 3-D spatial skills can be improved through training and practice.
- Spatial-skills training appears to have a significant positive impact on grades earned in a variety of STEM courses, including engineering graphics.

- Spatial-skills training appears to have a significant positive impact on student retention and graduation in engineering, particularly for women.

Engineering remains one of the least diverse of all STEM fields. Despite millions (perhaps billions) of dollars spent and the concerted efforts of many dedicated professionals, the percentage of women in engineering hovers around 17-18% and has been essentially unchanged for 30 years. While the work in spatial skills training has helped to retain those women who do choose engineering, this is only a piece of the puzzle. If engineering is to become more diverse in terms of gender, we must be able to attract more women into the field.

There is strong evidence to suggest that girls lose interest in science and mathematics in middle school (Catsambis, 1995). By the time most girls get to high school, they have “opted out” of the advanced math and science courses needed for engineering and the girls who do remain engaged with these courses are often attracted to careers in medicine, rather than one of the STEM fields. Thus, it is important to reach young women at a sufficiently young age, if we are to have an impact on their later career choices.

### **Current Study**

In 2010, the authors were awarded a grant from the National Science Foundation through the Gender in Science and Engineering program to conduct a study aimed at improving the spatial skills of middle school students and to determine the impact of this training on those students, particularly the girls. To conduct the study, we partnered with two school districts, Marquette Area Public Schools in Marquette, Michigan, and the Weld Region-8 District, in Fort Lupton, Colorado. Each school district has about 150-200 students per grade level. The Fort Lupton school has a significant Hispanic population with about 70% of the students who speak English as a second language.

During the summer of 2011, one seventh-grade math teacher from each district was trained in the use of the spatial skills curriculum. It should be noted that each district had two teachers responsible for seventh grade math instruction—the untrained teacher served as the “control” teacher for this study. The training sessions were conducted by faculty who have been teaching the spatial skills course at Michigan Tech for numerous years. Training for each teacher was completed in about 10-12 hours of instruction and consisted of time spent on an overview of the data obtained from previous research in spatial cognition followed by the teacher completing each module in the software/workbook, with guidance from the trainer. Teachers were told that they could decide how they wanted to incorporate the materials into their regular mathematics instruction.

The teacher in Marquette decided to intersperse the spatial skills training throughout the academic year, covering one module at the end of each unit in her math course. Thus, the spatial

skills instruction became the “fun” thing to do at the end of each unit. The teacher in the Fort Lupton school district chose to focus on the spatial skills training at the beginning of the year and had completed all of the instruction by Thanksgiving.

Students in both the experimental and control groups were administered a number of instruments prior to the start of the spatial skills training. Six of the instruments were used to assess spatial skills and included: 1) the Water-level task, 2) a paper-folding task, 3) a 2-D rotation instrument, 4) ten items from the Purdue Spatial Visualization Test: Rotations (PSVT:R) for measuring 3-D rotation ability, 5) ten items from the Modified Lappan instrument, and 6) ten items from the Mental Cutting Test (MCT). In addition, students completed three attitudinal surveys regarding their job interests and beliefs. The students completed all nine instruments again after completion of the spatial skills training. Students in the control groups completed the pre-/post-instruments at about the same time in the academic year.

Unfortunately, the teacher at Fort Lupton left the district at about the time that the spatial skills instruction was complete and we became concerned that the teachers' departure might have affected students' willingness to complete the post-test instruments. It seemed possible that the short-term results from this research may have been compromised by the sudden departure of the teacher although we expect that even if so, subsequent waves of data collection would not be affected. Given our concern, we decided to conduct the experiment again the following year at both districts, a modification to our original plans that also has the advantage of providing additional samples on which to test the effects of the curriculum.

For the second year of the study, the untrained teacher in each district went through the spatial skills training and incorporated the materials as they saw fit in their regular mathematics instruction. The teacher in Marquette chose to incorporate the spatial skills training throughout the year, as did her colleague in the previous year. The teacher in Fort Lupton chose to focus on the spatial skills training at the end of the academic year, rather than the beginning. Table 1 outlines the research design for this study.

Table 1. Research Methods (shading denotes spatial skills training within math course)

|        | Marquette |           | Fort Lupton |           |
|--------|-----------|-----------|-------------|-----------|
|        | Teacher 1 | Teacher 2 | Teacher 1*  | Teacher 2 |
| Year 1 |           |           |             |           |
| Year 2 |           |           |             |           |

\* In Year 2 of the study, teacher 1 at Fort Lupton was a new teacher hired to fill the position for the person who vacated the district during the previous year.

In addition to the pre- and post-testing with the instruments designed to assess spatial skills and attitudes towards STEM careers and learning, we are gathering data from each district regarding:

- Standardized math and science scores
- Grades in math and science courses

- Gender and ethnicity

## Results to Date

There is a great deal of data being generated by this study and analysis is still underway. There were issues with the collection of the data from Fort Lupton, so data from this district is not included in this paper. As expected, there were significant gender differences on most of the spatial tasks in the district for which those data have been analyzed. Table 2 includes the pre-test data by gender for year 1 of the study.

Table 2. Average Pre-test scores by gender for Marquette

|  | Males         | Females       |
|--|---------------|---------------|
| Paper Folding<br>(20 pts possible)                                     | 7.9<br>(0.5)  | 6.5<br>(0.4)  |
| 2-D Rotation<br>(30 problems with<br>multiple correct<br>answers each) | 38.2<br>(2.0) | 30.1<br>(2.0) |
| PSVT:R<br>(10 pts possible)  | 3.3<br>(0.3)  | 2.5<br>(0.3)  |
| MCT<br>(10 pts possible)   | 2.0<br>(0.5)  | 1.4<br>(0.2)  |
| Lappan<br>(10 Pts possible)  | 2.2<br>(0.3)  | 1.4<br>(0.3)  |
| Water-Level<br>(6 pts possible)  | 2.9<br>(0.2)  | 2.2<br>(0.2)  |

NOTE: Standard errors are in parentheses.

For the data presented in Table 2, statistically significant gender differences exist for 5/6 spatial ability tests that were administered. The only exception was MCT which was the most difficult test and may have suffered from a floor effect.

At the end of the intervention, students in both the experimental and control groups were post-tested with the same instruments. Table 3 includes these results for the first year of the study for Marquette.

Table 3. Pre-/Post-Test Scores for Marquette Schools

|               | Experimental Group |                   | Control Group    |                   |
|---------------|--------------------|-------------------|------------------|-------------------|
|               | Average Pre-Test   | Average Post-Test | Average Pre-Test | Average Post-Test |
| Paper Folding | 6.0<br>(0.5)       | 9.0<br>(0.6)      | 6.3<br>(0.5)     | 7.6<br>(0.6)      |
| 2-D Rotation  | 30.9<br>(2.3)      | 39.4<br>(2.6)     | 28.2<br>(2.0)    | 38.6<br>(2.3)     |
| PSVT:R        | 2.3<br>(0.3)       | 3.2<br>(0.4)      | 2.6<br>(0.3)     | 3.3<br>(0.3)      |
| MCT           | 1.0<br>(0.3)       | 2.9<br>(0.3)      | 1.2<br>(0.3)     | 1.7<br>(0.3)      |
| Lappan        | 1.1<br>(0.3)       | 2.6<br>(0.3)      | 1.4<br>(0.3)     | 2.0<br>(0.30)     |
| Water-Level   | 2.6<br>(0.3)       | 2.9<br>(0.2)      | 2.2<br>(0.2)     | 2.4<br>(0.2)      |

NOTE: Standard errors are in parentheses.

For 2-D rotation and PSVRT;R, all students improved significantly from pre- to post-test. For Paper Folding, Lappan, and MCT, the experimental group improved more from pre- to post-test than did the control group.

### **Conclusions**

This study is a work in progress. Seventh grade students in two school districts have participated in spatial skills training to determine the impact of this training. It is hoped that not only will the students improve their spatial skills, but that they will also perform better in their math and science courses and state-level testing, and that their interest in STEM will increase as a result. Results from this research will be reported in future EDGD conferences.

### **Acknowledgement**

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# Using Think-Aloud Exercises to Reveal Students' Solid Modeling Strategies

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## **Abstract**

*This paper describes the results of a think-aloud exercise wherein students describe the modeling strategy that they would use to create a 3D feature-based solid model of a simple part. Eleven students were asked to articulate their modeling decisions while sketching the intermediate solid shapes resulting from each feature creation step. The results show that students tend to select the easiest modeling methods based on their visualization of the part, using either additive or subtractive approaches. Most students did not tend to plan ahead, identify alternative strategies, or consider ease of alteration or other downstream uses of the model.*

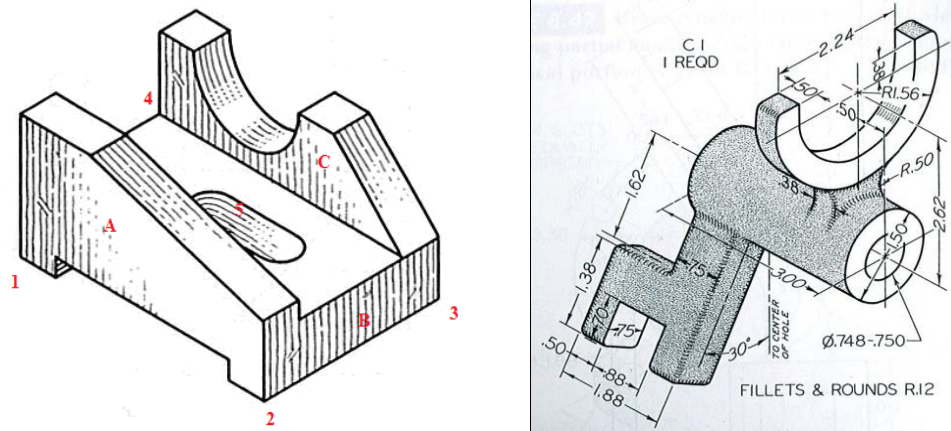
## **Introduction**

Think-aloud protocols ask participants to verbalize their thought processes during problem solving activities (Taraban et al, 2007). This study sought to reveal which factors are considered when students create models of simple parts using feature-based 3D solid modeling (CAD) software. The modeler must make a wide range of modeling decisions such as selecting the base feature and subsequent features, choosing sketching planes and sketch position/orientation, and establishing dimensional and geometric constraints. While there may be many possible methods for creating a specified geometry, best practices should be used to create a robust model that captures design intent and facilitates downstream use of the model (Chester, 2008; Rynne and Gaughran, 2008).

## **Methodology**

Students enrolled in a second year solid modeling course at XYZ University were invited to participate in the think-aloud study. Participants were asked to solve typical solid modeling problems and explain their strategies and methods. Students were shown isometric sketches of the selected parts (Figure 1; red lettering not included) and asked to describe the modeling procedures that they would use while sketching the resultant models at each step in the modeling process. Students were asked to identify and sketch each feature profile and placement, and explain their choices. The students' sketches and verbal responses were captured on video tape and transcribed for analysis.



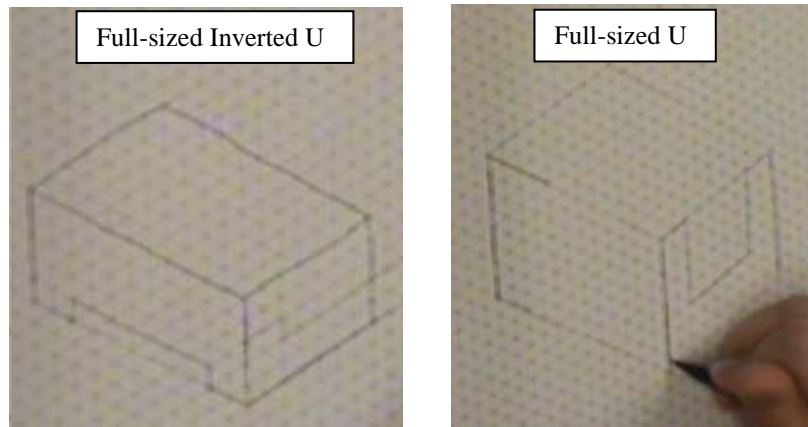


**Figure 1. Parts used for think-aloud modeling study.**  
**Block, left (Luzadder, 1993) and Shifter Fork, right (Giesecke, 2000).**

## Results

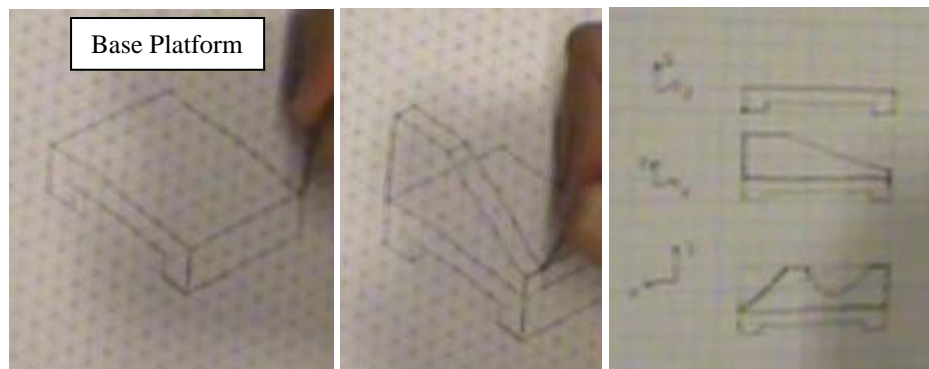
Eleven students participated in the think-aloud study (four sophomores, 2 juniors and 5 seniors). Only the results of modeling the Block are reported here. All of the students had completed a first-year graphics course which included sketching as well as both 2D and 3D CAD. Student majors included mechanical engineering, aerospace engineering, and computer graphics technology. In addition to different majors, students reported varying levels of CAD experience; five reported using solid modeling in high school (such as Project Lead the Way), five had used solid modeling during internships that lasted from 3 months to 2 years, and four reported using solid modeling for project work in other courses. A preliminary analysis of the data reveals three basic decisions that students made during the modeling procedure for this simple part: selection of the base feature, placement and orientation of the part in the global coordinate system, and use of constraints for sketches and terminal conditions.

**Base Feature Selection:** The first decision typically made is the choice of the base feature; the Block has a range of base features from which one could choose. The most common base features were a full-sized rectangular prism used by three of the students, and a full-sized U or inverted U shaped feature used by three of the students. See Figure 2. All six of these students then used similar cut features to remove material as needed to model the part, with rectangular sketches to create the U or inverted U cuts, then typically working from front to back using simple triangles and arcs for the cut features on the vertical protrusions. All of the students completed the part using an extruded cut for the central slot (Figure 1, feature 5). This subtractive strategy is sometimes taught at the secondary school levels in order to guide students to create models that are physically possible to manufacture (PLTW Inc., 2012). Some of these students mentioned manufacturing considerations when explaining their choice of modeling strategy.



**Figure 2. Student sketches of base features for the Block (subtractive strategy).**

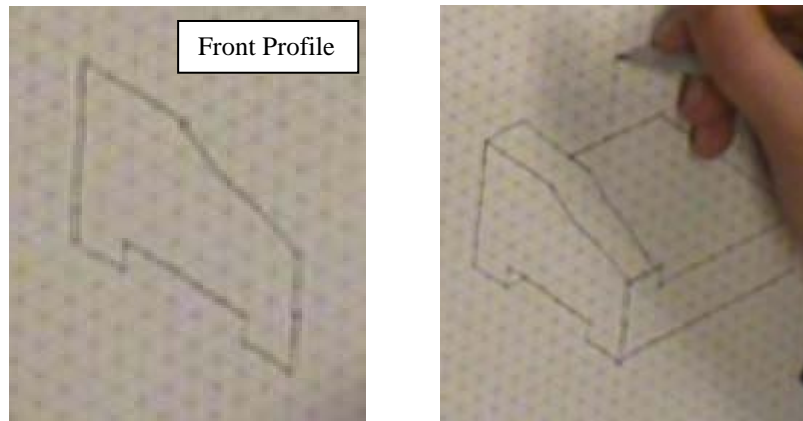
The remaining five students selected an additive modeling strategy. Four students chose a base platform in the form of a rectangular prism or the base prism with an inverted U shape as shown in Figure 3 (left). These students created the bottom cut feature if not included in the base platform, then added extrusions sketched on the front and back faces of the base platform to create the vertical features. Note that these sketches were more complex than those required for the subtractive modeling strategy. Students rationalized this modeling strategy by stating that they typically worked “from bottom to top” or “from front to back”.



**Figure 3. Student sketches of base and subsequent features (additive strategy).**

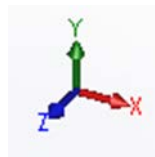
The remaining student chose to extrude the front profile as the base feature; Figure 4. The student then extruded the center section as a rectangle from the right end (Figure 1, surface B), extending the rectangle to the back face of the part. The third feature, for the top of the rear vertical protrusion, was modeled using a sketch on an offset plane as shown in Figure 4. This student had the least amount of solid modeling experience of all the student participants, appeared to struggle with the decomposition of the part into model-based features, and was focused on

simply reproducing the isometric sketch on paper. The student had difficulty visualizing the part and did not realize that the cut feature on the bottom of the part extends through the part.



**Figure 4. Student sketch of front profile for base feature (left), second feature and start of third feature sketch (right).**

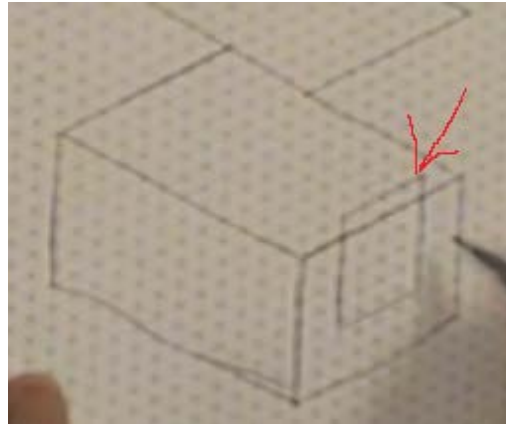
**Placement and Orientation of Part:** Six students did not discuss location and orientation. Even though base feature choice was grouped tightly, origin placement varied greatly. The three bottom corners visible in the isometric example (corners 1, 2, and 3 in Figure 1) were all cited as origin locations. These students believed their origin placement was for easy modeling. Note, however, that common solid modeling systems typically orient the global coordinate system as shown in Figure 5, and default to sketching on the x-y plane and extruding a sketch on the x-y plane in the positive Z direction. In this situation, the origin of the part would typically not be located in any of the locations cited by the students, but at the lower back corner of the part for base features shown in Figure 2 (left), Figure 3 and Figure 4. One student placed the origin in the bottom center so that he could locate the center of the slot there and that the slot would always remain centered in the part.



**Figure 5. Orientation of global coordinate system in default isometric view.**

**Constraints:** A common theme was the extension of sketches and cuts past the edge of the existing model geometry, as shown in Figure 6, in order to "make sure to get it all". Several students mentioned a mistrust of the software, as if the modeling software would not cut the part

correctly if the sketch is made right on the edge. This indicates a lack of understanding of constraints, assuming the sketch line always automatically constrains itself to the edge without specific action by the user. In addition, it was common for dimensional constraints to be used where geometric constraints would be more suitable for capturing design intent.



**Figure 6. Unconstrained sketch geometry.**

**Modeling Strategy Rationale:** Expert modelers often create fewer features than student modelers, which makes better use of the parametric modeling system and makes alteration easier (Chester, 2008; Johnson, 2011). Rynne and Gaughran (2007) claim that best practice strategies for solid modeling require the user to identify a base feature which will minimize the number of remaining features and facilitate alteration of the model. The majority of the students chose their base feature based on what they felt was the most prominent feature. Ease of modeling was the 2nd most popular reason for base feature choice, followed by manufacturing considerations. Ease of modeling and prominent feature were sometimes clarified with "it was the closest part" meaning that they choose the feature closest to the front in the presented isometric view, as shown in Figures 2-4. Students seem to model parts with primary consideration to simply reproducing the desired geometry without consideration of manufacturing, flexibility or relationships between features. Although this is their second SM course, and many of the students had additional high school, project or internship experience, these students did not express any strategic alternatives or planning decisions unless prompted by the interviewer. None of the students mentioned efficiency of modeling or ease of alteration, which are typically cited by experts as the basis for their modeling strategies. This is a skill that comes with learning modeling based on design intent and from experience modifying parts that have been created by other users.

## **Conclusions**

The most popular reasoning behind any decision made by the subjects is that it made the process easy; this was followed by small minority with some manufacturing concern. Alternatives

were not considered or stated; it seems like these solutions were the first ones that the students came up with rather than thinking about relationships between features and how each step will affect the usability of the final model. The forethought of design, normally shown by experts in industry is known as strategic 3dsm; the best practice is one which makes the model easiest to change (Chester, 2008). This strategic thinking should be taught in the classroom.

The brief analysis performed for this study suggests the need for expanded research. Some students demonstrated difficulty in visualizing and decomposing the parts. Although not reported here, the think-aloud exercise was also completed with additional parts such as the shifter fork shown in Figure 1. The effect of using alternative representations of the parts such as orthographic drawings vs. isometric sketches, and presence of dimensions may have some influence on the strategies used by the students. Although the use of sketching vs. directly modeling on the CAD system was intended to facilitate and expedite the study, some students were confused by the instructions and reverted to reproducing the isometric sketch rather than creating a representation of the features of the desired solid model. Thus, it would be of further interest to repeat the study using a solid modeling system rather than sketching. This could reveal modeling errors that students correct “on the fly” when these errors result in incorrect geometry or cause later modeling difficulties.

### **Acknowledgements**

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# Conceptualization in Visuospatial Reasoning Tasks: A Research Direction

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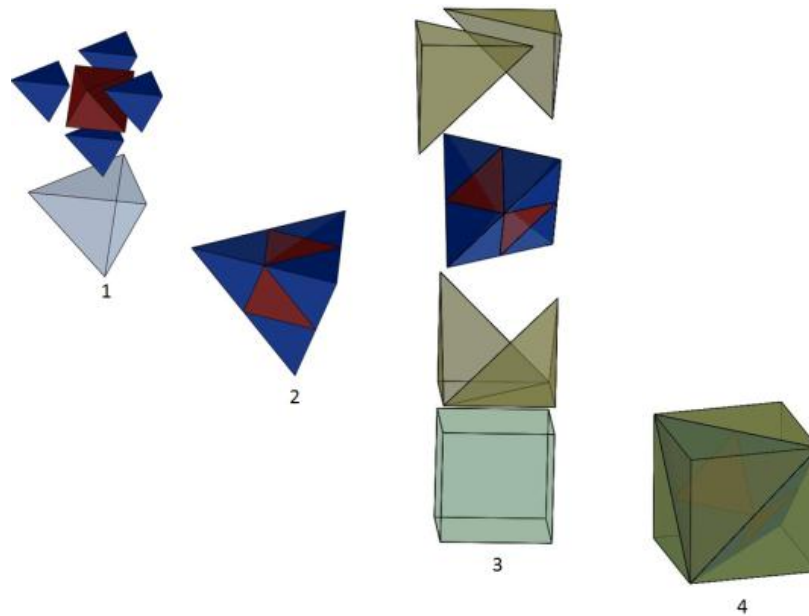
## **Abstract**

*Visuospatial skills are a critical component of problem solving within graphical education. Despite this importance, evidence exists to suggest deficiencies in students' reasoning abilities within graphical education in Ireland. The research presented in this paper delineates an initial exploration of problem conceptualization within the area of graphical education. Participants were asked to solve a typical graphical task while electroencephalographic data was recorded in order to track conceptualization processes. Findings indicate the possibility of multiple conceptualizations for a typical task which may provide further insight regarding issues of visuospatial reasoning abilities within graphical education. The study concludes with a number of possible research questions for future work.*

## **Introduction**

The critical role of robust visuospatial skills in problem solving and reasoning tasks is well documented in the literature. The work of Sorby (2005, 2009) has shown the benefits of enhancing spatial abilities in terms of success in a wide variety of University courses such as calculus and chemistry where visualization ability is a valuable aid in thinking and reasoning. Visuospatial skills are not just important in discipline specific contexts but also for a wide variety of human endeavors such as navigation, planning and even inference and deduction (Tversky 2005, 2011).

Graphical education is one of the subject disciplines where developing visuospatial competencies is a core focus. Despite this, previous research by Delahunty et al. (2013) has raised concerns regarding the approaches students took to problem solving within visuospatial graphical tasks. In this particular study, student teachers were tasked with solving an applied analytical problem. Prior to completing this problem students completed a stage of knowledge acquisition where the associated learning focus was directly relevant to the applied task. The participants displayed a wide variety of approaches to the applied problem (see figure 1) with some being more effective than others.



**Figure 1: Applied Analytical Task Used by Delahunty et al. (2013)**

The high number of ineffective approaches to the task, observed during this study, could be due to a number of underlying causes. Two different areas of concern are hypothesized to be of primary interest within the context of this research. One of the areas could be that of transfer where students are having difficulty applying previously learned knowledge to a novel situation (Bransford and Schwartz 1999, Thorndike and Woodworth 1901). The second area of interest is conceptualization. This area is critical for effective problem solving and reasoning and is often overlooked in research focused on problem solving (Clement 2000, Gómez et al. 2000). The research discussed in this paper will concentrate on this area of conceptualization as issues of transfer have been rigorously investigated by previous authors (Bransford and Schwartz 1999, Greeno 2006, Thorndike and Woodworth 1901).

### **Conceptualization**

Conceptualization is a diverse area but is known to be an extremely important component of the problem solving process. Gómez et al. (2000) describe conceptualization as “*modeling by the problem solver*”. This modelling process results in the formation of a “*conceptual model*” for that problem (Duit and Treagust 2012). However, it should be noted that there are a number of different conceptual models, which can be constructed for a particular problem (Adams 2001). This is not surprising given the different background knowledge and experience that students bring to the situation.



Conceptualization is posited to comprise of two distinct phases, analysis and synthesis (Gómez et al. 2000). Analysis is a regressive process where the problem is broken down and understood and involves elements of problem representation that is best described as a representation which solver's construct to summarize their understanding of the task (Duit and Treagust 2012, Novick and Bassok 2005). Synthesis is progressive in nature and allows all knowledge (representations) constructed in the analysis stage to be amalgamated and utilized to implement an approach (Gómez et al. 2000).

The most important characteristic of the area of conceptualization is the direct influence the solver's conceptualization has on the approach adopted to the task at hand (Adams 2001). This area is well studied within science education (Ozdemir and Clark 2007) but there exists a dearth in research within graphical problem solving contexts. This paper presents the first attempt in determining a relationship between conceptualization strategies and problem solving performance within a graphical education context.

As part of a larger research study currently underway at the University of Limerick, this paper will focus on conceptualization of typical graphical problems. Specifically this study will investigate whether typical graphical problems are conceptualized differently. Furthermore, it will explore the relationship between the conception and approach to the solving of the problem.

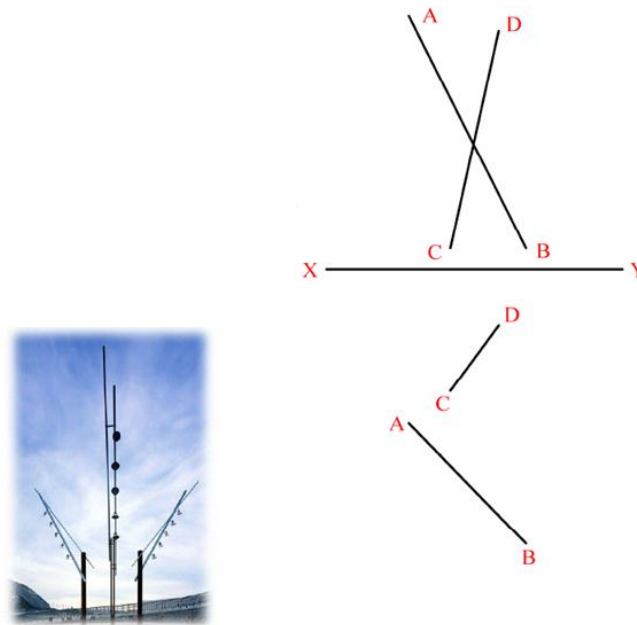
## **Method**

The method employed within this study was centered on a typical graphical task which is commonly implemented within graphical education in Ireland. The task, which is shown in figure 2, is based on knowledge of skew lines and the oblique plane, which is a core topic within plane and descriptive geometry. The participants in the study were two postgraduate research students who had previously attained qualifications in graphical education.



The graphic below shows a modern sculpture based on the concept of skew lines. The sculpture is represented by the skew lines AB and CD below.

Using a sketched approach, determine the projections of the shortest horizontal distance between the two lines.



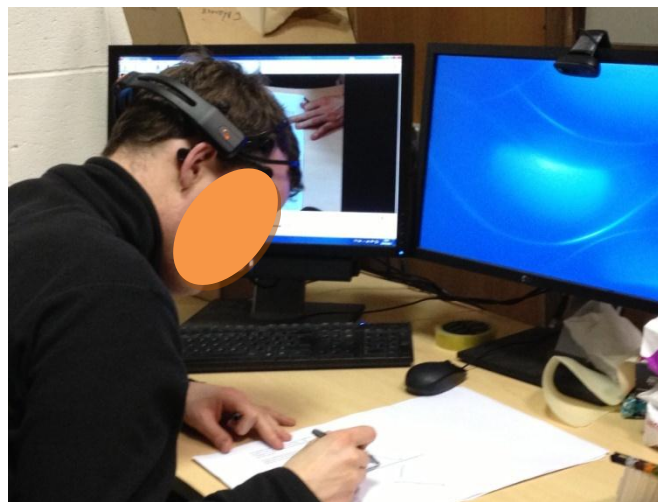
**Figure 2: Skew Lines Task**

In order to observe the style of cognitive activity occurring during the task, the participants were asked to wear an electroencephalographic (EEG) headset. This concept of using non-invasive EEG technology to monitor cognitive function was discussed by Delahunty et al. (2012). The use of EEG technology was shown to be applicable to educational research and is capable of highlighting underlying cognitive processes (Neill 2006). The headset used was developed by Emotiv technologies and is shown in figure 3. The headset consists of 14 sensors which are dispersed across the scalp in accordance with the international 10-20 system for electrode placement (Banich and Compton 2011). These sensors record electrical activity conducted in the cerebral cortex which is a rich source of data related to cognitive functioning (Rowan and Tolunsky 2003). The data recorded was processed using *eegLab* which is an open source tool for neuroscientific data analysis allowing statistical and graphical outputs (Delorme and Makeig 2004).



**Figure 3: Emotiv EEG Headset**

The implementation of the graphical problem and EEG recording procedure are depicted in figure 4. In addition to recording the EEG activity of the two participants a follow up discussion took place, post-task, in order to further qualify the data. Participants were asked if they would briefly describe the approach they took to solving the problem. The purpose was to explore if there were different conceptions of the task and if there existed a relation between the conceptualization constructed by the participant and the effectiveness of the consequent approach.

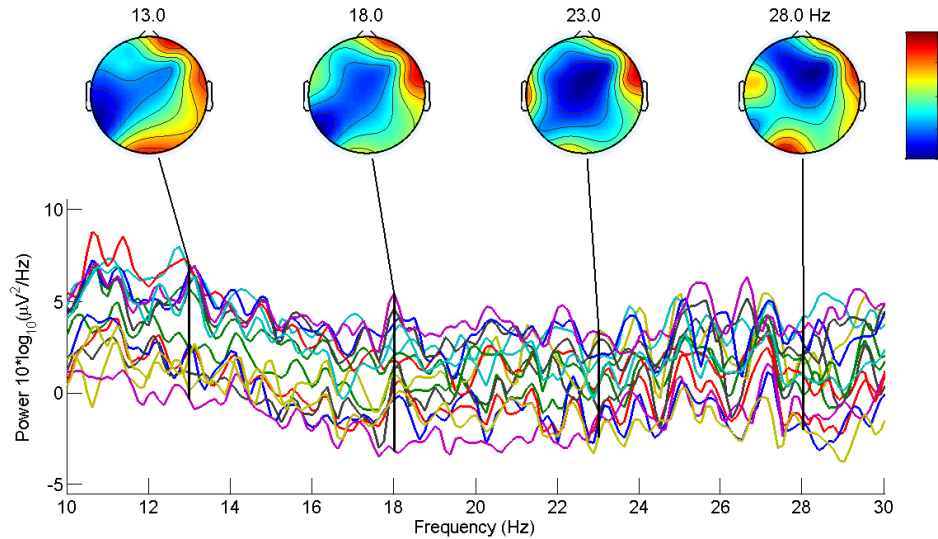


**Figure 4: Participant 01 Attempting Task**

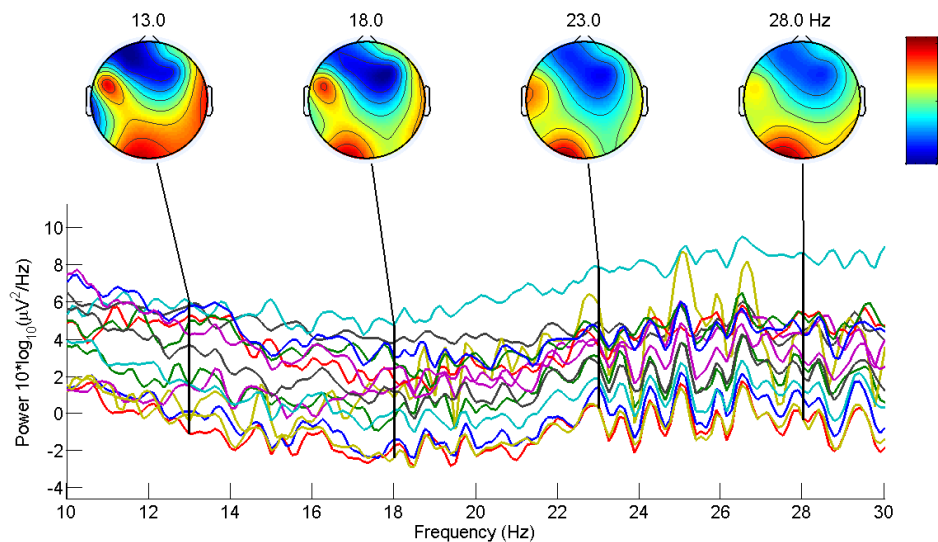
## Findings

EEG data is typically analyzed in different frequency bands which have been shown to be correlated with different styles of cognitive activity such as convergent/divergent thinking and memory (Molle et al. 1999, Osaka 1984). The frequency band of interest in this initial exploration

of conceptualization is the Beta band which has been shown to be widely associated with cognitive functions such as visualization (Razoumnikova 2000, daSilva 2010). The graphical outputs for both participants' EEG measurements displaying the Beta power dispersion are shown in figures 5 and 6.



**Figure 5: Participant 01 Beta Power Dispersion**



**Figure 6: Participant 02 Beta Power Dispersion**

As can be seen in the above figures there are two different patterns of activation occurring for each participant. As a brief comparison, it can be seen that participant 02 (figure 6) exhibited a more typical activation of someone who attempted to visualize the problem with more occipital

activation. Participant 01 (figure 5) showed more activation in frontal and temporal areas. The data seems to indicate two different approaches to this problem.

To clarify the approaches participants were asked to describe their approach to the task. Participant 01 described his approach as focusing on the lines as two dimensional entities and attempted to recall the steps in a logical fashion. On the other hand, participant 02 described his approach as one focused on visualizing the skew lines as a three dimensional concept and trying to implement a solution by working back.

Participant 01 (figure 5) conceptualized the problem as two-dimensional entities and was able to utilize a memorized strategy to complete a solution. The temporal and frontal activations, typically associated with memory functions (Banich and Compton 2011), evidenced in figure 5 and this participant's description of problem solving approach corroborate this finding.

In contrast, participant 02 displayed an activation more typically associated with visual strategies involving the occipital area of the cortex (Ward 2010). His description of approach correlated with this finding as he conceptualized the task as three-dimensional lines and attempted to implement a solution by working back. The most interesting finding though is the fact that participant 01 was the only one to display a correct solution.

### **Conclusions and Future Research**

The research presented here attempted to ascertain whether a typical graphical task can be conceptualized differently by participants of similar expertise and the findings indicate that this is indeed the case. As can be seen the EEG methodology combined with post-task interview support this finding.

The unexpected finding was that participant 02, despite having conceptualized and approached the problem as one would expect a graphical educator to do, did not solve it. Participant 01 conceptualized the task alternatively, as two dimensional, which may have allowed him easier access to long-term memory and consequently solved the problem. It should be emphasized that this study is only the first exploration into this area and it has raised significant questions:

1. What is the relationship between knowledge acquisition and conceptualization abilities within graphical problem solving?
2. Is there a relation between a problem solver's visualization ability and their ability to successfully conceptualize these types of graphical tasks?
3. Are the tasks currently utilized within graphical education in Ireland catering for the development of effective conceptualization skills?
4. Are there alternative methods of conceptualizing a typical graphical problem which may be more effective for solving the said problem?

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# Improved Visualization through Association - Connecting Engineering Graphics to Animations and Engineering Simulations

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## ***Abstract***

*The traditional engineering graphics course, developed for mechanical engineering freshmen, teaches the ability to create and interpret standard 2D drawings, incorporate functional design and manufacturing requirements of 3D parts, along with basic engineering principles and design intent, using CAD software.*

*Through registration data, non-freshman and other majors take this course. Incorporating non-conventional visualization techniques: animation, engineering simulation, rapid prototyping, photorealistic rendering, and augmented reality, assist students in their upper level classes.*

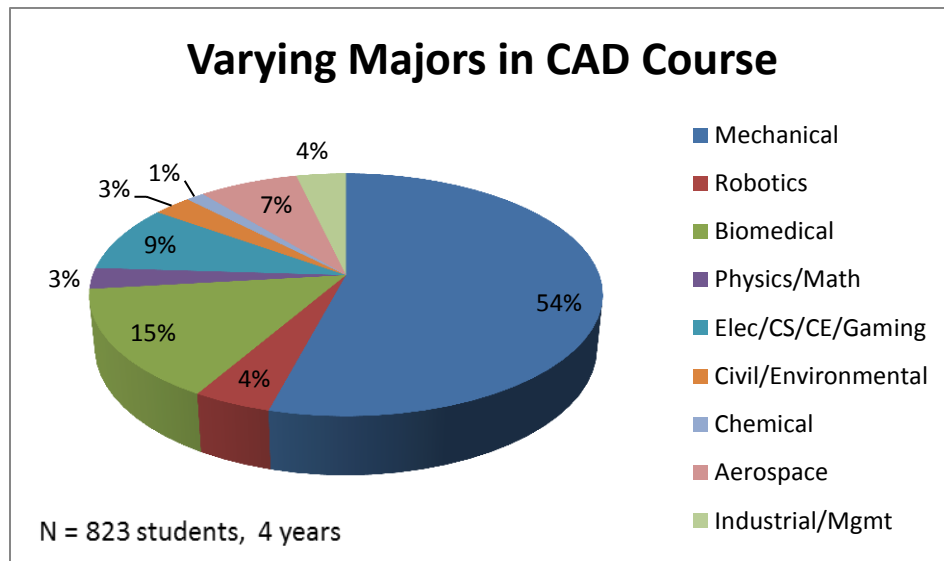
## **From Drawing Strengths to Engineering Principles**

Engineering students enroll in a basic course in engineering graphical communications, required by mechanical engineering students and optional by other disciplines. Student competencies include the ability to create and interpret standard 2D drawings, incorporate functional design and manufacturing requirements of 3D parts, along with basic engineering principles and design intent, using CAD software according to ASME Y14 standards. Students develop drawing strengths and make connections to future engineering principles and practices. The advances in technology make the use of visualization, animation, engineering simulation, rapid prototyping, photorealistic rendering, and augmented reality relevant early in the student's education.

Four years ago, the introductory course ran in a serial progression using model demonstrations in software with little or no animation, simulation, photorealistic rendering, or augmented reality. Students learned view orientation, orthographic projection, 2D drawings, planes, sketching techniques, and basic model feature construction.

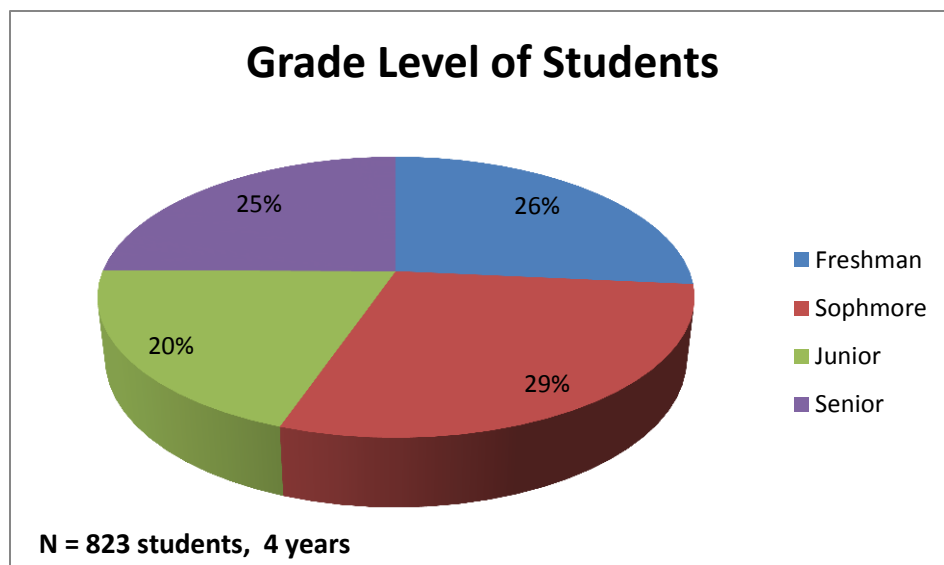
Students created fixed assemblies. They learned the ASME Y14 drawing standard and applied it to create part drawings and assembly drawings from a selection of classic models such as a Geneva gear mechanism or mechanical vise.

So how do you keep the drawing competencies and increase visualization skills required for different backgrounds, ages, and future courses with no additional time? Answer: change the course organization, create a library of models based on student majors, and vary the use of lecture/lab time. In the first three lectures, students are introduced to reading and interpreting drawings, illustrating model behavior with animation, and associating models with engineering applications through engineering simulation, all in parallel with the geometric model.



**Figure 1. Varying Majors, 2009-2010, 2010-2011, 2011-2012, 2012-2013**

Through registration data, 54% of the students were studying mechanical engineering as illustrated in Figure 1.



**Figure 2. Varying Grade Levels, 2009-2010, 2010-2011, 2011-2012, 2012-2013**



Approximately 26% of 31 sections, since 2009 were actually freshman as illustrated in Figure 2. The amount of freshman per section varied during different times of the year. Every model begins with an animation to illustrate its working physical behavior. Presented, through engineering simulation and animation are short introductions to future engineering principles that students will learn in upper level courses such as kinematics, fluid dynamics, stress analysis and sustainable design. Illustrated models include pumps, valves, 4-bar linkages, Geneva gear mechanisms, mechanical vise, binder clips, and plastic bottles.

Models are provided for Mechanical, Aerospace, Biomedical, Civil, Electrical, Gaming, Robotics and Physics/Math students, now based on previous students' final projects. By illustrating previous students' work, with no previous CAD experience, new students see what they can accomplish. The stage is set for new students to learn more and to do more. With simulation, first year students, without theoretical prerequisites, understand simple boundary conditions, applied forces and the resulting animations.

Once students understand how the assembly works, the model is broken down into its components. Now students must answer the questions on how to create the parts. With design intent of the sketch, the features and the part, students learn to design for future changes and to produce different results. At the same time, students are learning drawing skills. Students read dimensions and tolerance, fastener annotations, manufacturing notes, and fit types on existing drawings to create parts. For the final project, they create engineering drawings based on their parts and assemblies per the ASME Y14 drawing standard.

### **For Extra Credit**

Students learn how to create and animate an exploded assembly view with a Bill of Materials, Balloons, Notes, and a Revision table. For extra credit, they are quickly shown photorealistic rendering, animation, and simulation of a model. In 2012, 91% of 156 students received extra credit applying photorealistic rendering and creating an animation and or engineering simulation – even though concepts were never officially taught or required as outcomes.

With the introduction of non-conventional visualization techniques; animation, engineering simulation, rapid prototyping, photorealistic rendering, and augmented reality, to engineering graphics, course enrollment has increased over the past 4 years and is now consistently taken as an elective by students in engineering (aerospace, biomedical, chemical, civil, electrical, gaming, industrial, robotics), and science and mathematics. Enrollment limits now are based on classroom space and instructor availability.

### **Library**

With a diverse student population, lecture/lab time features non-conventional visualization techniques relevant to student background and level. An engineering library is available where

instructors can display animations from a variety of models, created by past students with no former experience.

In addition to course requirements, students select a final project to successfully complete the course. During the first week, they are presented with a series of final project options as listed below.

**Option 1 Minimum requirements:** Select a standard final project. Create all parts and the final assembly. Create all part and assembly drawings with required views and a BOM and Revision table.

**Option 2 Additional credit:** Select a standard final project and modify it. Create all parts and the final assembly. Create all part and assembly drawings with required views and a BOM and Revision table. Create a basic animation and simulation of the assembly. Apply photorealistic rendering to the final assembly.

**Option 3 Additional credit:** Create a final project, with instructor approval. Final projects are related to student major or interest. Create all parts and the final assembly. Create all part and assembly drawings with required views and a BOM and Revision table. Create a basic animation and simulation of the assembly. Apply photorealistic rendering to the final assembly.

Based on six sections in 2012-2013, 156 students, 38 freshman, 85 mechanical engineering majors, 15% of students chose Option 1, 10% chose Option 2 and 75% chose Option 3 for their final project.

### **Expanding Visualization Skills**

Students explore geometric models using new technology such as affordable rapid prototyping and augmented reality with smart devices. For example, all students, for a fee, can produce a rapid prototype of their models. Since students have to pay, there is a sense of getting the dimensions, tolerance and fit right the first time from the corresponding engineering drawing.

Augmented reality software provides the student a visual perception of the geometric model in the environment that is mediated. In a product concept sketch, the designer places a pencil, penny, or coffee cup to convey the sense of scale. When students create a 3D model, their perception of scale is skewed just looking at the model in the graphics window.

Utilizing augmented reality, students visualize the 3D model with a sense of scale. A Quick Response Code (QR) activates a smart device with a camera. A true model, 1:1 scale, can be displayed. Students understand the actual size of the CAD model and manipulate the model through either an iPhone or iPad. Scaling the QR code allows larger objects to be displayed.

### **Summary**

Animation, engineering simulation, rapid prototyping, photorealistic rendering, and augmented reality, show students the capabilities and potential for utilizing these tools during their academic courses and professional careers.

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# Capturing Graphical capability through Ipsative enquiry using Adaptive Comparative Judgement

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## Abstract

*This paper gives an overview of a student centered approach to assessment that serves two functions. Firstly, to facilitate an opportunity for each student to develop a personal construct of what it means to be graphically capable and secondly a capacity to track their level of competence based gain both normatively and ipsatively.*

*The study tracks the performance of a cohort of student teachers (N=119) in a core graphics module during a year three semester. Four consecutive design tasks, applying graphical principles, were designed to elicit core graphical skills and knowledge. An adaptive comparative judgment method (see Pollitt (2012) and Kimbell (2012)) was employed by the students to rank the responses to each task.*

*The paper highlights the potential of this approach in developing students epistemological understanding of graphical education, while tracking competence based gain through ipsative enquiry within the collective performance of their peers.*

## Introduction

The tacit nature of teacher education requires careful consideration when devising assessment methodologies. The approach to this study focuses on integrated assessment and learning processes, which facilitates each student exercising their personal construct of capability. Petty (2009, pg. 175) encourages the self-correcting classroom and supports the idea of students developing skills of self-appraisal and self-audit as a means of insuring effective learning. However, the difficulty with engaging students in meaningful assessment and appraisal arises when there is ambiguity surrounding the role and function of assessment. Broadfoot (1996) highlights the dominance of the social role and purpose of assessment as opposed to its educational function. This dual role focuses the discourse on formative and summative assessment and becomes problematic when considering Wiliam's (2000) suggestion that teachers are reluctant to operate parallel assessment systems.

## Adaptive Comparative Judgement

This study considers an alternative approach to assessment that integrates assessment as learning and facilitates the student making judgement on their peers work as a means of developing a personal construct of capability. The method carefully considers marrying summative reliability with formative feedback.

Assessing the quality of students work has traditionally been approached using rubrics of assessment criteria and standards. Making a judgement about a piece of work based on abstract or generic criteria can be quite difficult on its own, but becomes much easier when compared to an exemplar. Comparison with

exemplars and comparison between students work will lead to the assessor generating a rank order of quality of students' performance. The subjective nature of this individual judgement is of concern and can be addressed by having multiple judges assessing pupils work and reaching consensus on the order of quality. This is the basis of the Adaptive Comparative Judgment (ACJ) method (Pioneered by Kimbell et.al (2009). The ACJ method provides students with the opportunity to assess their own conception of value in comparison to their peers and exposes them to a broad range of qualities and levels of attainment.

This approach integrates two key pedagogical characteristics highlighted by Torrance and Pryor (2001), firstly it provides the opportunity for shared construction and comprehension of assessment criteria and secondly, it provides direct feedback to the student during the judging session as a reflective catalyst.

## Method

Simultaneous to the development of declarative and procedural knowledge within the descriptive geometries, students completed four consecutive graphical design tasks.

The governing importance statement for the four tasks (50% of the module grade) emphasised the development of graphical analytical skills, development of effective communicative skills and conceptual design. The students were tasked with analysing and deconstructing geometry, then synthesising the deconstructed geometry supported by specific descriptive principles to create a conceptual design solution. The students were then required to represent their solutions using what they determined to be appropriate graphical methods. Table I outlines a sample brief, linking the declarative knowledge with the design task.

**Table 1: Outline of Design Brief for Assignment 2**

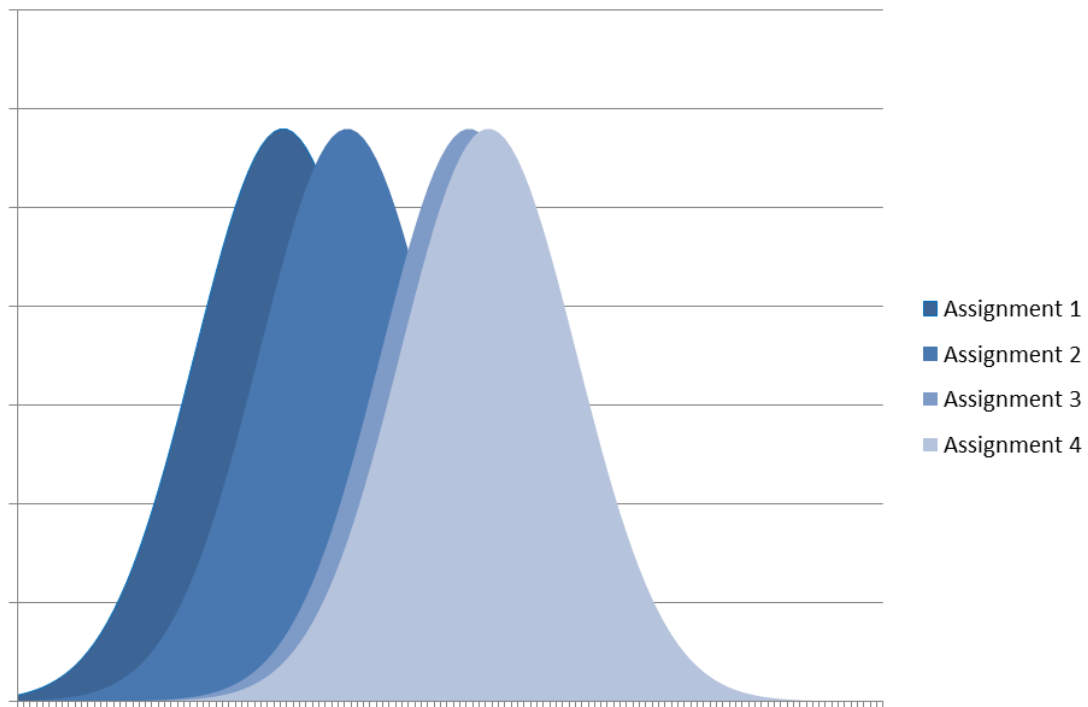
|   |
|---|
| <b>Rationale:</b> The focus of this Assignment is to explore and apply your knowledge of intersecting solids, both plane and curved surfaces and oblique solids.  |
| <b>Brief -</b> You are commissioned to design a sports building to either house or support a particular sport. You must show evidence that you have considered the following:   |
| 1. The sport or sports – paying particular attention to scale, proportion, the user, spectator and particular needs analysis of that sport  |
| 2. The location of the building relevant to its surroundings and infrastructural support  |
| 3. The overall aesthetics of the building (focusing on intersection of solids and surfaces) clearly illustrating the key characteristics of the building, including focal points and projections from the spectator/user (utilising your knowledge of projection systems including orthogonal and auxiliary projection) |
| 4. The function of the building in terms of user experience, accessibility and capacity   |

The research utilised a number of data collection tools to capture consensual measures of performance, student perception of their improvement and student insights into the role of graphical education.

## Findings

The findings give a brief overview of the cohort's graphical competency, students' perception of their visuospatial development and some insight into an evolving personal construct of graphical capability.

Using the ACJ method students produced a rank order of each design task, recording a reliability score of above 0.94 for all four ranks. Graphed on the same absolute scale (for objective comparative purposes), the differences in the mean of each Assignment is indicative of a shift in student performance scores towards a higher grade percentile (Figure 1).



**Figure 1 – Initial Teacher Education Students Distribution of Performance**

To qualify the overall effect, it was necessary to examine the performance variance between the first and last task. The first Assignment recorded a skewness value of 0.54 indicating a clustering of grades towards a lower quartile. Assignment 4, by comparison, had a skewness value of -0.13 which indicates a significant shift of grades towards a higher quartile. A Wilcoxon Signed Rank test was used to test for statistically significant differences between variables and returned a significance value of  $p < 0.005$ , indicating a significant difference between performance scores in Assignment 1 and Assignment 4.

The ipsative enquiry achieved through peer assessment using the ACJ method also increased the students self-rated scores. Pre and post data was captured to measure the perceived change in students' capacity to build and manipulate mental images. Students were asked to complete a self-report measure of their development in the area of visuospatial cognition. Students were asked to rate their ability on a scale of 1-10 pre and post the module in relation to the following cognitive competencies:

- The ability to build visual mental images
- The ability to manipulate visual mental images

There was a 74% response rate from the student population. The data are summarised in the following table.

**Table 2 – Summary of self-rated cognitive competencies**

|          | <i>Ability to build visual mental images</i> |      | <i>Ability to manipulate visual mental images</i> |      |
|----------|--|------|---|------|
|          | Pre  | Post | Pre   | Post |
| Mean     | 3.5  | 7.5  | 4.5   | 7.5  |
| Std. Dev | 1.8  | 1.0  | 1.8   | 1.2  |

The statistical analysis of the data using a paired samples t-tests on both reported cognitive measures returned a significant difference between pre and post scores in the category “Ability to build visual mental images” ( $p < 0.001$ ). A significant difference was also found in the difference between pre and post scores in the category “Ability to manipulate visual mental images” ( $p < 0.001$ ).

In addition, the student’s perception of graphical education was captured. Responding to an end of semester anonymous survey (74% response rate), 94% of student said the module changed their perception of graphical education. A sample of comments below qualifies this change.

*“I think that my perception has changed because I now see that the subject Design and Communication Graphics in L. Cert can be helpful for many jobs down the road. Take for example our last assignment on designing the surgical plate for the broken jawbone, I never thought a background in graphical education could help you in that” (David - PN4305 2012)*

*“My outlook has broadened it isn’t just about drawing lines and working from textbooks to gain knowledge just to pass exams. It is about solving real life problems through graphics, using graphics as a language to explore and demonstrate ideas. Graphical education is very important for everyone to be able to communicate in some shape or form” (Padraig - PN4305 2012)*

## **Discussion/Conclusion**

This study utilises binary decision making to produces a rank order of student work. The collective decision making of the student body aligned on four consecutive assessments with considerably high levels of reliability. Exposure to a broad range of student responses forced the learner to develop appraisal skills beyond their own interpretation of the task. Consecutive tasks facilitated the student in building a more comprehensive understanding of what it means to be graphically capable through ipsative enquiry.

This study suggests an approach that can not only develop the core graphical skills required but also develop a personal construct of what it means to be graphical capability.

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# A Preliminary Scheme for Automated Grading and Instantaneous Feedback of 3D Solid Models

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## Abstract

*A scheme for the grading of CAD solid model files is presented. The method rests on the original drawing's relationship to the design intent. By testing whether the solid model's parameters agree with the original drawing dimensional values in a one-to-one correspondence, the changeability and robustness of the model is quickly ascertained. The method is currently used manually but will be tested in a computer application in the future. The method will allow consistent, non-subjective, and repeatable scoring and fast turnaround of feedback.*

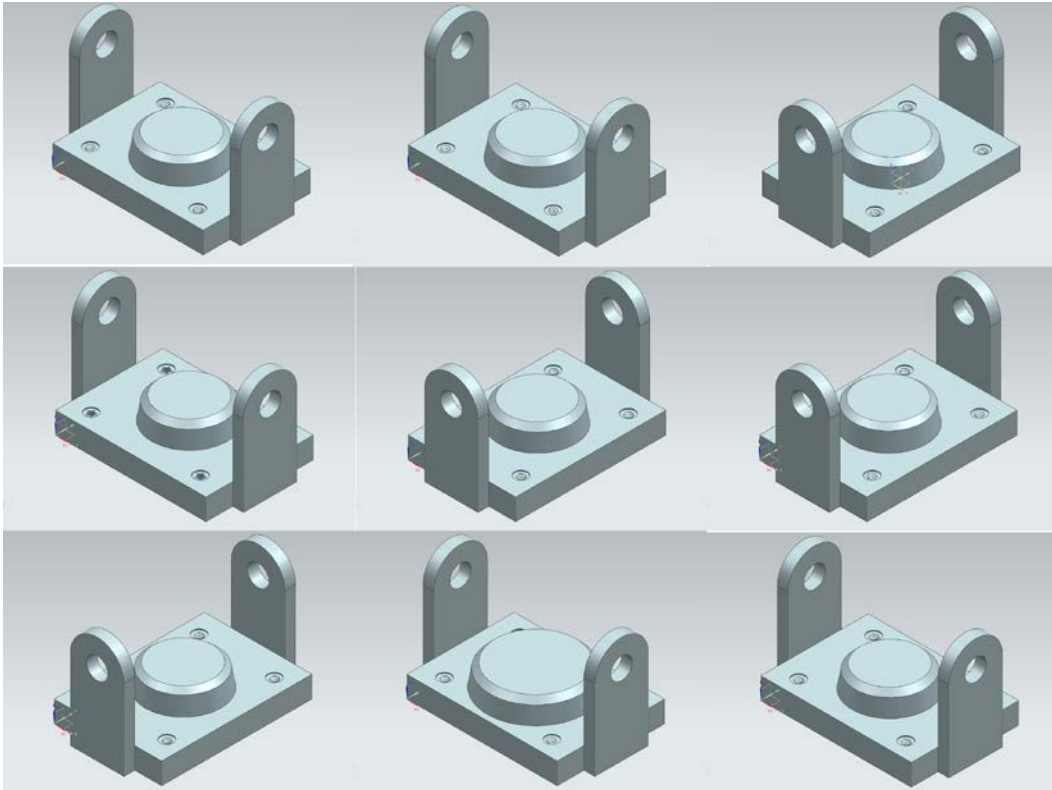
## Introduction

With some basic training and enough time, today's CAD packages allow most anyone to create a 3D solid model that appears to look like some specific object. At our university, we are seeing more and more first-year students that have quite a bit of experience in one or more CAD packages and can seemingly reproduce some requested geometry quite well. However, even though the various solid models may all look the same at first glance, major differences result when one or more parameters of the model are altered. When the design intent of the original drawing is not successfully transferred into the 3D solid model, the model will break or unexpected results will occur when a specific solid model parameter is changed.

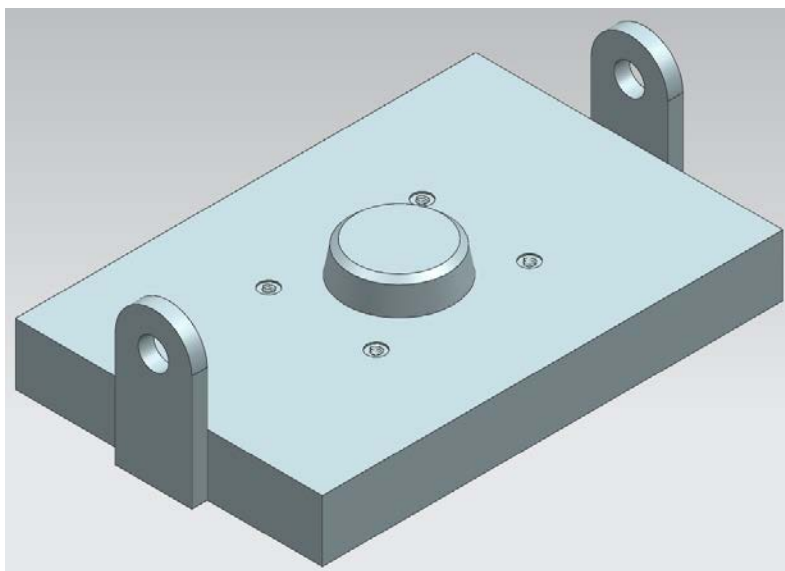
For instance, Figure 1 shows nine student-created solid models that closely resemble the requested part. A few students got the view orientation incorrect and the bottom center model has an oversized center boss, but basically the geometry looks correct in all nine models. If the three parameters controlling the thickness, length, and width of the base plate are changed, we expect to see what is shown in Figure 2. In this case, the end brackets travel with the ends of the revised base plate and stay centered. The center boss and pattern of threaded holes travels with the top surface of the base plate and stays centered. This type of change is a valid real-world occurrence and is a test of model robustness and changeability. Others have called it "model flexing" (Ault, 2013) or "dynamic modeling" (Wiebe, 2003).

However, when the three parameters are changed in the set of nine student-created models, we see many issues (Figure 3), including: end brackets failing to stay with the ends of the base plate (2X), end brackets failing to stay centered (4X), center boss failing to stay centered (4X),

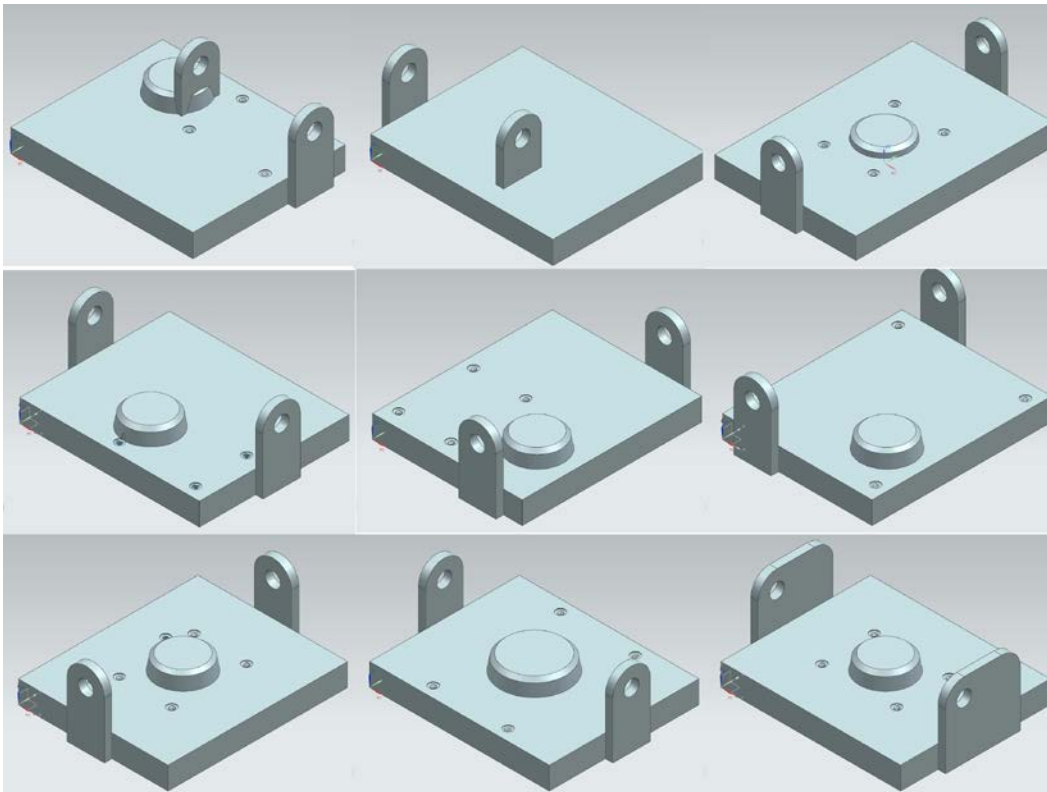
hole pattern not staying centered (6X), disappearing center boss (1X), and the appearance of an extra threaded hole (1X). Depending on the drawing specifications, some of these behaviors could be correct – but not by the particular drawing that was provided.



**Figure 1. Nine student-created solid models that closely resemble the requested part.**



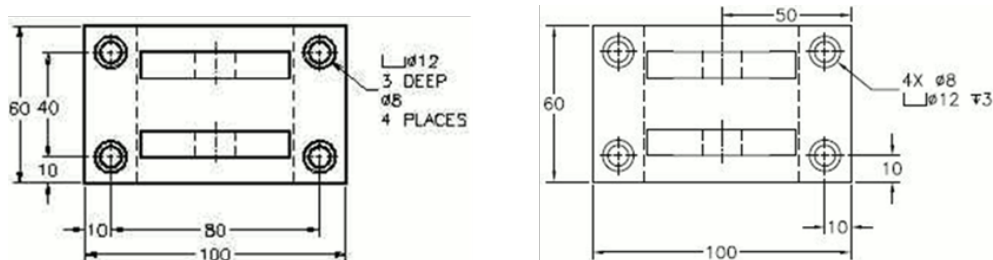
**Figure 2. Desired result if the base plate is made thicker, longer, and wider.**



**Figure 3. The same nine student-created models collapse during base plate alteration.**

### The Original Drawing Controls the Design Intent

In Figure 4, the same geometry is specified in two different ways. The left sketch shows the top view of the Chapter 8 Tutorial 2 part from Tickoo's NX 6 book (2009) and the right sketch shows the same part in his NX 7 book (2010). The left sketch communicates that the 80x40 hole spacing is important, while the right sketch communicates that all four holes are 10 mm from the adjacent corners. Also, in the left sketch the brackets are centered by default, while in the right sketch the brackets are 50 mm from the right edge (centered now, but not necessarily after changes in the base plate). While they produce the same static geometry, changes in base plate size will cause dramatically different results in models based on these two drawings. Neither drawing is necessarily incorrect: either drawing may be valid for a particular design intent.



**Figure 4. Two different specifications of the same static geometry.**

The successful transfer of design intent from original drawing to solid model means that the solid model is changeable and robust. Some simple guidelines can be useful in specifying what makes a robust, changeable solid model.

#### **Guidelines for transferring design intent from drawing to solid model**

- Use only dimensions that come directly from the original drawing. For instance, if a diameter is specified, use it; if a radius is specified, use that. In this way there will be a one-to-one correspondence between all the parameters in the original drawing and those in the solid model.
- If extraneous dimensions were provided in the drawing, then over-constrained sketches will result. In this case, the design intent may be ambiguous and the drafter will have to make some choices. At first glance, reference dimensions can appear to be extraneous dimensions, but they are generally ignored in the creation of a solid model and they will resurface when a drawing is produced from the solid model.
- The creation of new dimensions that are not on the original drawing are not usually required if the design is non-ambiguous. Computing dimensions that are not on the original drawing requires mathematics, which is rarely needed or wanted in solid modeling when provided with a clear, non-ambiguous drawing of a part. Usually nothing more than the original drawing dimensions and properly selected geometric constraints are all that is needed. In the rare instances when math is needed, perhaps as in specifying the angular spacing of holes in a circular pattern, let the CAD software do the math by entering an angular pitch of  $360/5$  (if permitted) rather than entering 72 degrees. In this way should the design need to be changed to support six uniformly spaced holes, the 5 just needs to be changed to 6, rather than a new math computation being carried out. Surprisingly, the math computation is too often incorrect and the hand entering of a number can lead to confusion about where the number came from.

#### **Proposed Scheme for Automated Grading**

Students can have difficulty in grasping the concept of design intent. Frequent and clear feedback from the instructor appears to be the best method for guiding the student into the habit of creating robust solid models that contain the design intent of the original drawing. A significant issue is that manual evaluation of a moderately complex part may require examination of the part tree and several fully constrained sketches. The time spent evaluating the model and then writing up some useful feedback for the student has been reported to be as little as six minutes (Ault, 2013), but even after teaching our solid modeling course ten different times, I find that providing a grade and useful feedback can take two to three times longer than that. Additionally some

homework assignments can involve up to three different models. As others have noted (Ault, 2013 and Baxter, 2003), the automated grading of digital CAD models can eliminate the variability and subjectivity of individual graders and offer feedback very quickly, perhaps in real time. But before moving to computer-assisted grading we need to define exactly what we are looking for. Although it can process instructions very fast, the computer can only do what we tell it.

The scheme rests on the importance of the dimensions in the original drawing to define design intent. All the key dimensions of the model are “parameterized”, or set as “driving dimensions”. Early in the semester, the models are quite simple with perhaps just a few individual parameters. Towards the end of the semester, models can contain up to 30 individual parameters.

For any assessment, the instructor creates a solid model and from it a drawing that shows all critical parameters. It is advantageous that each parameter value is a unique numerical value. In evaluating student work, the set of student parameters is examined. All parameters equal to zero are ignored. We also ignore the “2” in parameters showing a divide by 2 (such as  $p5=225/2$ ), likely to represent a radius when diameter was provided on the drawing (not ideal but acceptable: the diameter dimension would be greatly preferred), or used to center objects (geometric constraints would be preferred), or to create half lengths. In rare cases, issues arise to confound this proposed method. For instance, sometimes NX converts to intermediate variables, such as angular pitch when count and span were provided. The sorted student’s list of parameters is compared to the sorted set of instructor parameters. There should be a one-to-one correspondence between the two parameter sets.

### **Model Scoring**

In general, all models start with a perfect score of 100 and deductions bring the score down. The deduction scheme proceeds as follows:

- Every repeated parameter is given a weight of 2. Repeated parameter usually occurs when insufficient geometric constraints are applied. Repeated parameters limit the changeability of the model and the model will break or do unexpected things upon alteration.
- Dimensional parameters used in the model but not from the original drawing are given a weight of 1. This occurs when insufficient geometric constraints are applied. Alternatively, it may come from specifying a radius when a diameter was specified.
- Dimensional parameters that are in the original drawing but absent in the model are given a weight of 2. When parameters are absent, they are impossible to change.
- Additional deductions occur if there are any unconstrained sketches, errors or conflicts in the part tree, or unnecessary complexity in the model.

The grade is computed by deducting from 100 the three products of the sums with the corresponding weight factors and a scaling value:

$$\text{Grade} = 100 - \text{val} [ n\text{Repeats} \times 2 - n\text{New} \times 1 - n\text{Absent} \times 2 ] - \text{otherDeducts} \quad (1)$$

where,

nRepeats is the total number of repeated parameters

nNew is the total number of parameters that were not in the original drawing

nAbsent is the total number of parameters that are absent the original drawing

otherDeducts represents other deductions based on visual inspection of model or part tree

For complex models, val may be a low number in the range of 2 points. For simpler models, the deductions can be scaled up by setting val to a larger number.

## Conclusions

The general scheme is independent of CAD software used. While most schemes verify a subset of included parameters or test the model robustness with just a few parameter changes, this scheme checks that all parameters are present. If all parameters are present in a one-to-one mapping between drawing and model, then the model is almost certainly robust and changeable. Without examination of the actual model geometry, comparison of parameter sets is all that is needed to evaluate the models in the bulk of the cases. An important distinction of this approach is that a model is not judged by the modeling approach. Models can be created by many different techniques and are all good as long as there is a one-to-one correspondence between the parameters in the original drawing and those in the model.

Future work will involve implementing this scheme in a computer program. Ideally, this work would involve direct reading of the NX file with the prt extension. More likely, it will require access to the NX program. A center of gravity check will be easy to do when interacting with an application programming interface (API) and will be useful in determining if the proper orientation of the part was provided.

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# Assessing Design Intent in an Introductory-Level Engineering Graphics Course

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## **Abstract**

*This paper describes an assessment strategy used in an introductory engineering graphics course to help introduce the concepts of 3D solid modeling and design intent. The assessment strategy incorporates immediate feedback for students on 3D solid modeling assignments using self-checks (formative assessment) as well as limited “automatic” post-submission grading (summative assessment).*

## **Introduction**

The increased emphasis on dynamic rather than static CAD models has changed the rules of assessment in engineering graphics education. It is no longer acceptable to merely look at student CAD models or printouts and compare them to the instructor’s static answer key. The assessment criteria today not only include dimensional accuracy, but also modeling strategies and the overall robustness of the CAD model. Many instructors are now required to manually interrogate each CAD model submitted by students to probe the design intent that was built in to the model (Ault & Fraser, 2013; Branoff, Wiebe, & Hartman, 2003; Branoff, 2004). Assessment of student work in this new paradigm is proving to be a very laborious and time consuming activity for instructors, making it very difficult to provide timely feedback to students. Instructors are therefore searching for tools to help assess student CAD models with efficiency and consistency. This paper will describe a “low-tech” assessment strategy used in an introductory engineering graphics course to help introduce the concepts of 3D solid modeling and design intent. The strategy incorporates immediate feedback for students on 3D solid modeling assignments using self-checks (formative assessment) as well as limited “automatic” post-submission grading (summative assessment).

## **Literature**

It is important that assessment of student competencies be measured in a venue that will provide students with the opportunity to demonstrate the knowledge and skills that they possess.



Self-assessment from in-class exercises provides formative assessment that is essential to the learning process. Formative assessment that includes feedback to the student is necessary for students and without it the learning opportunity is minimized (Brown et al., 1997). In-class assessment during the practice phase (i.e. lab activities) provides formative feedback that reinforces student learning. Formative assessment encourages students to seek answers to difficult problems they face, and practice in an environment where they obtain constructive feedback to enhance the learning process. In-class studies have shown that students' self-assessment has raised student achievement significantly (Black & William, 1998; Chappuis & Stiggins, 2002; Rolheiser & Ross, 2001; White & Frederiksen, 1998).

With the prevalence of parametric solid modelers today, the assessment criteria for student CAD work not only include dimensional accuracy, but also modeling strategies and the overall robustness of the CAD model. In response, several innovative assessment approaches have been presented in the literature. Branoff, Wiebe & Hartman (2003) described the use of a simulated Engineering Change Notice (ECN) to assess the robustness and design intent of student CAD models. Branoff (2004) described the use of grading rubrics that explicitly make students aware of the design intent that should be built in to the model. The instructor then assesses the student model by manually modifying the CAD model as outlined in the grading rubric. Baxter (2002) and Baxter & Guerci (2003) developed innovative software that automatically assessed student models. And Ault & Fraser (2013) described the early stages of their work to develop an automatic grading system for Pro-Engineer models.

The message in the literature is clear; assessment of parametric solid models should include some manner of exercising/modifying the CAD file in order to assess if the model was created using appropriate methods. Towards that end, the authors are using an assessment strategy that requires students to assess the design intent, robustness, and overall accuracy of their own models for both formative and summative assessment purposes. In this instance of assessment students apply knowledge, skills, and abilities to prepare a model from set criteria, and manipulate the model per instructions to achieve new results. The result of the model dimensional changes demonstrate the level of competency the student has achieved through verification of the constraints and procedures used to create the model. Students are provided feedback through practice exercises to reinforce modeling concepts, and confirmation of accurate completion of the assigned task.



## **Overview of Assessment Strategy**

The TEC116 Introduction to Technical Drawing and Constraint-Based Solid Modeling course is an introductory-level engineering graphics course that is designed to introduce students to a variety of engineering graphics topics including 3D solid modeling. Because students having prior experience with solid modeling are not required to take this course, it is assumed that students in the course have very limited prior experience in the field. The solid modeling software used in the course is Autodesk Inventor and the class meets two days per week for 1 hour and 50 minutes in combined lecture/lab class periods.

During each class period a new solid modeling topic is discussed and demonstrated. After the brief demonstration, students are given a lab assignment that is to be completed during class. The lab assignments typically include assignment instructions and dimensioned part drawings for two to three parts to be modeled. Students are provided two self-check opportunities for each assigned model where they are required to measure one 3D distance, one face area, and the total face area of each part. The self-check includes the correct values for the measurement checks, so students have immediate feedback regarding the geometric accuracy of their model. This first set of measured values correspond to the initial part dimensions and as such help the students verify that they have read the dimensions for the part correctly and have accurately created a solid model of the original part design.

The second self-check requires students to change several dimensions on the part. The dimensions are purposefully selected by the instructor to require students to modify several features in the history tree as opposed to a single sketch. Students are again given the correct dimensions for the three geometry checks so they can get immediate feedback regarding their choice of modeling strategies to achieve the required design intent.

Once students have made any required corrections to their models and the self-check exercises are successful, the work is electronically submitted for evaluation using a learning management system (LMS). To submit their work students must change the self-check dimensions to yet another specified value and make the same dimensional measurements they did in the two self-check exercises. This time the correct measurements are not provided for the students who must manually enter the measured values into an assessment screen in the LMS to be automatically graded for accuracy. Students are also required to upload their CAD models into the LMS as well.

In addition to the lab exercises, students are required to complete a daily homework assignment that is identical in format and relative complexity to the lab exercise they completed in class. The use of self-check exercises and submission procedures for the homework exercises are

exactly the same as for the lab, thus providing additional opportunities for student practice. Periodic in-class performance exams use the same format and procedures that are used in the lab and homework assignments.

## **Conclusion**

Before the authors implemented the assessment strategy described above, all student models were graded manually using printouts containing one set of distance checks and a screen-captured image of the part. The model dimensions were not modified by the students and student design intent skills were understandably poor in more advanced courses. This initial assessment process was woefully inadequate and was changed to the strategy described in this paper.

Although the strategy presented in this paper is decidedly “low tech”, it does incorporate many of the CAD assessment attributes recommended in the literature. These attributes include:

- a grading rubric so students understand exactly what they are expected to do and how they will be graded;
- immediate feedback for students in the form of formative assessment;
- verification of design intent using model manipulation;
- reduced assessment time for instructors; and
- improved assessment consistency.

This assessment strategy also has several notable shortcomings. For example, the self-check feedback provided to the students is very limited. Students receive a go/no-go check on the correctness of their measurements but are not told why their measurements are wrong. Furthermore, the dimensions of the model may be correct even though the overall quality of their model may be less than ideal. These limitations are mitigated by the fact that this is a face-to-face course with instructors present at all times. Students are given individual, detailed feedback by the instructor when they have difficulty determining why their dimensions do not match the answer key. Furthermore, students submit their models electronically, thus allowing instructors to browse student work looking for problems.

While the assessment strategy presented in this paper is not the assessment “magic bullet” that we are all looking for, it has proven to be a low-cost tool to assess introductory level design intent and instructors have observed improved student modeling performance in advanced modeling courses. Perhaps this strategy will be helpful for other instructors until a more elegant assessment solution had been developed.

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# Consensual Assessment: A Means of Creativity Evaluation for Engineering Graphics Education

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## Abstract

*The perceived inability to assess creative attributes of students' work has often precluded creativity instruction in the classroom. This digest discusses the use of the Consensual Assessment Technique (CAT) for assessment of creative products, emphasizing its suitability to engineering graphics education. A brief methodology of the instrument is offered including techniques for ensuring the validity and reliability of its results. A practical example of using the CAT to assess engineering graphics is provided. The digest concludes with a call for further studies expanding upon the growing body of research that addresses creativity assessment in the classroom.*

## Introduction

Promotion of creativity and innovation in engineering education is essential to the production of engineers capable of contributing solutions to society's most demanding technological challenges (Felder, 1987). In addition to cognitive operations involved in engineering design processes-- not least among them the ability to "accurately perceive the visual-spatial world and transform these perceptions" into graphical plans (Harris & Meyers, 2007)-- engineering students must learn to effectively "communicate their designs and engineering analyses using both verbal and graphical languages" (Ault, 2002). Hansberry and Lopez (2005) identified "graphic illiteracy" as a source of communication breakdown in the engineering field. Central to the development of graphic literacy, they said, lies "the ability to combine creativity and visualization to make unique designs."

Fostering creativity and creative problem-solving skills can prove challenging amidst the classroom expectations of explicit objectives and measurable outcomes. This can be especially difficult within the current goal framework of the average K-12 public school classroom, a context in which engineering education is gaining traction with the release of the Next Generation Science Standards (Achieve, Inc., 2013). Part of the challenge is that teachers may view creative students as "inattentive and disruptive," tending to "wander away from the regular paths of thought" (Lau

& Li, 1996, p. 348). Westby and Dawson (1995) found significant negative correlations between teachers' favorite students and their creative students.

The need for promoting creative thinking and innovative problem-solving in classrooms has been identified in the research literature (Todd & Shinzato, 1999; National Center on Education and the Economy, 2010). Moreover, the field of technology and engineering education has identified creativity as essential to its mission (ITEA/ITEEA, 2000/2002/2007). Unfortunately, creativity has not always explicitly been part of the goals, objectives and measured results in K-16 classrooms for numerous reasons, including the perceived difficulty in assessing it (Lau & Li, 1996; Westby & Dawson, 1995). Lewis (2005) attributed the fledgling state of creative problem-solving assessment to a lack of research on developing ways to help teachers identify and assess inherent creativity in students' design work.

Studies have shown, however, that the reliable assessment of creativity in students' design work *is* possible (Amabile, 1996; Hennessey, Amabile, & Mueller, 2011; Hickey, 2001). This paper proposes the use of the Consensual Assessment Technique (CAT) for creativity assessment in engineering design graphics education.

### **The Consensual Assessment Technique (CAT)**

The CAT is an evaluation tool used by creativity researchers for assessment of creative products by panels of raters. The method is based on the assumption that "a panel of independent raters familiar with the product domain, persons who have not had the opportunity to confer with one another and who have not been trained by the researcher," are best able to make judgments regarding "the nature of creative products and the conditions that facilitate the creation of those products" (Hennessey, Amabile, & Mueller, 2011, p. 253).

The application of the CAT for making inferences about students' work, and subsequent inferences about pedagogical strategies used in producing that work, depends upon acceptance of an operational definition of creativity: "a product or response is considered creative to the extent that appropriate observers independently agree that it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated" (Hennessey, Amabile, & Mueller, 2011, p.253). Inter-rater reliability "quantifies the closeness of scores assigned by a pool of raters to the same study participants. The closer the scores, the higher the reliability of the data collection method" (Gwet, 2008, p. 29). "In the case of the Consensual Assessment Technique," explained Hennessey, Amabile, & Mueller (2011), "reliability is measured in terms of the degree of agreement among raters as to which products are more creative, or more technically well done, or more aesthetically pleasing than others. [ . . . ] By definition, interjudge reliability [ . . . ] is equivalent to construct validity: If appropriate judges independently agree that a given product is highly creative, then it must be accepted as such" (p. 253).

Inter-rater reliability is key to making claims about the usefulness of the CAT in classroom evaluation of student work. If stakeholders believe that student work cannot be reliably assessed for creativity because the concept is too enigmatic or inconsistent, then weaving creativity into curricula presents problems for goal setting and measurement. If, however, it can be shown that creativity can be reliably assessed in the classroom, then curricula and education policy can evolve to meet the changing needs of learners. Factors in determining valid and reliable results in the classroom application of the CAT include consideration of the types of raters available to instructors, raters' experience in the given domain, and the number of raters employed.

In early applications of the CAT, Amabile (1983) referred to raters as "experts." What constitutes an appropriate "expert rater" depends upon the researcher's judgment that a rater possesses both knowledge of the domain and "familiarity with the kinds of creative products typically produced by the kinds of subjects in the study" (Kaufman, Baer, Cole, & Sexton, 2008). In recent years researchers have looked at comparisons of novice and expert judgments. At least three categories of raters stand to provide valuable assessment data for technical graphics education: self-evaluations conducted by students; peer-evaluations conducted by students enrolled in the same or similar courses; and adult ratings conducted by raters with experience in the domain (Buelin-Biesecker & Wiebe, 2013; Kaufman, Russell, & Plucker, 2013). Across a range of domains, preliminary but significant correlations have been seen between peer evaluations or otherwise nonexpert, but somewhat experienced, raters and those made by adult raters with expertise in the domain (Kaufman, Baer, Cole, & Sexton, 2008), suggesting that further investigation could lend insights into greater flexibility of the CAT in classroom practice.

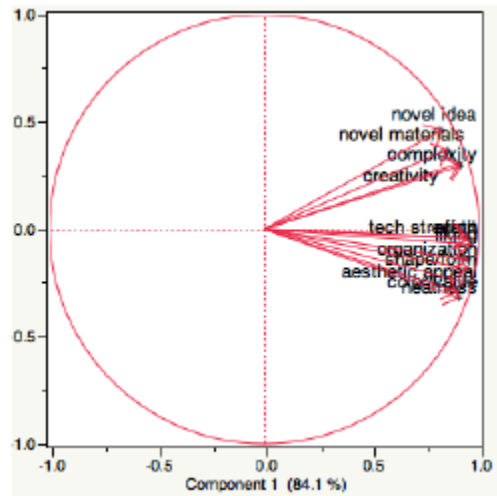
The number of judges used can impact the value of the inter-reliability coefficient. The available literature, as well as practical limitations such as time and cost, point to an ideal of approximately seven to ten raters (Fiske, 1977; Kaufman, Baer, Cole, & Sexton, 2008).

### **Inter-rater Reliability and Discriminant Validity**

Agreement among raters has been reported using several different coefficients for inter-rater reliability. Debate as to the best coefficient for tests using multiple raters is abundant in the literature and is beyond the scope of this digest. Cronbach's  $\alpha$  is recommended for reporting inter-rater reliability (Uebersax, 2010a & 2010b; Amabile, 1983; Gwet, 2010 & 2011). According to Hennessey, Amabile, & Mueller (2011), who have used Cronbach's  $\alpha$ , "in most instances, a reliability figure of .70 or higher can be considered evidence of an acceptable level of agreement between judges" (p.256).

In order to claim that creativity is being isolated and measured apart from other characteristics of students' work, it is essential to demonstrate an instrument's discriminant validity. Items related to creativity will ideally receive consistently different ratings from items related to

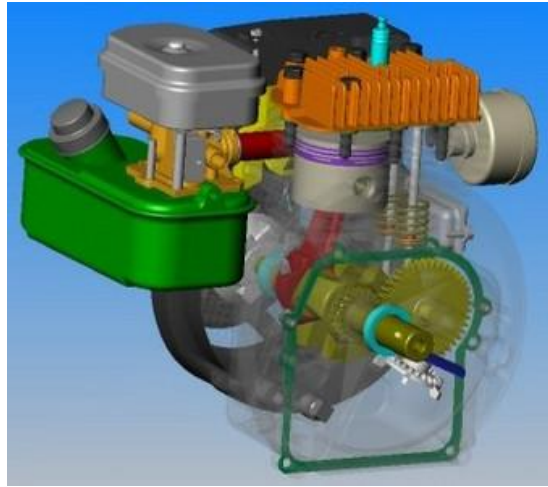
categorically different types of items. Many studies using the CAT have followed Amabile's (1983) three clusters of dimension types: creativity, technical strength and aesthetic appeal, and have included ratings of multiple related subdimensions (Buelin-Biesecker & Wiebe, 2013). Factor analysis determines the CAT's discriminant validity; optimally items within each of those three clusters will consistently load together.



**Figure 1. Factor analysis reveals the emergence of a ‘creativity cluster’ comprising creativity and the three related subdimensions of creativity: novel idea, novel use of materials, and complexity. This factor loading indicates discriminant validity for creativity; i.e., raters judged creativity and related subdimensions apart from dimensions of technical strength and aesthetic appeal (Buelin-Biesecker & Wiebe, 2013).**

### **Consensual Assessment in Practice: Assessment in the Technical Graphics Classroom**

The CAT is adaptable to a range of formative and summative assessment situations in technical graphics education. Engineering students’ undergraduate matriculation usually culminates with a capstone engineering design experience. Given a design challenge, students develop a solution that meets prescribed design criteria and stays within design constraints. It is imperative that students effectively use graphical representations to communicate their designs in order to explicate the functionality and features of their solution. Many instructors are adept at assessing technical aspects of student designs but the ambiguity often associated with creativity presents teachers with an assessment conundrum. The CAT provides a valid, reliable tool to assess creative aspects of design solutions.



**Figure 2. A final project from a capstone engineering design graphics course is a suitable product for evaluation using the Consensual Assessment Technique. Major dimensions measured include creativity, technical strength, and aesthetic appeal. (Courtesy of Prof. T. Branoff, North Carolina State University.)**

### **Limitations of the CAT**

Classroom adaptation of the CAT can be limited by time constraints, expense and logistical challenges. Suitable projects must be open-ended enough to allow creative solutions. Appropriate raters must be procured and possibly compensated. Raters must work independently and must have access to all products at once. Statistical analysis is a necessary step in interpreting results. However, these challenges can be overcome with thoughtful planning, particularly in higher education.

### **Conclusions and Recommendations**

A growing body of work supports the assertion that creativity can be reliably assessed using the CAT and that the method is appropriate for the domain of technical graphics education. The need to promote engineering students' abilities to think creatively and to effectively communicate their innovative ideas graphically is fundamentally important.

Larger-scale investigation could be useful in exploring potential benefits of self and peer evaluation to student achievement as well as to classroom creativity assessment. Additional investigation is needed into effective methods for training students to act as peer raters. Consistently high levels of inter-rater reliability found in preliminary cross-domain studies have laid a groundwork for pedagogical investigations comparing, for example, the effects of variables such as design processes, pedagogical strategies, and design prompts on engineering students' creative outcomes.



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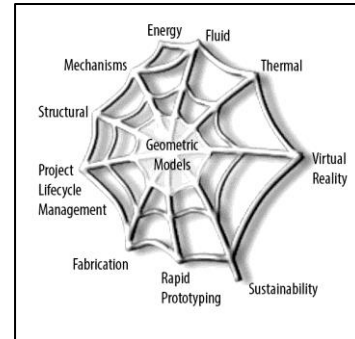
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# Preparing Freshmen Engineering Students for the Web of Graphics: Three Taxonomies

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## Abstract

*This paper addresses the educational topics needed to prepare engineering students for the “Web of Graphics” activities proposed by this conference logo (right). This discussion focuses on the need for instruction in 1. engineering graphics fundamentals, 2. geometric computer modeling, and 3. computer modeling applications. Tables of taxonomies in these three areas are presented as a methodology to start broad discussion amongst the engineering design graphics (EDG) community.*



## Introduction

Central to the “Web of Graphics” theme is the ability to develop the core 3-D geometric model. In order to perform geometric modeling, students must be proficient with the current technology. The engineering graphics educational paradigm has been significantly transformed from a 2-D drafting class to a new 3-D geometric modeling course over the years. Recent EDG surveys (Barr, 2012) that spanned this past decade indicate that changes in the engineering design graphics curriculum have stabilized, leading to an educational experience that supports this conference theme. This educational paradigm has three phases as shown in Figure 1.

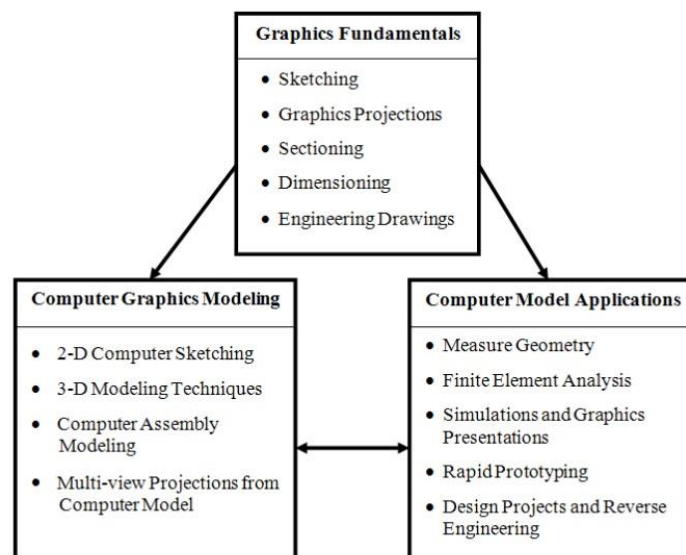


Figure 1. Three Areas of Modern Engineering Graphics Teaching Paradigm (Barr, 2012).

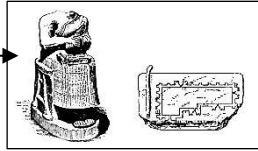
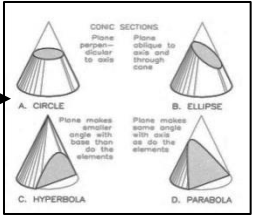
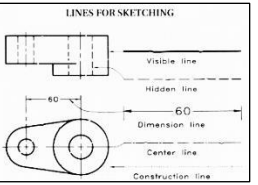
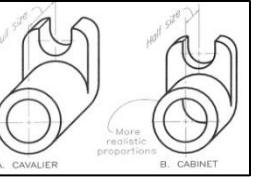
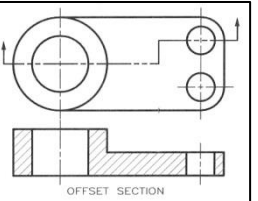
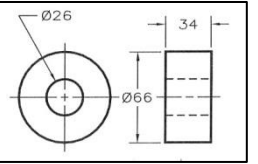
This paper focuses on the engineering graphics course we should be teaching in 2014, and beyond, that supports the “Web of Graphics” theme. As Figure 1 implies, this should address: 1. engineering graphics fundamentals; 2. computer graphics modeling fundamentals; and 3. computer graphics model applications. The proposed strategy is to develop taxonomies for each of the three areas. It is assumed that there is a lecture class with 2-D sketching activities and a computer lab class for learning 3-D geometric modeling, with applications (Ross, 2013).

### Engineering Graphics Fundamentals Taxonomy

There are fundamental engineering graphics topics that remain independent of the current technology. Table 1 offers a starting point for discussing this taxonomy. Freehand sketching offers an excellent mode for learning these basic topics. Sketching simple drawing primitives and making simple constructions are a good place to start. The various forms of graphics projections show the different ways the students can

visualize 3-D geometry on a 2-D piece of paper. Then the concept of engineering drawings can be introduced, with the most important techniques and conventions stressed. All of these activities

**Table 1. Engineering Graphics Fundamentals Taxonomy**

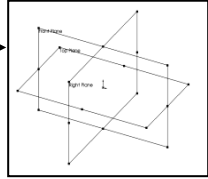
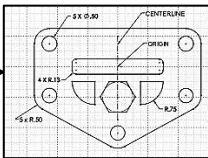
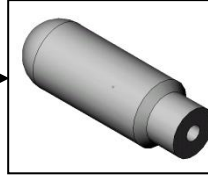
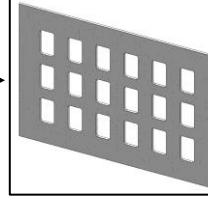
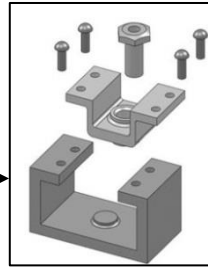
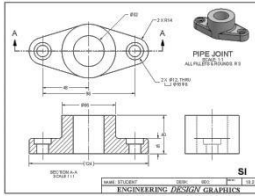
|   |   |
|---|---|
| A. History of Graphics<br>B. Graphics Sketching Tools<br>1. Pen Types<br>2. Paper Type and Grids<br>3. Measuring Devices  |    |
| C. Graphics Drawing Primitives<br>1. Line<br>2. Circle and Arc<br>3. Rectangle<br>4. Polygon<br>5. Lettering  |    |
| D. Graphics Constructions<br>1. Parallel<br>2. Tangent<br>3. Bisector<br>4. Conic Sections  |    |
| E. Visualization Techniques<br>1. Line Representation<br>2. Missing Lines<br>3. Mental Rotations  |  |
| F. Graphics Projections<br>1. Axonometric<br>a. Isometric<br>b. Dimetric<br>c. Trimetric<br>4. Oblique<br>5. Orthographic<br>a. Six View<br>b. Three View<br>c. First/Third Angle   |  |
| G. Engineering Drawing Basics<br>1. View Positioning<br>2. View Alignment   |  |
| H. Section Views<br>1. Full<br>2. Half<br>3. Offset<br>4. Broken-Out<br>5. Revolved/Removed   |   |
| I. Dimensioning<br>1. Dimension Line Types<br>2. Linear Dimension<br>3. Circular/Radial<br>4. Leaders and Notes<br>J. Drawing Standards<br>1. Drawing Sheet/Scale<br>2. Title Block |   |

Illustrations (Earle, 2003)

can be taught and learned in a freehand sketching mode (Marklin, et al. 2013). No tools beyond a pencil and paper are needed.

### Computer Graphics Modeling Taxonomy

Computer graphics modeling techniques may vary with the software used. However, there are some fundamental methods that seem to span all software. For example, most geometric models start with a closed 2-D sketch on a defined plane, and then you either extrude or revolve the sketch into a 3-D body. To define the sketch, a set of common 2-D primitives and editing tools are available. Table 2 offers a taxonomy of these generic computer graphics modeling commands. Of course, some complex parts may use advanced features such as lofting or sweeping. Most engineering designs are an assembly of parts, so assembly modeling is a natural extension of building individual parts. Finally, the author believes that an engineering drawing is still needed in practice, so the computer graphics lab can nicely culminate with this student exercise, including printing a hard copy.

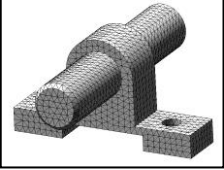
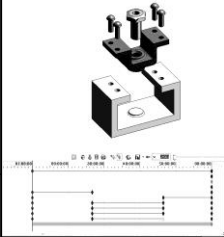
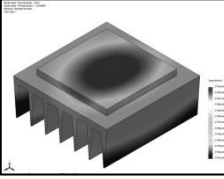

| Table 2. Computer Graphics Modeling Taxonomy |   |
|--|---|
| A. Screen Layout                             |   |
| 1. Main Menu Structure                       |   |
| 2. View Orientation                          |   |
| 3. Grids and Units                           |   |
| 4. Sketching Planes                          |   |
| 5. Feature Tree Manager                      |    |
| B. Basic 2-D Primitives                      |   |
| 1. Line/Centerline                           |   |
| 2. Rectangle/Polygon                         |   |
| 3. Circle/Arc                                |   |
| 4. Curve                                     |    |
| C. Basic Editing Tools                       |   |
| 1. Edit Dimension                            |   |
| 2. Trim/Extend Line                          |   |
| 3. Offset/Mirror Entity                      |   |
| 4. Chamfer/Fillet                            |   |
| 5. Linear/Circular Repeat                    |   |
| 6. Add Relations                             |    |
| D. Building 3-D Parts                        |   |
| 1. Extrude                                   |   |
| 2. Revolve                                   |   |
| 3. Sweep                                     |   |
| 4. Loft                                      |   |
| 5. Repeat Features                           |   |
| 6. 3-D Edit Features                         |   |
| E. Assembly Modeling and Mating              |   |
| 1. Tiling Views                              |   |
| 2. Adding Parts                              |   |
| 3. Mating Parts                              |   |
| a. Coincident                                |   |
| b. Concentric                                |   |
| c. Parallel                                  |   |
| d. Perpendicular                             |   |
| 4. Explode Assembly                          |  |
| F. Generate Multi-view Drawing               |   |
| 1. Insert Drawing Sheet                      |   |
| 2. Projecting Views                          |   |
| 3. Add Centerlines                           |   |
| 4. Add Dimensions/Notes                      |   |
| 5. Insert Pictorial                          |   |
| 6. Print Drawing                             |  |

Illustrations (Barr, et al., 2012)

### Computer Graphics Modeling Applications

While the first two taxonomies could represent a common set of topics for all engineering graphics courses, the third taxonomy on computer graphics modeling applications will represent a diversity of local interests. Table 3 shows some possible applications that engineering graphics faculty may wish to engage. Some faculty may create modules to measure mass properties of the

part. For others, finite element analysis is a powerful application that is now easily available for the freshman course. Kinematic animation and physical simulations are additional applications that can be explored in the graphics course. A current popular team project is reverse engineering, in which the team dissects and completely reconstructs a mechanical assembly in the computer lab, including printing a 3-D prototype. Yet, some schools may have other types of team design competitions for freshmen students, or service learning projects to design for local community needs. It is not likely that any individual course or faculty member will be able to explore all the applications listed.

| Table 3. Computer Graphics Modeling Applications  |  |
|---|--|
| <ul style="list-style-type: none"> <li>A. Measure Geometry               <ul style="list-style-type: none"> <li>1. Measure Length/Area</li> <li>2. Assign Material</li> <li>3. Mass Properties</li> <li>4. Design Tables</li> </ul> </li> <li>B. Finite Element Analysis               <ul style="list-style-type: none"> <li>1. Meshing</li> <li>2. Stress/Strain</li> <li>3. Displacement</li> </ul> </li> <li>C. Kinematic Animation               <ul style="list-style-type: none"> <li>1. Create Assembly</li> <li>2. Create Script</li> <li>3. Explode Assembly</li> </ul> </li> <li>D. Physical Simulation               <ul style="list-style-type: none"> <li>1. Thermal Analysis</li> <li>2. Fluid Flow</li> <li>3. Vibration/Buckling</li> </ul> </li> <li>E. Rapid Prototyping               <ul style="list-style-type: none"> <li>1. Create STL File</li> <li>2. Print 3-D Part</li> <li>3. Post-Process Part</li> </ul> </li> <li>F. Design Projects               <ul style="list-style-type: none"> <li>1. Teamwork</li> <li>2. Reverse Engineering</li> <li>3. Design Competitions</li> <li>4. Service Projects</li> <li>5. Final Project Reports</li> </ul> </li> </ul> |     |

Illustrations (Barr, et al., 2012)

## Conclusions

The engineering graphics curriculum has stabilized in recent years due to the near-universal adoption of 3-D geometric modeling as the central theme. This is a fortunate development, because engineering graphics faculty can now show relevance of graphics to up-stream engineering topics through the “web of graphics” applications. To develop the students’ abilities in geometric modeling, a set of fundamental topics in engineering graphics and geometric modeling have been proposed, as a starting point for broad discussion in the EDG community.

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# Update on a Delphi Study for Developing a Concept Inventory for Engineering Design Graphics

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## **Abstract**

*In 2010 the authors were awarded a grant from the National Science Foundation to conduct a Delphi study as a first step in defining a concept inventory for engineering graphics. The rationale for the need for a concept inventory in engineering graphics is that unlike many other foundational subjects in engineering such as statics, dynamics, or strength of materials, engineering graphics instruction has changed significantly over the past century, and, in this climate, it is important that graphics educators keep sight of the fundamentals in graphics education. The primary reason for the change in graphics education over the past few decades is the development of new graphical tools and methods at an increasingly rapid pace. In an ideal world, educators should not rush to change for the sake of the new tools, ignoring fundamental concepts along the way. Unfortunately, there is little agreement about what constitutes the fundamentals in graphics education. In other science and engineering fields, such as physics, mathematics, statistics, and engineering science, concept inventories have been developed in recent years to define the fundamental concepts in those disciplines. The concept inventories provide educators with a standardized instrument that they can use to help design their courses and to determine if their students understand the fundamental concepts. As a first step in the development of a nationally normed concept inventory for engineering graphics, a Delphi study is being conducted to define the fundamental concepts. The concept inventory itself will be developed as part of the next steps. This paper describes the Delphi method and outlines progress to date on the project.*

## **Introduction**

Throughout its history, engineering graphics has embraced the “tool of the day” migrating from hand-drafting tools to 2-D and, finally, to fully integrated 3-D design systems. Graphics educators have discussed the benefits of one CAD package versus another, debated the need for

inclusion of topics such as traditional descriptive geometry, and focused on industry needs in designing their graphics courses. However, rarely, have they discussed the foundational concepts that should be included in a graphics course at any level. This Delphi study seeks to define these foundational concepts so that educators can design courses to meet the needs of today's students and the ever changing tools and graphics techniques.

### **Need for a Concept Inventory in Engineering Graphics**

Engineering graphics is one of the highest enrollment courses in all of the STEM fields. Graphics remains a requirement for many engineering and technology disciplines. Common first-year engineering programs including Virginia Tech, Purdue, Texas A&M, and Michigan Tech contain a strong graphics component. At Purdue, College of Technology professors teach engineering graphics courses to freshman engineers, as well as engineering technology students. Graphics is also taught in pre-engineering and in engineering technology programs at community colleges and high schools. High school graphics is often taught primarily for students who intend to major in a STEM field after graduation. No consensus regarding optimal content for graphics courses exists, resulting in a large degree of variation among courses across the country.

A concept inventory for engineering graphics would identify "core" graphics topics so courses could be designed around this core. A concept inventory would lead to a better connection between all levels of graphics courses ensuring that high school and community college courses map to the expectations of university-level graphics courses. A concept inventory would also enable faculty at all levels to assess student understanding of fundamental concepts in graphics, to evaluate the effectiveness of the courses they teach, and to make adjustments as necessary.

### **Delphi Technique**

A Delphi study is a consensus-building, forecasting technique that has been used by organizations, agencies, and corporations for making predictions and setting agendas. Although this technique was developed in the "business world," a number of educational leaders including Clark & Scales (1999), Volk (1993), and Zargari, Campbell, & Savage (1995) have suggested its use in the design of curricula and programs. A Delphi study typically consists of three to four rounds, conducted with a panel of experts, to reach consensus on defining the important elements of a curriculum. A Delphi study also lends itself to reaching consensus without a need for face-to-face meetings among panel members, making the study relatively easy to implement, especially for a panel with broad geographic representation among its members.



## **Project Activities**

Upon notification of award by the National Science Foundation, the project team has been implementing the planning and organizational activities required to conduct the Delphi study. The following activities have been accomplished to date:

- An initial brainstorming session with a small group of faculty leaders in graphics education was held in conjunction with the 66<sup>th</sup> midyear meeting in Galveston, Texas. Topics in graphics education were listed and put into categories with no attempt to distinguish between “topics” and “fundamental concepts.” The idea was to be as inclusive as possible with “weeding out” to be conducted in later stages of the Delphi study.
- A second meeting was held in conjunction with the ASEE annual meeting in Vancouver (June 2012) to examine the list of topics produced at the first meeting and to assign the topics to members for illustration purposes.
- Participants created 20-40 slides depicting the topics or concepts that had been assigned to them.
- A third meeting was conducted in conjunction with the ASEE annual conference in Atlanta in June 2013. The final slides were examined and put into categories based on conceptual “themes.”

With the topics/concept slides completed, the following activities were planned:

- The concept/topic slides will be incorporated into the electronic Delphi instrument with the Delphi study commencing in August 2013. Invitations for participation in the Delphi survey will purposefully include university, community college, high school, and industry leaders.
- In the first round of the Delphi study, participants will answer two questions regarding each item:
  - 1) Is this a concept or a topic?
  - 2) Is it essential?

Based on the results from this round, we expect to eliminate a significant number of the items.

- Further rounds of the Delphi study will be conducted as needed to winnow the topics to a remaining few fundamental concepts. After round one, we will ask participants:
  - 1) Is this an important/fundamental concept?
  - 2) Is this a concept where there are significant student misconceptions?

## **Adaptive Comparative Judgment (ACJ)**

In the process of conducting the activities associated with the Delphi study, the authors were

introduced to the adaptive comparative judgment technique for reaching consensus regarding the “preference” of items from a list of many. Through this technique, participants view two pairs of items and make a judgment about which is more important. At any given time, the participant only sees two items; however, s/he may see the same item more than once. Each participant will not see all of the items and will make judgments based on the two presented at any given time. Depending on the number of participants and the number of items, each person may rate 20-40 pairs during a session. Since they are comparing only two items at a time, the process is not overly time-consuming.

Adaptive comparative judgment is used for consensus-building among disparate groups, which is also the key goal of the Delphi study. Typically, the correlation coefficient for the consensus on the ACJ is around 0.9, meaning that there is a high degree of agreement for the final results. For this reason, the authors wondered could the ACJ replace the Delphi study for educational consensus-building. Could the adaptive comparative judgment be used to augment the Delphi study to arrive at consensus much more quickly?

The decision was made to conduct the ACJ technique simultaneously with the Delphi study to answer the following questions:

- 1) Do we achieve essentially the “same” consensus among the group members through the two different techniques?
- 2) Is there an advantage in terms of implementation between the two methods? (i.e., is one method or the other easier to employ)
- 3) How do participants feel about the two methods, (i.e., do they “prefer” one method over the other)

Depending on the results from this research, we could identify an exciting new approach for achieving consensus around curriculum design while simultaneously, identifying the critical concepts for Engineering Graphics.

### **Acknowledgements**

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# **A Sophomore Proto-Simulation Course**

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## **Abstract**

*The fast growing advances in the development and use of computational tools in different engineering fields requires engineers who are well versed in the use of these tools. To address this need we have designed a course called “Engineering Technical and Graphical Communication” to familiarize students with several major simulation packages. In this course students learn the fundamentals of these software programs in their third semester at Manhattan College and then make use of them at all levels of the mechanical engineering curriculum. In their last two semesters they are able to utilize multiple computational packages required for the “senior design project”. This systematic exposure to different software tools helps students to prepare themselves for a profession that demands a complex mix of different simulation and modeling packages.*

## **Introduction**

Engineers have always used different techniques to create and communicate their design ideas, and as time as gone by representations have evolved from maps on stone to 3D Computer Aided Design and Drafting (Barr and Juricic, 1994). Unfortunately traditional educational methods may not provide students with the skills and tools that the workplace demands (Mailhot 2008). In an effort to tackle this concern many mechanical engineering schools introduce simulation software as it is needed in appropriate courses. This approach however requires time to be taken out of the class schedule to teach the students the basics of the program in question. This could also be done by requiring the students to become familiar with the program outside of class, however, this often results in a poor understanding of all the features associated with the software and in some cases a complete misunderstanding of the mathematical principles employed by the program. In the mechanical engineering department at Manhattan College this issue is addressed by introducing the students to the department’s major simulation packages (word, excel, Mathcad, Revit, and NX) in a required first semester sophomore class. In the following section the details of the course and its advantageous are explained.

## **Course description**

The class has four contact hours split into two, two hour sessions. This allows the salient features of the software to be presented in the first hour, followed by a “Simon-says” hour where the students follow the instructor as he or she uses the primary elements of the software to tackle problems that the package is specifically designed to address. In second two hour session the students are given their own set of tasks that they have to address using the features of the software that they had learned in the previous two hours. A small quiz is then given the following week to gauge how well the students understood the material.

### **Packages Covered**

Word is not a simulation package, however since it is used ubiquitously throughout the Mechanical Engineering Program in laboratories and design classes, it was felt that all students should be familiar with the more advanced features of the software, such as how to construct tables correctly, how to use the drawing features, and how to create well formatted equations using the equation editor. This part of the course is covered within the first week of the class and is associated with a departmental writing style manual that all students are expected to follow when submitting written material associated with any mechanical engineering class.

Excel may not be regarded as a “true” simulation package either; however, it is so common throughout the engineering profession that it is necessary that all students be conversant with such features as Goal Seek, Solver, and the Data Analysis Add-In. In addition, the students are given a rigorous grounding in all aspects of graph creation and formatting to allow them to produce professional quality charts in all subsequent classes. Again, as with word, only one week is devoted to this software package.

Mathcad is the next package introduced to the students and is a package that is used widely throughout the department for use in homework, design projects, and laboratory assignments. The main features of the program are covered in this class such as the basic equation solver, graphical presentation, statistical analysis, vector and matrix calculations, numeric differentiation and integration, and elementary symbolic manipulation. This takes five weeks of the course and at the end of this section the students also have a collection of Mathcad files that are directly usable in subsequent classes, such as statics, solid mechanics, fluid mechanics, thermodynamics, and heat transfer.

Revit is the first major simulation package to which the students are exposed. AutoCAD, the two dimensional companion to Revit, is used in a freshman general engineering class to provide all engineering students with the ability to produce basic two dimensional renderings of engineering components. Revit however, being a three dimensional simulation software tool, permits students to construct full three dimensional buildings, which can be used in conjunction with HVAC tools to analyze the heat load and thermal behavior of buildings, thereby giving the

students a more realistic appreciation of heat transfer concepts in the required thermal/fluid system design class and in the elective HVAC class in their senior year.

The primary computer-aided engineering package used by the department is NX, however to ensure that the full power of this package is employed correctly a good solid model has to exist; therefore a significant amount of time is spent on different solid modeling, assembly, and drafting aspects of NX such as extrude, loft, and feature creation. Time is also taken to engender good solid modeling practices and thereby facilitate the creation of parts that are easy to export to other software packages such as Abaqus and Inventor, and are easy to use in the subsequent required junior finite element class and junior manufacturing laboratory where the computer-aided manufacturing component of NX is used to generate g-codes for a four-axis mill. The good solid modeling practices learned in this class also allow full natural frequency and modal analysis projects to be undertaken in the senior vibration class. Finally, the drafting component is introduced to the students as a tool that can be used in their senior design class where correct part drawings of assemblies are required.

## Results

A questionnaire was given to the present (Fall 2013) senior class of mechanical engineering students to gauge the degree to which they believe the material covered in this course was of use to them during their second semester sophomore and junior years. The question asked was “When it was suitable to use *Software Package X*, to what degree did you use it effectively in courses after MECH 211?” with the options being from Not at all (1) to Very often (5). The results (Table 1) showed that the students found Excel and Mathcad to be of significant use, while both NX-Ideas and AutoCAD were deemed to be of little use (based on a Chi-Square test these results had a level of significance of at least 10%).

|                 | Degree of Use |    |   |    |    |
|-----------------|---------------|----|---|----|----|
|                 | 1             | 2  | 3 | 4  | 5  |
| <b>Excel</b>    | 0             | 0  | 2 | 10 | 22 |
| <b>Mathcad</b>  | 2             | 5  | 8 | 13 | 6  |
| <b>AutoCAD</b>  | 11            | 11 | 2 | 2  | 4  |
| <b>NX-Ideas</b> | 11            | 7  | 8 | 2  | 1  |

Table 1: Results of the student software package usage questionnaire

The disparity between the results associated with excel/Mathcad, and AutoCAD/NX can be explained by the fact that excel and Mathcad have been a part of the course since its inception, however, AutoCAD and NX-Ideas was replaced with Revit and NX8 in the Fall of 2012 to accommodate changes in industry. Consequently, the present senior class which was taught how to

use AutoCAD and NX-Ideas have not had the opportunity to experience a continuous use of the two drafting packages that they were taught. However, this survey will provide a baseline with which to measure the future effectiveness of this pedagogical approach.

### **Conclusions**

To fully prepare students to enter the engineering profession, we have introduced a new course called “Engineering Technical and Graphical Communication” which is a required first semester sophomore course. In this course we introduce major simulation packages (word, excel, Mathcad, Revit, and NX) to the students. By presenting simulation software in this way several advantages have been observed: 1) time is not wasted in later classes to teach them the software; 2) by introducing the packages to the students at such an early stage in their academic career they have the opportunity to use the programs in many subsequent classes thereby improving their familiarity with the software and allowing them to learn new features easily; and 3) by the time the students then become seniors their multiple exposures to these various packages allows them to use the software productively in their two semester long senior design class.

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# Introducing Design Revision into a Freshman Level Engineering Graphics Course

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## **Abstract**

*To better prepare students for their upper level design courses including a senior capstone course, a simple design project was introduced in a freshman level engineering graphics course. This project required the students to initially sketch design ideas while in class, then additional refined sketches were required as a homework assignment. From these sketches, one design idea was selected by the instructor and feedback was given on the design ideas. At the completion of the project, students submitted their sketches, a model of their product, working drawings and a cost estimate prepared using spreadsheet software.*

## **Introduction**

In the School of Engineering at Penn State Erie - The Behrend College, a two course sequence of introductory engineering graphics courses is offered as part of the Mechanical Engineering Technology program. The first course covers sketching, multiview projection, dimensioning, 3D modeling methods, assemblies, and an introduction to detail drawings. The second course covers section and auxiliary views, threads and fasteners, detail drawings, and advanced CAD applications. In the second course, during the sixth week of a fifteen week semester, a design project was introduced. This project included many of the topics addressed in the two semesters of engineering graphics course sequence.

## **Project Overview**

The students were given the following description of the project along with a graphic that included specific details about the air compressor:

I bought a new air compressor for my workshop. Your task is to design a device which can be used to easily move the compressor and its associated accessories and tools around in the workshop. The result of your design effort is a complete set of working drawings



for the device which will convey all the necessary information to make it. You also need to use a spreadsheet to create a bill of materials listing the materials and parts that need to be purchased. This spreadsheet will also serve as a material cost estimate.

Function of the Device:

- To store and transport a pancake type air compressor and its associated accessories and tools.

Design Requirements:

- It shall be compact, stable and portable
- Must be inexpensive
- Safe to use
- Has to be made using tools found in a typical home workshop (saws, drills, hammers, etc.)
- The compressor weight and dimensions are defined in the catalog cut above
- The air hose is 1/4" diameter (1/2" OD) and is 50-ft long
- Device is to be human powered, not motorized in any fashion
- The compressor is used with a pneumatic nailer which is shown in the figure below

### **Project Timeline**

During a lecture session in week six, the students were given the project information and approximately 30 minutes at the end of class to sketch three different design ideas. These sketches were initialed by the instructor and retained by the students with the instructions that they should analyze their sketches, think about their design ideas, and in one weeks' time turn in a set of detailed sketches based on their initial ideas. During week seven, the original in-class sketches were to be turned in along with revised sketches which were to include basic dimensions, initial material choices, and any necessary notes. From the detailed sketches, one of the three design ideas was chosen by the instructor for further sketching/ideation and students were given detailed feedback from the instructor.

In week eleven, the following was due: the original sketch of the design idea that was selected for the student to refine; a new sketch, including notes describing any substantial or required changes made to the design; an isometric sketch of the final design idea; detailed orthographic sketches including dimensions of the non-standard components including any necessary detail sketches; and a detailed parts list including specific materials, costs, and the names of the local vendors where the necessary items can be obtained.

The sketches and parts lists were returned to the students in week twelve. The returned items included detailed feedback on the design and selected materials as well comments on the

effectiveness of the design in meeting the original project scope and needs of the end user. In the initial assignment, a budget was not specified beyond “inexpensive” and the total cost for the designs ranged from approximately \$50 to over \$300. Students were instructed during week twelve that the total budget for the project could not exceed \$75. This required a few designs to be changed substantially. Most students were able to meet the new budget by changing the specified material instead of making major configuration changes to their design.

The completed final project was due in week fifteen and the requirements were expressed as follows:

Based on the feedback on your refined sketches, create the following:

- Creo assembly (.asm) that includes all parts, including fasteners, wheels, etc.
- Exploded assembly drawing (.drw) with BOM that indicates how each part fits together; also include smaller scaled view of full assembly
- Dimensioned detail drawings (.drw) of all parts that are not standard
- Instruction sheet complete with graphics (created in Word or PowerPoint) that has all the steps for building the cart including:
- Tools necessary to build the cart (saws, screwdrivers, glue, etc.)
- Notes and any necessary graphics that indicate specifically how and in what size/length to cut plywood, dowels, pipes and any other material that needs to be modified from its purchased state
- Cost sheet (in Excel) that has the price of all items and where they can be purchased - total cost not to exceed \$75

### **Project Examples**

Figure 1 shows two examples of the first sketches completed in class during week six after the project was initially introduced. There were no specific instructions given on the format of the initial sketches. Some students used standard orthographic views like the example on the right, others created only isometric views, and some used a combination of view types and notes as in the example on the left. In Figure 2 are examples of the detailed sketches that were based on the initial design ideas. The examples in Figure 3 are of the final set of sketches that were required to include detail sketches, a parts list and costs. Figure 4 shows assemblies and exploded assemblies created using Creo.

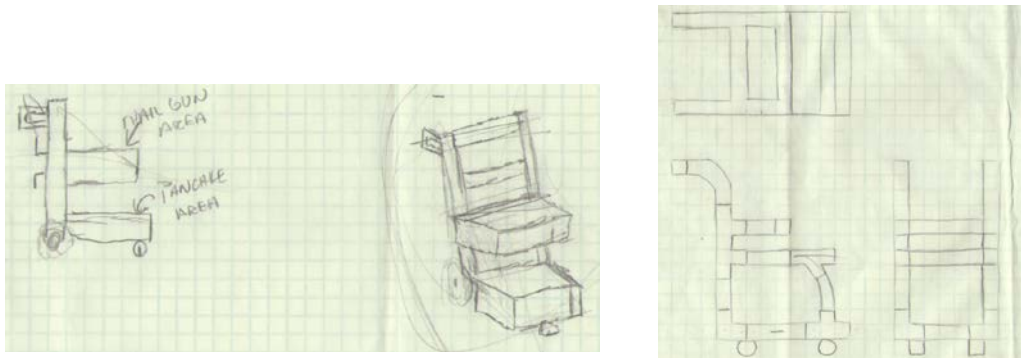


Figure 1. Initial sketch examples

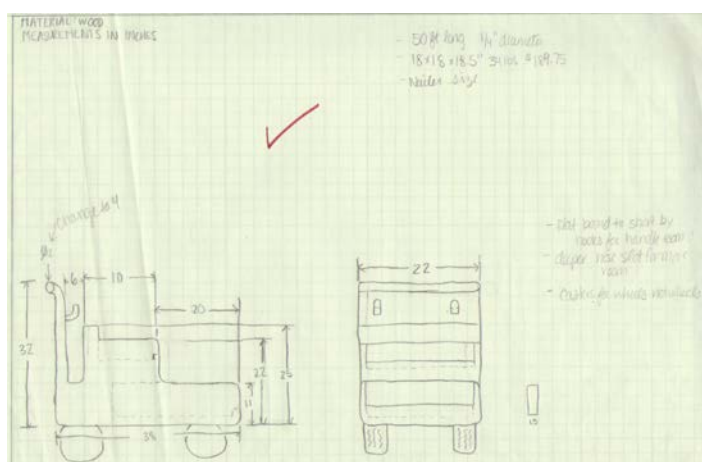
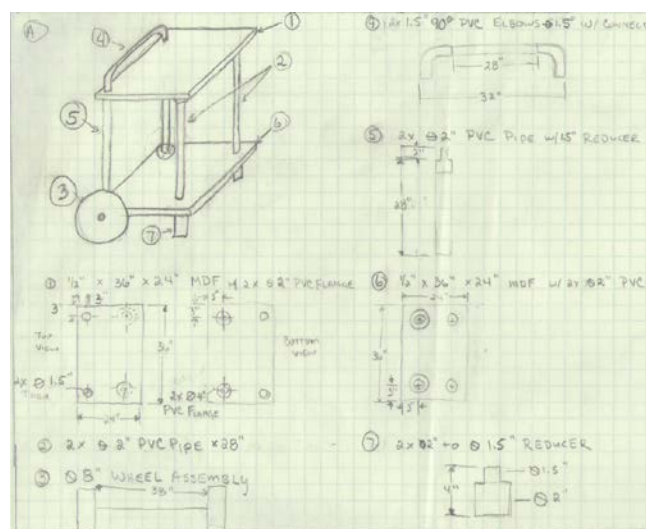


Figure 2. Detailed sketch examples

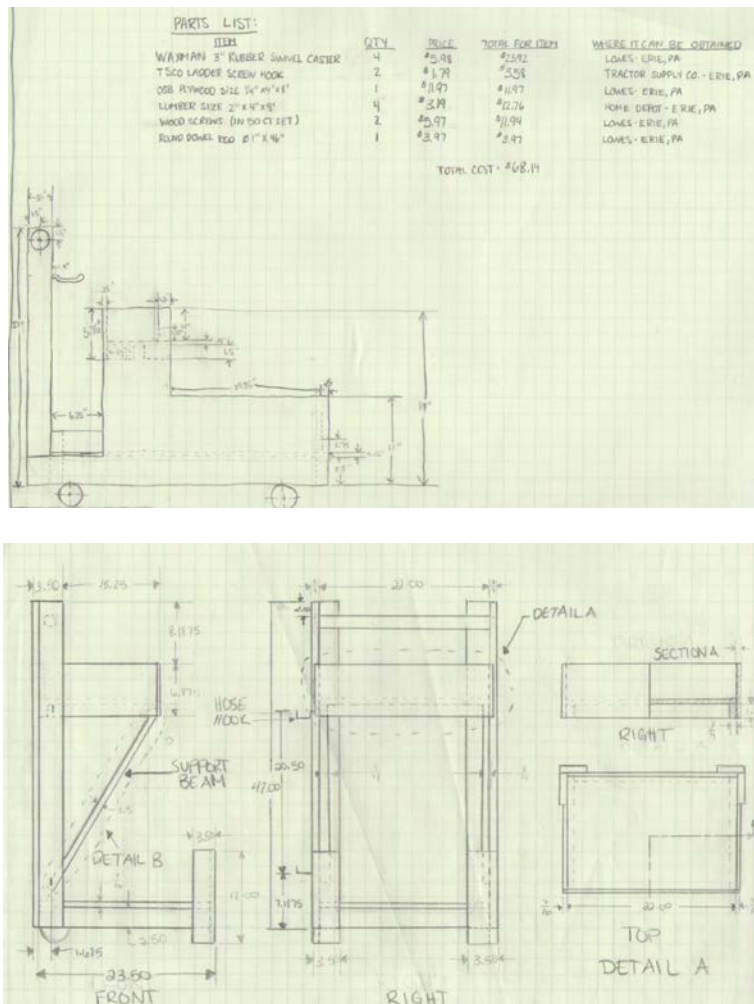


Figure 3. Final sketch examples

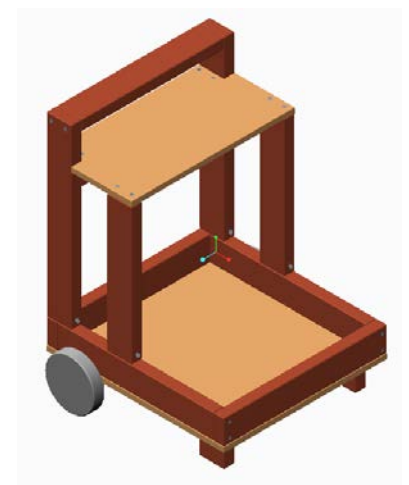
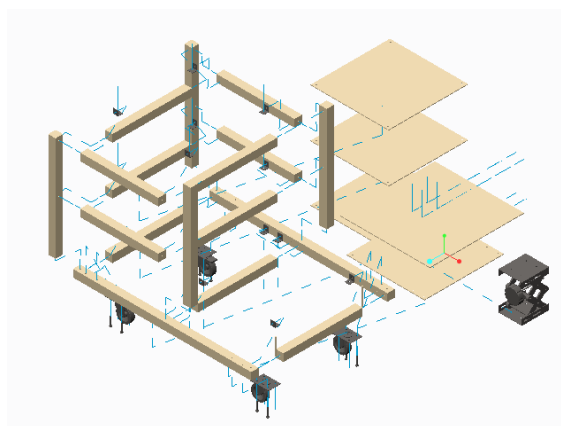


Figure 4. Creo assembly examples

## Conclusions

Overall, the project was effective in that it required students to consider different design solutions along with implementing a variety of engineering graphics techniques in the finished project. Student feedback included comments like: (instructor) didn't choose the design I liked best; sometimes things that are easy to sketch are actually hard to model and build; I wish we'd had more time to do the Creo work; I thought my design looked good but couldn't figure out how to attach everything together so I had to change it; project was interesting and fun but harder than it sounded when (instructor) first assigned it.

The requirement of having students list the specific tools needed to make the cart, along with finding local vendors for all of the components added a practical element to the project. Some students even commented that going to the store along with searching online for parts helped them make specific changes to their designs, especially for fasteners and wheels. The requirement of multiple sets of sketches and revision of ideas before CAD modeling began, along with the instructor selecting which design idea to go forward with, prevented the issue seen previously in different courses where students would start to design using CAD software instead of sketching and then have difficulty and express frustration in making design changes because of the time already invested in modeling.

In future offerings of the course, students will be given smaller assignments earlier in the semester to introduce them to the process of looking for alternative ways of designing specific features. For example, they would have to sketch three different ways two boards can be assembled to form a 90° corner. Time allowed for CAD modeling will also be reconsidered, along with the overall scope of the project since student comments and instructor observation both indicated that time required outside of class to complete the final project may have been a little too extensive.

# **A PLM Certificate Program Update: Teaching PLM Online Using VMs in the Cloud**

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## **Abstract**

*Purdue University Department of Computer Graphics Technology in conjunction with the Boeing Company developed a Product Lifecycle Management (PLM) Certificate Program for Boeing employees. Several cohorts have been through the Certificate Program. This paper will outline the successful fundamental aspects of the program which include curriculum, online delivery and the lecture/lab format. This paper will address changes that have been made in course length and course delivery architecture including using virtual machines in the cloud. Additionally, this paper will discuss strategies for keeping the program viable and relevant to working professionals of the Boeing Company as well as other companies.*

## **Introduction**

Product Lifecycle Management (PLM) has been an area of specialization of the Department of Computer Graphics Technology (CGT) Department in the College of Technology at Purdue University for more than a decade. As described by Hartman and Springer (2011) the PLM Certificate Program (PLMCP) began as a collaborative effort between the Boeing Company and Purdue University to address the knowledge gap between management's directive to implement PLM and the workforce's use of PLM tools to perform their job function. Once the corporate decision is made to practice PLM, the key to PLM success, by the very definition of PLM, is to have everyone in the organization understand PLM. Product lifecycle management is generally defined as managing a product from concept to disposal in an effort to make better business decisions and leverage a competitive advantage (Hartman & Springer 2011). As a product moves through its lifecycle from concept to disposal, everyone in the organization in the course of performing their job duties comes into contact with some aspect of the product. In this way, everyone in the organization becomes part of the practice of PLM and would benefit from an overview of PLM.

CGT had experience with PLM curriculum that could be leveraged for such an overview. Boeing's internal training and development organization provided access to subject matter experts and training coaches. The Center for Professional Studies and Applied Research (ProSTAR) in the College of Technology addressed the logistics of managing a professional educational program. It was the combined efforts of these three organizations working together as described in Hartman

and Springer (2011) that the PLM Certificate Program content was derived and in June 2007 the first cohort of 20 participants started their coursework. With three 10 week courses covering the three core areas of PLM: CAD, PDM and manufacturing, the first cohort concluded in March 2008 with 12 participants receiving completion certificates (Hartman & Springer, 2011). The first cohort had a 60% completion rate. Participant and employer feedback gathered at the end of each course validated the curriculum but required major changes to the laboratory portion of the program. As a result, the start of the second cohort was delayed until September 2009 with 22 participants. The second cohort completed the certificate program in April 2011 with 12 participants receiving completion certificates (Hartman & Springer, 2011). The second cohort had a 54% completion rate.

### **Building on Success**

The author joined the faculty portion of Purdue's PLM Certificate Program team specifically to teach the third cohort and build on the successful characteristics that emerged from the first two cohorts. The third cohort began in September 2012 with 13 participants using the adult learning strategies and synchronous online delivery model described by Hartman and Springer (2011). The three course format with the same goals and weekly topics as described in Hartman and Springer (2011) were also used but the length of each course was reduced to 8 weeks. The weekly lecture covered concepts but emphasized tool independence and was not industry specific. The weekly lab exercise gave participants experience working with PLM tools without being typical tool training. The software tool used for the lab exercises was for illustration purposes only and the core processes and methods could then be applied to any PLM toolset. This would ensure anyone looking to enhance their knowledge of PLM would benefit from the courses regardless of which PLM tools their organization used. In Boeing's case, different PLM tools were used at different business units. Participants were awarded Continuing Education Units (CEUs) as they successfully completed each course and awarded a Purdue University Certificate after completing all three courses. The third cohort concluded when seven participants completed the certificate in May 2013. The third cohort had a 54% completion rate. There were nine participants in each of the second and third courses because the requirement that the courses be taken in order was dropped. This change was made to give participants more flexibility in how they could complete all three courses based on reasons cited for dropping out of the program in end of course surveys described in Hartman and Springer (2011) including change in work assignment, scope or priorities and personal reasons. The change also increased enrollment by almost 29% which helped lower breakeven point for the course budget.

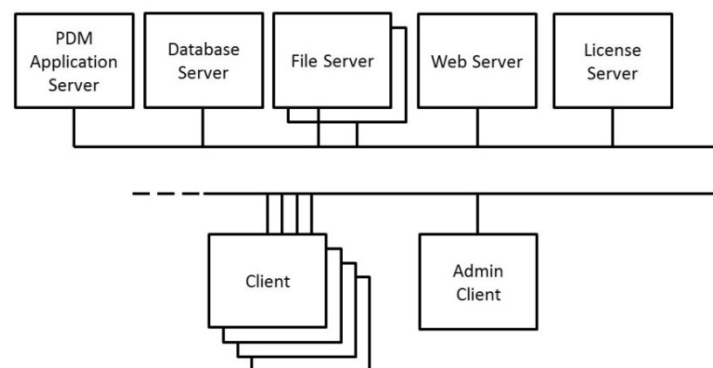


### Continuous Improvement Continues

As noted in Hartman and Springer (2011), the method of delivery of the hands-on labs to online participants has undergone the most dramatic changes and presented the most challenges. The initial goal was to come up with a solution that would work on any computer that had internet access. At first, this was accomplished by giving participants a guest account to access to Purdue's software access utility called Software Remote. This is a Citrix based technology that gives students access to software that they would normally have to go to a computer lab on campus for. This was marginal at best to access CAD software but to use it to access the client-server environment that PDM requires turned it into an administrative headache. For Course 2 and 3, CAD and the PDM rich (or thick) client had to be packaged and served up as an application on the Software Remote web site. Any mid-course changes made to the course required the package be remade and reposted. Making changes was a hassle but it was a solution. During the lab sessions CAD performance was poor as it depended on the participant's proximity to the university.

Despite the poor performance, the hands-on lab sessions were the most popular part of the courses and consistently received high marks on course surveys. Finding a solution that would provide the best lab experience to PLMCP participants was a high priority for the third cohort. "As such, the PLMCP is moving in the direction of using a hosted virtual machine solution from an external solution provider" (Hartman & Springer, 2011). The third cohort was the first to use such a configuration: VMs in the cloud. Boeing had experience with cloud services and recommended one of their cloud service providers, Skytap.

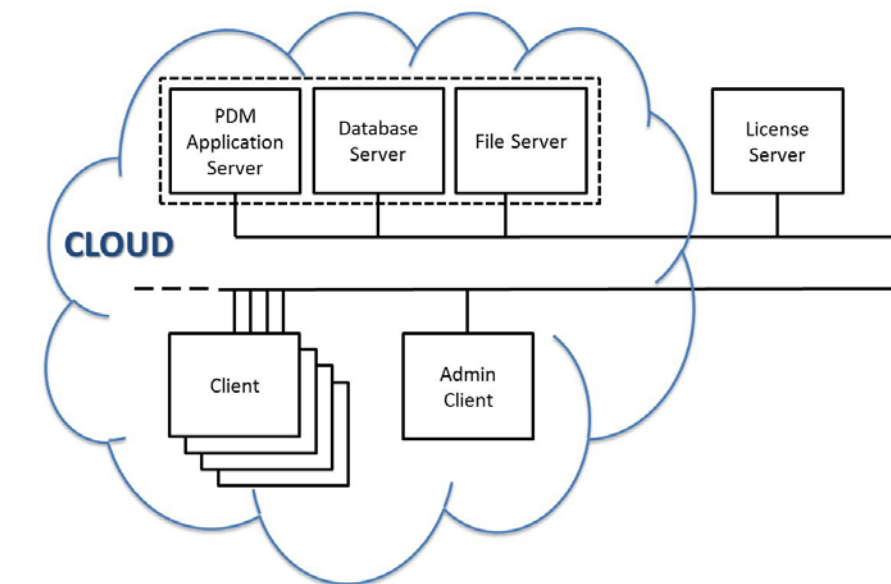
The Skytap configuration for the third cohort was designed to provide participants the flexibility to work on the labs anytime and not just during normal labs hours with a PDM server that was up 24/7. This is very similar to how a typical physical PDM network would be set up. A typical PDM set up includes an application server, database server, file server(s), license server and optionally a web server. The clients are all pointing to the same instance of the database on the application server (see Figure 1) and it is available 24/7.



**Figure 1 Typical Physical PDM Components**

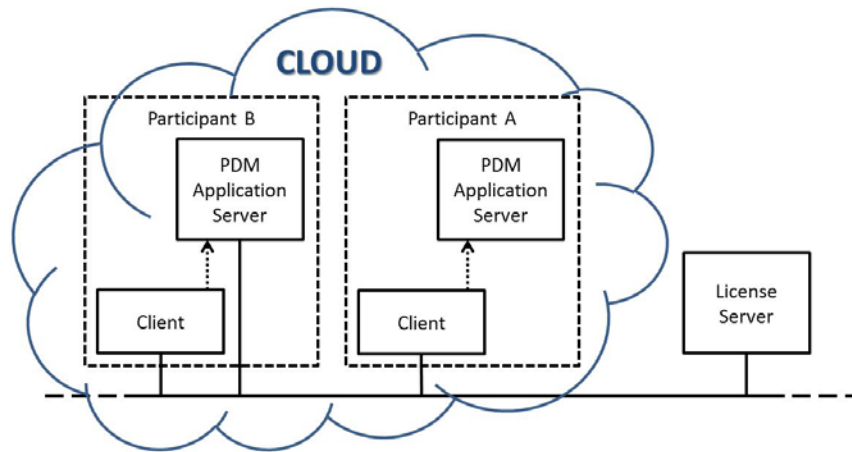


A simplified configuration was used in the cloud with virtual computers. The application server, database server and file server were combined into one virtual “server” that would be on all the time. Each participant had a client virtual machine (VM) and the instructor had a client with administrative privileges (see Figure 2). As in the typical scenario, all the clients pointed to the single PDM instance on the application server. The client VMs were powered up only when needed. The license server was on the Purdue network so the client VMs would get license authorization from the Purdue pool of licenses. With this configuration labs were included that illustrated issues involved with multiple clients hitting a single PDM instance such as file naming, part numbering and workflows.



**Figure 2 Cloud configuration for PDM with a single 24/7 server**

Running an application server 24/7 was not typical for a cloud pricing structure which is oriented to on-demand usage. Even though the lab portion of the course is designed for the participants to be online with the instructor for 2 hours once a week, if participants didn’t finish the lab or missed the preset time for the lab, they could log into their virtual computer in the cloud and complete the lab when it was convenient for them. This outside of class time availability was what required the server to be running 24/7. The fourth cohort began August 2013 with 23 participants and the configuration being used is one where each participant gets their own application server as well as their own client. The participant’s client points to the instance of PDM on the participant’s server (see Figure 3). This means that the server VM (as well as the client VM) is only powered up when the participant is online. The plan is that this will make the lab portion of the course more cost effective and efficient and scalable to an asynchronous version of the PLM Certificate Program as well.



**Figure 3 Cloud configuration with on demand servers**

Running the labs on the virtual computers in the cloud worked well from an access and control point of view. Initially, however the mouse keys did not map correctly for the CAD application. This made model manipulation tedious at best. Spinning shaded images was hard for the graphics processor to keep up with initially as well. These issues were resolved mid-way through the second course. Another issue with virtual computers running on a cloud was latency or lag time. If latency was high, users would get frustrated. High latency was attributed to distance from the servers on the west coast and internet band width. The cloud service provider brought an east coast service center online before the third course started and we saw improvement for our participants east of the Mississippi including the instructor. We also emphasized that a broad band, high speed internet connection was required for labs.

### **Evolution Continues**

In addition to adjusting the number of weeks in each course and the method of delivery for the labs, the PLM Certificate Program at Purdue has evolved and will continue to evolve. Course 1 started out with standalone CAD, now PDM is integrated with CAD from the beginning. The course has become less industry specific by not having a Boeing subject matter expert participate. The content features examples from a wide range of industries as participants from companies other than Boeing are actively solicited. The fourth cohort features the first non-Boeing employee. An asynchronous version is being developed so participants can take the courses at a time convenient for them instead of a set time each week. The curriculum is being reorganized into smaller modules partly to facilitate the asynchronous version of the program but also to keep it flexible enough so that different PLM toolsets could be used for the labs. Delivering dynamic

interactive experience with the PLM toolsets has been challenging but using VMs in the cloud looks promising.

### **Reference**

Hartman, N. W. & Springer, M. L. (2011). *A distance learning Product lifecycle management (PLM) certificate program in technology*. Paper presented at the 2011 Annual Conference and Exposition of the American Society for Engineering Education, Vancouver, B. C., Canada, June 28, 2011.

# Management Preparation of Design Technologists

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East Carolina University*

## **Abstract**

*An investigation into the management preparation of design technologists was begun. In this study, selected data were collected on the extent to which management coursework completed by students influenced the students' performance on a certified technology manager examination. Initial measures suggest the pursuit of a business administration minor and the extent to which students had completed management course work or were in the process of completing management course work had an impact on student performance on a certified technology manager examination.*

## **Introduction**

Because of its program objectives and outcomes, an Association of Technology, Management, and Applied Engineering (ATMAE) accredited BS in Design, requires its students to complete seven, three semester hour management courses in order to comply with its accreditation body's standards. In addition, the program also requires its students to complete a statistics course and an industrial psychology course, which are categorized as math and general education courses respectively by the accrediting body. The two however could just as easily be categorized as management courses by that same accrediting body.

By course title, the seven, three semester hour management courses required of the students are as follows:

FINA 2244 Legal Environment of Business

FINA 3004 Survey of Financial Management or ITEC 3800 Cost and Capital Project Analysis

ITEC 3290 Technical Writing

ITEC 3292 Industrial Safety

ITEC 3300 Technology Project Management

ITEC 4300 Quality Assurance Concepts

MGMT 3202 Fundamentals of Management or ITEC 4293 Industrial Supervision

The two additional three semester hour courses include MATH 2283 Statistics for Business or ITEC 3200 Introduction to Statistical Process Control and PSYC 3241 Personnel and Industrial Psychology.

By one of ATMAE's measures then, the BS in Design students are completing at least 27 semester hours of management course work even though the Program Structure & Course Sequencing standard only requires between 12-24 semester hours of management courses work (ATMAE, 2013).

In an attempt to ascertain the appropriateness and effectiveness of the management courses requirement, the BS in Design began requiring students taking a senior level design course to sit for ATMAE's certified technology manager (CTM) examination in 2012. While the CTM got its start with the formation of an ad-hoc certification committee in 1991, in its present state, the CTM exam had been deployed by the summer of 2001 according to Field and Rowe (2001). By 2009, an additional evaluation of the safety content of the CTM exam had been completed by Freeman, Field, Lott, and Schwab (2009).

The composition of today's CTM exam appears in Table 1. The exam items sub-categorized as Chemistry, English, Math, and Physics are a part of the Production category, and the exam items sub-categorized as Psychology are part of the Management category. A more detailed breakdown of the four exam categories appears in Appendix A.

**Table 1. Category Breakdown.**

| Category          | Question Count | Proportion |
|-------------------|----------------|------------|
| Production        | 64             | 40.0%      |
| Chemistry         | 4              | 2.5%       |
| English           | 3              | 1.9%       |
| Math              | 19             | 11.9%      |
| Physics           | 3              | 1.9%       |
| Quality Control   | 24             | 15.0%      |
| Industrial Safety | 33             | 20.6%      |
| Management        | 7              | 4.4%       |
| Psychology        | 3              | 1.9%       |
| Total             | 160            | 100%       |

The purpose of this study was to determine whether the BS in Design can reduce its management courses requirements and still produce effective graduates or possibly more effective graduates.

## Method

The population for this study was comprised of twenty-six students pursuing a BS in Design. Thirteen of the students were pursuing an architectural technology concentration. Of the thirteen, one was double majoring in engineering. The remaining fourteen were pursuing a mechanical

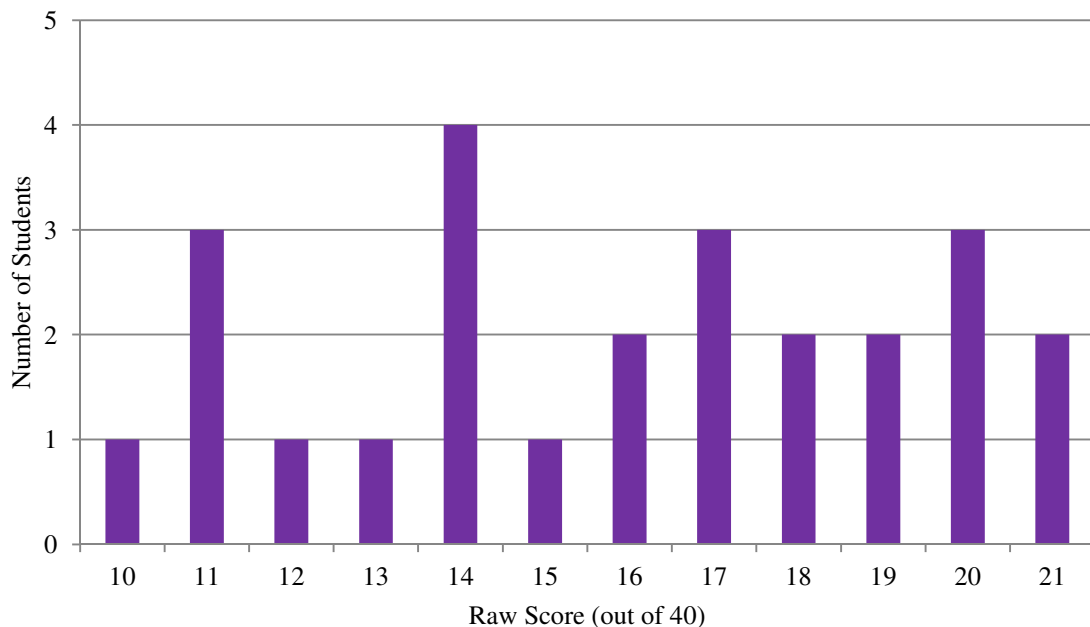
technology concentration. Of the fourteen, two were pursuing a second concentration in architectural technology and two were pursuing a second major in industrial engineering technology. All students pursuing a BS in Design are required to fulfill a seven, three semester hour management courses requirement.

In order to develop a profile of the students and in an attempt to ascertain the readiness of the students, a pretest and survey were administered during the course's second class meeting. The students were only informed of the fact they needed to bring a bubble sheet and pencil for a pretest and were not informed of the nature of the pretest and survey.

The pretest was comprised of all 40 multiple choice items available in the certification exam study guide: ten each from the four certification exam content areas. (ATMAE, 2009). The forty-first item sought information on whether the students were pursuing a minor and the remaining twelve items sought the status of management courses completion.

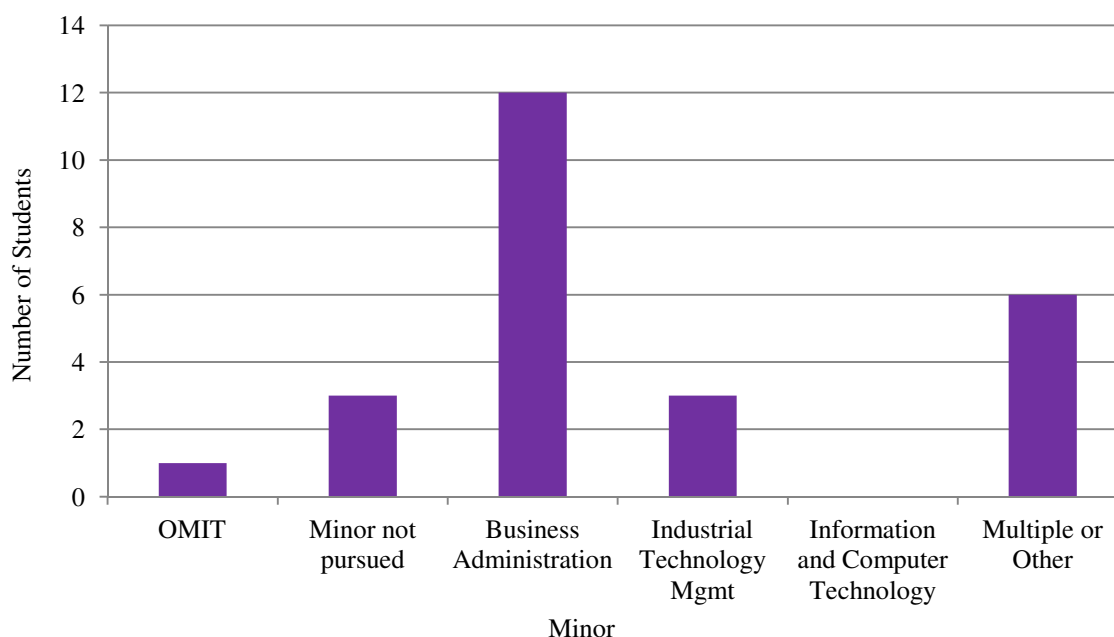
## Results

The performance of the students on the forty sample certification exam items is graphed in Figure 1. Based on the students' performance on the pretest, none would have passed the exam. A raw score of 24 or a 60% was required to pass the exam.



**Figure 1. Student Pre-Test Performance.**

Figure 2 reflects the minors the students were pursuing. At least 24 students were pursuing a minor. The majority of the students (12) were pursuing a minor in business administration.

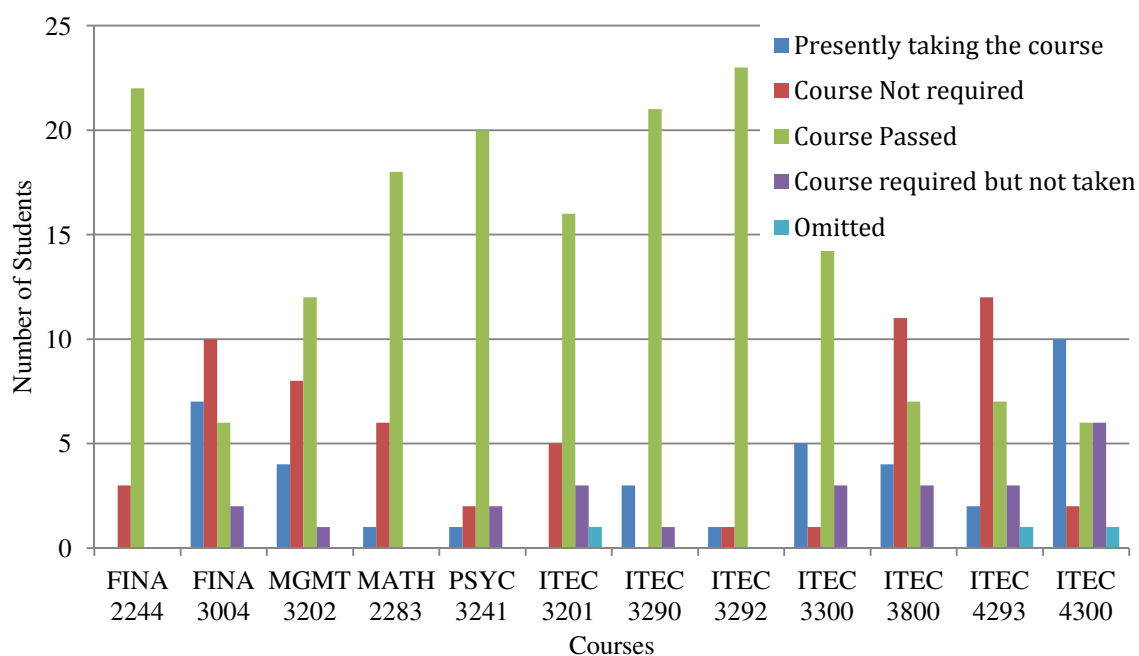


**Figure 2. Minors Pursued by the Students.**

The extent to which the 27 semester hours of what could be categorized as management course work was completed or in progress during the semester in which the students sat for the CTM exam is graphed in Figure 3. At a glance, one could conclude that the majority of the BS in Design students had fulfilled their management course work requirements or were in the process of completing those courses the semester they sat for the CTM exam.

Of those who sat for the exam, nineteen passed. During an optional retake, six of the seven who did not pass during the initial sitting chose to sit for a retake. Four of the six passed for an overall pass rate of 88.5%. Of those who did not pass, two were pursuing an architectural technology concentration, the other, a concentration in mechanical technology.

The performance of the twenty-six students who sat for the exam during the initial sitting is summarized in Table 2—Ques Count, Session Average, and Session Std Dev. The Current Year columns refer to the performance of all sitters of the exam the year in which the twenty-six students sat for the exam. The Historical columns refer to the performance of all sitters of the exam during the history of the exam.



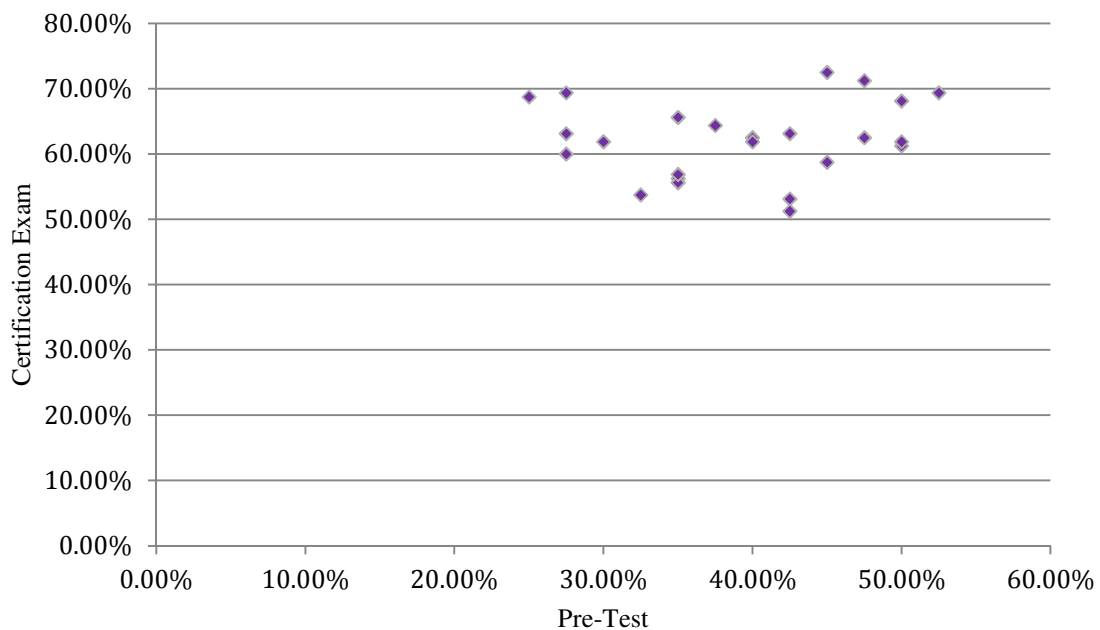
**Figure 3. Completion of Management Courses.**

**Table 2. Performance on the Certified Technology Manager Exam.**

| Category          | Ques Count | Session Average | Session Std Dev | Current Year Average | Current Year Std Dev | Historical Average | Historical Std Dev |
|-------------------|------------|-----------------|-----------------|----------------------|----------------------|--------------------|--------------------|
| Production        | 64         | 40.35           | 6.39            | 37.05                | 11.57                | 38.36              | 11.35              |
| Chemistry         | 4          | 2.42            | 1.06            | 2.1                  | 1.04                 | 2.23               | 1.02               |
| English           | 3          | 2.27            | 0.72            | 1.99                 | 0.96                 | 2.05               | 0.94               |
| Math              | 19         | 11.73           | 2.16            | 9.79                 | 3.74                 | 10.23              | 3.72               |
| Physics           | 3          | 1.23            | 0.91            | 1.07                 | 0.94                 | 1.08               | 0.92               |
| Quality Control   | 24         | 12.12           | 2.88            | 10.38                | 4.26                 | 10.79              | 4.27               |
| Industrial Safety | 33         | 21.73           | 5.62            | 19.55                | 6.2                  | 19.95              | 6.07               |
| Management        | 7          | 5.23            | 1.18            | 4.41                 | 1.7                  | 4.54               | 1.69               |
| Psychology        | 3          | 1.69            | 1.01            | 1.47                 | 0.99                 | 1.52               | 1.01               |

The scatter plot—see Figure 4—characterizes the relationship between the students’ pre-test scores and their exam scores. The correlation coefficient between the students’ performance on the pre-test and the CTM exam was 0.1385. One student’s score was not included in the tabulation due to the system timing out early. However, the student was permitted to complete the exam and passed. Another student’s exam score, even though they passed the exam, was not included because they did not take the pre-test. It should be noted too, the pre-test was a closed book paper and pencil test with no time limit, whereas the CTM exam was an open book online exam with a 2 hour time limit. That is, the students had an average of 45 seconds to respond to each item.





**Figure 4. Relationship Between Student Pre-Test and Certification Exam Performance.**

### Discussion

Even though 27% of the students failed the exam during the initial sitting, overall the students who sat for the exam during the initial sitting performed better than all those who sat for the exam (a) during the current year and (b) for as long as the exam has been in existent. Student performance on the pretest, however, cannot be used to predict their performance on the CTM exam. But there may be value in making the students aware of their overall level of management knowledge. It however appears there may be a relationship between the management courses completed or in progress and the students' performance on the CTM exam. There may also be a relationship between the students' pursuit of a business administration minor and their performance on the CTM exam. It still remains to be seen whether the number of management courses required of BS in Design majors can be reduced.

An item analysis needs to be completed to ascertain the extent of content duplication among the management courses the BS in Design majors are required to complete to fulfill their graduation requirements. A survey of all the management course owners needs to be completed to determine the extent of duplication. Once the extent of duplication is acknowledged, an effort can be made to mitigate the replication in course work.

### References

ATMAE. (2009). *Study Guide for the Certified Technology Manager (CTM) Certification Exam*. Retrieved from <http://atmae.org/certif/CTMStudyGuide.pdf>

ATMAE. (2013). *2011 Outcomes Assessment Accreditation Handbook*. Retrieved from <http://atmae.org/accred/2011OutcomesAssessmentModel01-14-13.pdf>

Field, D. W. & Rowe, S. E. (2001). Development and analysis of a national certification exam for industrial technology. *Journal of Industrial Teacher Education*, 38. Retrieved from <http://scholar.lib.vt.edu/ejournals/JITE/v38n4/field.html>

Freeman, S. A., Field, D. W., Lott, C. W. & Schwab, C. V. (2009). Evaluation of the safety content in the National Association of Industrial Technology certification exam. *Journal of Industrial Technology*, 25(1). Retrieved from <http://www.atmae.org/jit/Articles/freeman122408.pdf>

## Appendix A

### Production, Planning and Control

- inventory management
- industrial organization structures
- production philosophies (JIT, MRP, KANBAN, Group Technology, etc.)
- production charts (process flow chart, Gantt, PERT, etc.)
- industrial waste
- preventative maintenance
- overhead vs. production costs
- laws regarding discrimination plant layout and materials handling
- patents, copyrights, trademarks, etc.
- material data safety sheets
- Environmental Protective Agency forms
- in-house vs. outsourcing
- labor standards
- purchasing
- locating industrial sites
- product life cycles
- inspection techniques
- forecasting
- fluid power
- time and motion study
- scientific management and some fundamental Physics, English, Economics, and Trigonometry

### Quality Control

- basic statistics
- upper and lower control limits
- various QC charting methods (R-chart, p-chart, u-chart, np chart, etc.)
- sampling methods reliability
- variability
- attributes
- military standards
- distributions
- quality indicators
- types of errors
- probability
- QC curves

### Safety

- OSHA regulations and history
- workers compensation
- industrial hygiene
- ergonomics
- safety inspections accident prevention
- ventilation
- personal protective equipment
- respiratory protection
- fire protection
- citations
- NIOSH

### Management

- communication methods
- classes of human needs
- informal vs. formal information
- work motivation techniques
- human nature
- time and motion study
- communication methods
- classes of human needs
- informal vs. formal information
- work motivation techniques
- human nature
- time and motion study
- unions
- job evaluation
- history of work study
- business Law
- facilities layout & materials handling
- industrial communication industrial ergonomics
- industrial supervision
- leadership
- marketing
- management and behavior pioneers (Maslow, Herzberg, Mayo, Taylor, Gilbreath, etc.)

# Using Multimedia Online Learning Tools to Supplement the Classroom Instruction

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## **Abstract**

*This paper introduces the use of multimedia tools to create an online self-study environment to supplement the classroom instruction in Graphical Communications. The topics in this course extend from hand sketching demonstrations to the solid model creation using CAD software such as CATIA. Webcam and Camtasia software were used to capture live examples and the recorded videos were placed on Blackboard. Multimedia tools provide students an efficient way to review the topics covered in the class, in that hand sketching and complex CAD models are often difficult to interpret through words and pictures alone. The positive survey results reflect an initial success of using multimedia tools to supplement the classroom instruction.*

## **Introduction**

Multimedia forms of obtaining information have been recognized in the last 20 years as a way to supplement classroom instruction. It has been widely adopted by students when available and has proved to be an efficient way to achieve students learning outcomes (Barrance and Heimcke, 1992, His and Agogino, 1994). Its value has been seen in both traditional and non-traditional learning environments. Students at the United States Military Academy needed greater control, flexibility, and utility as to when and how they learn course material. This was provided by network-based multimedia presentations and hypertext documents, primarily the classroom material (Carver and Biehler, 1994). Others have taken a more focused and integrated approach by developing topics related software to address a particular issue in students learning. The study of engineering dynamics is difficult with traditional classroom teaching tools since they cannot show motion therefore packages such as BEST (Basic Engineering Software for Teaching) Dynamics were produced (Flori, 1994). These individual initiatives can also be developed into university-wide multimedia instruction enterprises that provide media-based resources to assist faculty members across multiple disciplines (Chin and Frank 1996). However, the ability to distribute and share these resources were limited by the delivery system in the early 1990's and, for example, the freshman engineering graphics class at UC Berkeley was given an interactive

multimedia CD. The approach was extremely well received, even in this format, and helped with the understanding of the course material (Lieu, 1999). As increased internet bandwidth and new delivery systems became available, media-based teaching tools improved especially for engineering applications in which complex components and assemblies are often difficult to visualize. One such approach was EDICS (Engineering Design Instructional Computer Program) which took the students through a series of interactive screens that included media such as pictures, animations, videos, and even games (Jimenez, 2006). Multimedia courseware has also been used in teaching mathematics to increase the student's motivation when learning topics such as loci in two dimensions (Zaini and Ahmad, 2010). The value of a multimedia approach to supplement classroom learning is well understood however its implementation is still limited.

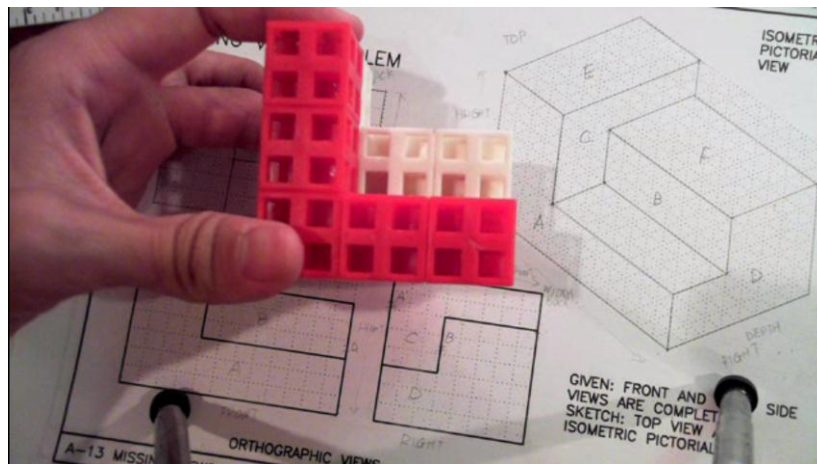
Graphical Communications is a core course taught to all the first-year undergraduates at Embry-Riddle Aeronautical University. It is designed to familiarize the students with the basic principles of drafting and engineering drawing, to improve three dimensional (3D) visualization skills, and to teach the fundamentals of a computer aided design. The students meet the instructor twice a week during this three-credit-hour semester course with each class lasting two hours. The first hour of each class is the scheduled lecture time after which the students are allowed to complete their assigned homework and ask questions as needed. The students learn the principles of orthographic projections and apply the principles to multi-view drawings by hand during the first four weeks of a fourteen-week semester. A 3D computer aided parametric modeling tool, CATIA, is then introduced after hand drawing, followed by auxiliary and section views, dimensioning, and tolerances. However, the students often struggle with visualization at the beginning of the semester; especially, how to complete an incomplete or missing orthographic view and the isometric view of the orthographic projections. If this lack of understanding continues the students will quickly fall behind and will have a difficult time transitioning to understanding the 3-D computer aided parametric modeling tool. The relatively short class time means that not all students get the immediate help they need. In addition, many of them do not follow up during office or tutoring hours for additional assistance. Since it is early in their university career they often are not mature enough to admit they are unsure of the material and need help.

This paper shows that multimedia online learning tools such as thoughtfully constructed videos with step-by-step audio illustrations, the creation of 3D model visualizations, and pictures provide students with unlimited contact with the instructor. They are an effective supplement to classroom instruction that helps students with understanding the course material that can be more broadly implemented outside of Graphical Communications. Surveys taken for multiple classes showed that more than 95% of students who used this online resource 'liked' it.

### **Video Files Creation**

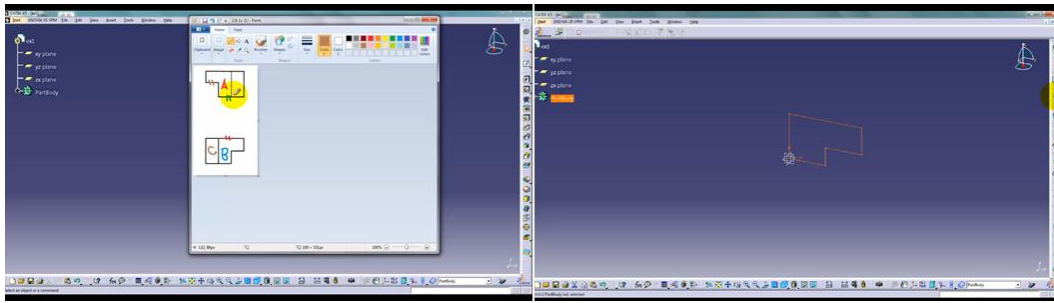
LifeCam Studio® from Microsoft was used to record and better illustrate the more challenging concepts of hand sketching. Camtasia Studio® from Techsmith was used to capture CATIA model problems and to post process demonstrating the use of the 3D CAD software. The video files, approximately 10 minutes long, were saved as Mpeg4 HD files and posted on Blackboard via the Kaltura® video application.

The topics covered include engineering scales and orthographic projections to auxiliary views. In Figure 1, the audio illustration explained the layout of the given views and how to complete the missing top view and the corresponding isometric view. The cubes were used to construct the 3-D model to visualize the different views and the relationship between the orthographic views and the isometric view.



**Figure 1. Hand Sketching Video**

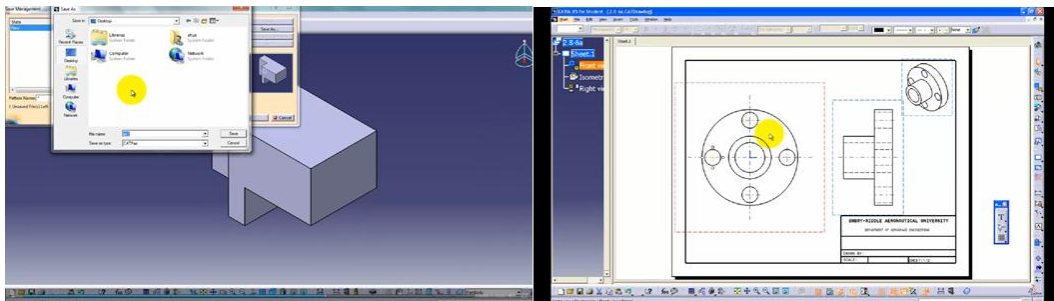
Figures 2 and 3 document CATIA, Camtasia Studio® was used to capture the CATIA screens to demonstrate how to create a 3D solid model. Figure 2 (a) shows how to use paint software to illustrate the given two orthographic views and which view should be selected to create an efficient 3D model Figure 2(b) demonstrates how to use a yellow magnifier in Camtasia to highlight the icon which would be used to create the 2D profile. Figure 3 (a) describes how to use a zoom-n-pan tab to add zoom and pan animations to video files. Figure 3 (b) was used to demonstrate how to create 2D drafting file using CATIA. It was found using animation, pictures, and audio narrations for hand sketching or CATIA 3D models facilitated another types of learners, visual learners to further improve the their comprehension (Felder and Silverman, 1988).



(a)

(b)

**Figure 2. (a) CATIA screen and paint screen; and (b) CATIA model.**



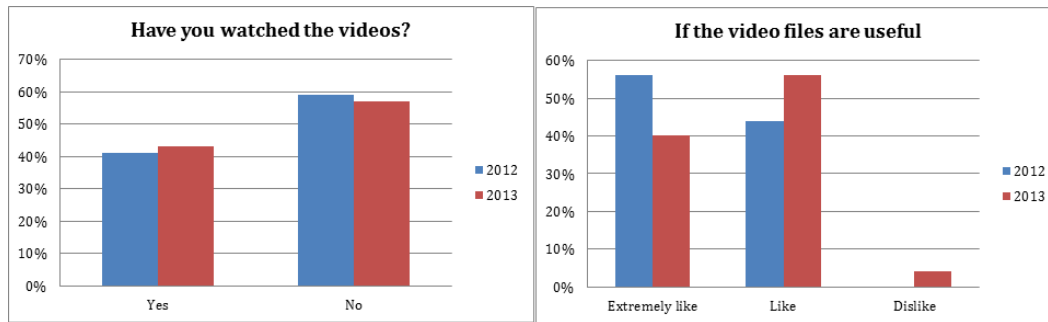
(a)

(b)

**Figure 3. (a) A zoom-n-pan screenshot; and (b) CATIA drafting file**

## Results and Discussion

The survey was completed by 78 students in the fall 2012 semester and 55 students in the spring 2013. The survey was at the middle of both semesters and yielded positive results. Figure 4 (a) presents the results for question one asked students if they watched the video files. 41% students in the fall 2012 semester and 43% students in the spring of 2013 watched the video files. The second question asked the students for the reasons they did not watch the video files. Of those who did not watch the videos indicated they did not need to watch because they fully understood the material covered in the class. Figure 4 (b), for the students who watched the videos, all but one 'extremely liked' or 'liked' them. The one student who did not like the material, stated the material in the videos was covered too quickly.



**Figure 4. (a) A survey to check if students watched the videos; (b) Video files usefulness.**

### Conclusions and Future Work

Multimedia tools offer students another approach to study hand sketching and CAD software that can often be initially difficult to learn or understand during the limited class period. The paper demonstrates that the video files help students better understand the graphics concepts, as these can often be difficult to visualize. The design intent via audio narration, pictures, animations, and the creation of 3D models can be more clearly shown. Further improvements will include that updating video files to incorporate new content and/or update existing course content, adding captions to be ADA compliant, and tracking the number of views to get a clear understanding of what video content does well to help guide the future video creation.

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# Drafting Project with Design Intent to Improve the Application of Dimensioning Specifications

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## ***Abstract***

Teaching first-year engineering students graphical communications has highlighted a specific issue: a lack in their ability to apply dimensioning specifications to open-ended design problems. Students will need that skill in order to properly and effectively, describe any engineering solution that they might develop in the future. This paper describes an attempt to engage the learner by involving them in a design exercise where they are required to provide a detail solution to a problem of their choosing. It is proposed that by allowing the students to invest effort and time in a project of their interest, it will yield better results as they apply dimensioning to describe their personal design.

## **Introduction**

At Embry-Riddle, the objective of EGR120, Graphical Communications, is to provide students with the basics of visualization, dimensioning, and computer-aided drafting that is fundamental to be successful as engineers. These topics form the basis of design expression, which is, the output of much their work.

Currently, EGR120 provides a strong foundation for these areas, achieved by continually providing exercises that reinforce these underpinning concepts. This structured lecture model is heavily framed by the traditional approach of: repetition during class, lab time, and homework provide continuous exposure to new topics. Over time, the course topics combine to create the comprehensive picture required for the completion of the course capstone design project.

One aspect that is of particular interest is the student's application of the abilities learned in class to specific design solutions. This is done through a final project that gathers the material learned in the course into a larger exercise. In an effort to improve the application of knowledge acquired, the final project is split into two parts. The first half of the design project is open ended, students are asked to create a complete 3D assembly of an object of their choice. For the second half, the students are provided a set of pre-designed and pre-sized parts. These form an assembly, for example, last semester the product was a vise grip. The assembly is modeled in

CAD and the correct set of drawings is produced as output to this section of the project.

This format, while providing the basis for good skill application, has highlighted an important issue: the student's struggle with the application of specific knowledge, in particular the application of dimensioning specifications, to new open-ended design problems.

### **Purpose**

The struggle to adapt to open-ended solutions must be addressed in the course. With a pre-defined problem, students spent a lot of their time just trying to replicate the problem given rather than understand the design intent of it. At this stage, it is posited that the lack of involvement in the object's design is the reason for this struggle. It is proposed that a personal project, chosen and developed by the students, could help them address any uncertainty in its creation.

There has been a previous attempt to create a set of dimensioned drawings for a design chosen by the student. At the time, the main problem that arose was the scope of the design chosen. Often, the student choice was too large given the time allowed during the semester. For example, a student tried to model a full motorcycle but it was so large that he found it too overwhelming to cope even with just a portion of it. There is clearly a need for evaluative or formative assessment during this process to build and correct the student's skills as they approach the end of the final project.

To fully realize the idea of an open-ended design from concept to drawing set, the capstone project will change from one final larger exercise to one that would span throughout the entire semester. This would provide appropriate instructor supervision, feedback and guidance at the critical design stages and guidance up to the creation of the CAD models and dimensioned drawing set. With more focus on the design portion, it is expected that the learner's inside knowledge of their own design solution would lead to a better application of drafting and documentation of their concepts. An example of this is dimensioning. Students often have difficulty with properly setting up dimensions on parts given to them since they not always fully understand the purpose of the product. If the project is their own, they would not be trying to deduce how it was made but rather, as it is desired, they would be able to show how it should be manufactured.

This type of internal knowledge of design is also used on other skill learning courses, such as programming. In that case, understanding the complexities of a problem is a necessary aspect to the critical thinking skills required to apply appropriate solutions (Wright, 2007).

## Design

The class is taking place during a six-week summer term and two sections are being taught. The total number of students is 34 and for the majority of them it is their first university course, though they are not all incoming freshmen. Twenty-four of them are high school students that are enrolled during this summer term prior to their senior year. However, there is no difference in the content of the course from a regular semester.

To manage the scope of the project, a single problem is chosen by the students but it is approved by the instructor prior to start of the project. The assembly must contain at least 8 distinct parts (though they may repeat) that must be modeled, dimensioned and finally assembled into the final product.

The course-long project will also have multiple milestones. These intermediate markers would allow timely feedback from the instructor in regards to the scope and appropriateness of the design choices. This constructive feedback will have a formative quality that will enable the students to develop the final project by following design intent and with the understanding of their own design (Leahy, 2012). The four milestones are:

1. Present a proposal for the product to be designed. This should be a small set of both hand sketches and a small report that shows the overall sizing and configuration of the proposed assembly. A minimum of eight individual parts was required.
2. Present the detailed dimensions of each individual part. Again, hand sketches would suffice but the objective is to work out the final size of each individual part of the assembly. Attention would be observed to mating dimensions.
3. Fully realized 3D CAD models of the assembly to show the feasibility of the assembly.
4. Full set of dimensioned drawings for the assembly. Specifically, the final set is composed of:
  1. Isometric of assembly.
  2. Orthographic views of assembly.
  3. Exploded view of assembly.
  4. Parts list.
  5. Dimensioned views of each part.

The students should be able to create a correctly constrained CAD model of each part of the assembly of their product, an assembly of that product to demonstrate that the mating dimensions are correct and fully dimensioned orthographic views of each part.

## Results

Collection of results was done through a rubric, provided in Appendix A, that had a specific scoring component for dimensioning. In addition, notes regarding the errors were documented in order to compare to anecdotal data from previous semesters.

There were a total of 13 projects, in groups with an average of three members. Table 1 lists the results by project final score and its relation to the dimensioning score. It appears that the more understanding students have of dimensioning the better their final project grade.

**Table 1. Summary of results of dimensioning scores**

| Dimensioning score % | Project Letter Grade | Number of Groups |
|----------------------|----------------------|------------------|
| Above 90%            | A                    | 6                |
| Above 80%            | B                    | 1                |
| Above 70%            | -                    | -                |
| Above 60%            | B                    | 3                |
| Above 50%            | B/C                  | 3                |

Aside from the score data, the most common dimensioning errors are provided in Table 2. Given that the previous experience was based on observation, this helps with comparison with current results. The errors are grouped in three categories: Missing Dimensioning, which are cases where a dimension is not provided at all, Improper Dimension Location, in this instance the dimension might be there but located incorrectly on the view, and Incorrect Displayed Units, for example displaying feet instead of inches.

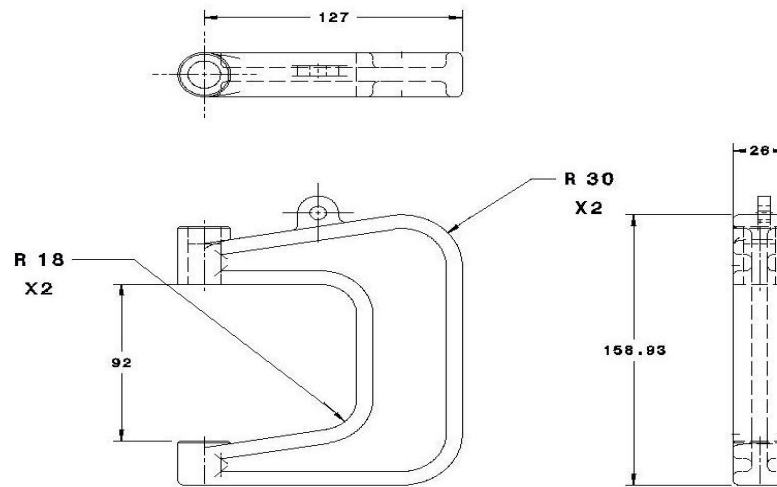
**Table 2. List of most common errors.**

| Type of Error               | Number of Projects Containing the Error |
|-----------------------------|---|
| Missing Dimensioning        | 8                                       |
| Improper Dimension Location | 6                                       |
| Incorrect Displayed Units   | 6                                       |

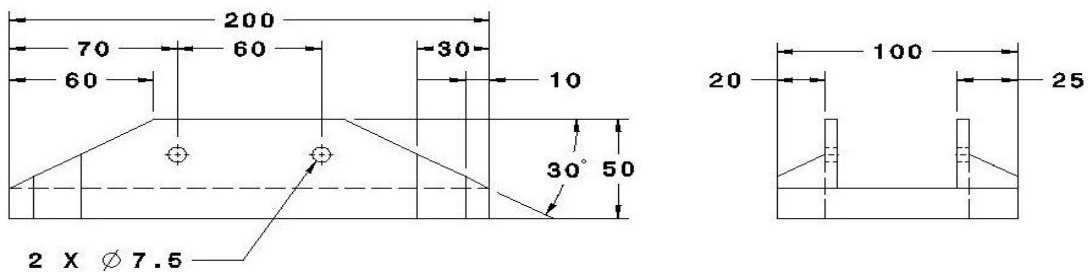
It is worth noting that with exception of one project, most of the errors occurred fewer than 5 times per project.

One of the areas of concern was the completion of the drawing set according to the team's proposal. Every team was able to complete their assembly and corresponding drawing set. At the same time, they accounted for all the parts used in their product in their drawings.

Completed dimensioning was also an area of concern. One the reasons these changes were attempted, is that students would often not provide dimensions at all. An example from previous years is shown in Figure 1. The assumption is that since the students were given all relevant information about the part, they did not feel the need to fully describe the object that they replicated. In Figure 2, from the Summer 2013, a greater effort in dimensioning is seen on the part of the student. This held true throughout all the projects submitted, even in the worst dimensioning cases the students were still making an effort to fully express the information regarding the part as compared to previous semesters.



**Figure 1. Orthographic view from previous years. Note the significant amount of missing information in the dimensioning process.**



**Figure 2. Dimensioned views from Summer term during which the changes were implemented.**

While missing dimensions are still an issue, extreme cases, such as the one referenced in Figure 1, did not appear during this term. Cases with a missing dimension or two in a particular

view were more common than several missing dimensions in a view. From Table 2, it is worth noting that incorrect dimensioning location occurred about the same number of times as incorrectly displayed units. While these issues are certainly related to a quality control check, it is not known if the problem was exacerbated by the fast-paced nature of a summer term and bears further investigation. The grounds for this reasoning is that units displayed is a default that can easily be changed in CATIA but is quite often overlooked in some views, in particular when corrections have been made. This leads to the belief that students were rushing to submit the project by the due date.

## Conclusions

As students had a higher vested interest in the project, the completion rate of the final project this semester was improved as compared to previous semesters. This semester, every team was able to create all parts and drawings for their project.

The principal conclusion is that students do benefit from the knowledge of the product they are building. An immediate advantage seems to be the reduction of cases that have a significant number of missing dimensions. While this problem has not eliminated but it has been reduced. For continuous improvement, it is recommended that an extra milestone of quality control corroboration be implemented in the future. This milestone will exist just prior to the final submission. The students will peer review each other's work using the final project evaluation rubric as an assessment tool.

Given the improvement seen, this study will continue to be implemented during the upcoming Fall 2013 and Spring 2014 semesters with published results to follow.

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## Appendix A

Rubric for evaluation of final project.

### FINAL PROJECT RUBRIC

|                            |       |      |
|----------------------------|-------|------|
| NAMES:                     | _____ |      |
| ASSEMBLY:                  | _____ | / 10 |
| ELECTRONIC FILES:          | _____ | /5   |
| ISO, ASSEMBLY:             | _____ | /5   |
| ORTHO, ASSEMBLY:           | _____ | /10  |
| EXPLODED:                  | _____ | /10  |
| PARTS LIST:                | _____ | /10  |
| INDIVIDUAL PARTS:          |       |      |
| DIMENSIONING               | _____ | /30  |
| VIEWS                      | _____ | /10  |
| PRESENTATION (TITLE BLOCK, |       |      |
| PRINTING, NEATNESS)        | _____ | /10  |
| TOTAL                      | _____ | /100 |

NOTES