

# Incorporating product lifecycle concept, rapid prototyping, and certification in a solid modeling course – Final Report

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## 1. Overview

The goal of this project is to enhance students' spatial visualization and solid modeling skills through modifications to two courses: ENGR 127 *Fundamentals of Engineering I-Computer Lab* and ME 160 *Solid Modeling*. We have completed multiple activities to help in achieving this goal and made the following changes in existing courses: (1) developed and implemented specially designed activities, quizzes, and homework to improve students' visualization skills and to help students better transition from 2D drawing with AutoCAD to 3D solid modeling with SolidWorks, (2) introduced the product design lifecycle concept by developing new examples and exercises, using every items, whereby solid models are utilized directly for engineering analysis, motion simulation, mold design, and manufacturing, (3) integrated solid modeling with rapid prototyping by developing new labs and projects using 3D printers, and (4) allowed students to take certified SolidWorks Associate (CSWA) exams and count the test results in their grades.

Innovations developed in this project allow students to (a) appreciate the importance of solid models in the entire product design lifecycle; (b) learn to make physical objects via rapid prototyping processes, (c) more effectively use SolidWorks in junior and senior level courses for course projects or senior design projects; (d) gain the formal recognition of their solid modeling skills for career development. Improved solid modeling skills will make students more successful in upper level classes and improve marketability when searching for employment. In addition, the innovations in this proposal will improve students' spatial visualization skills, which has been shown to be a significant factor in retention and important skill for successful practice of engineering.

Methods of evaluation include pre- and post-testing with the Purdue Spatial Visualization Test - Rotations (PSVT:R) (Guay, 1977), testing with certified SolidWorks Associate Exams, and surveying students for achievement of learning outcomes, attitudes, and behaviors.

## 2. Background

EngageEngineering<sup>1</sup> is an initiative funded by the National Science Foundation, whose overarching purpose is to “increase the capacity of engineering schools to retain undergraduate students by facilitating the implementation of three research-based strategies to improve student day-to-day classroom and educational experience.” The three strategies recommended by EngageEngineering include:

1. *Improve spatial visualization skills*, especially among first-year students with weak skills.
2. *Integrate everyday examples* that are familiar to students in first- and second-year courses.
3. *Improve and increase level of faculty-student interaction* among 1st & 2nd year students.

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<sup>1</sup> For more information refer to <http://www.engageengineering.org>

The principles, supported by educational research, that influence this project are related to *improving students' spatial visualization skills* and *integrating everyday examples in engineering courses*.

Numerous studies (see e.g. references on p. 15) show that strong spatial visualization skills are linked to success in science, technology, engineering, and mathematics (STEM) fields. Mechanical engineering students at IPFW develop their spatial visualization skills in a two-course sequence ENGR 127 – *Engineering Fundamentals I* (the computer lab) and ME 160 – *Solid Modeling*. These two courses (see Figure 1) introduce computer-aided-drawing (or design) (CAD) using two popular, commercial software packages, i.e. AutoCAD and SolidWorks. The skills introduced and developed in these two courses are used by our students throughout the rest of engineering curriculum, in required courses, technical elective courses, and senior design projects, as well as by our co-op students and eventually by our graduate engineers working in local industry.

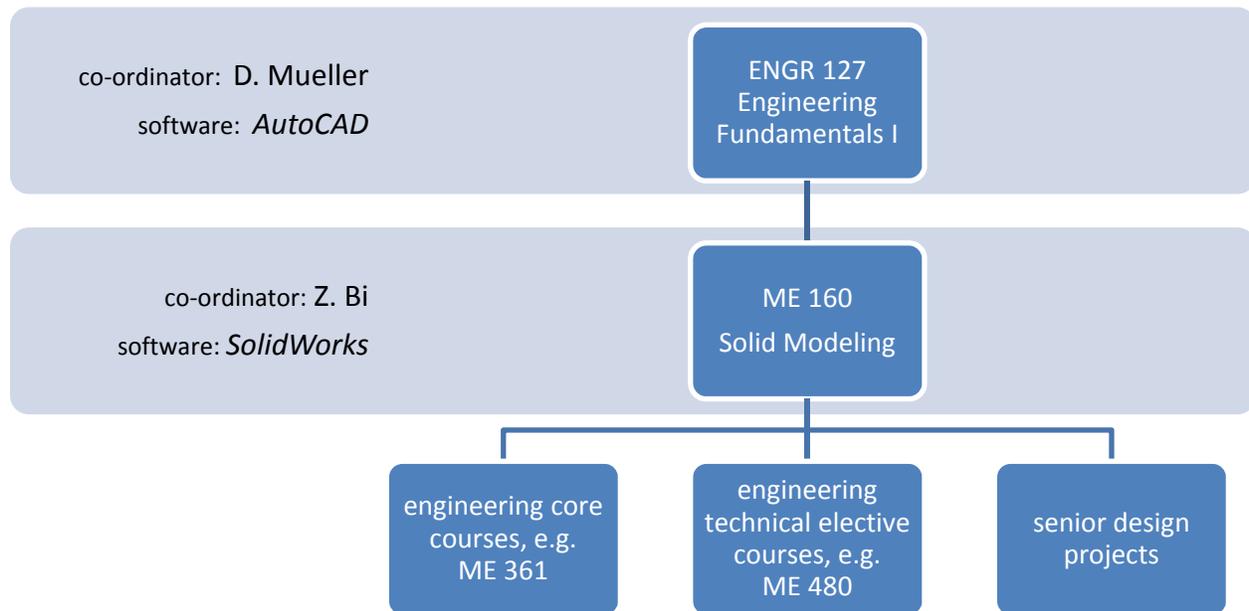


Figure 1: Vertical structure of CAD in the mechanical engineering program curriculum.

### 3. Project Innovations

The first innovation is to devise new activities and assignments to enhance spatial visualization skills and to better bridge the gap between 2D wireframe modeling taught in ENGR 127 and 3D, parametric solid modeling taught in ME 160.

Development of these activities has been guided and influenced by the spatial visualization resources from EngageEngineering and workbook by Sorby and Wysocki (2003). Students in ENGR 127 were made aware of spatial visualization during the first lab period when they took the PSVT:R. Throughout the semester, lectures were given on multiview projection, pictorial representations, drafting conventions, and sections views. Then students worked on visualization activities, using both CAD as well as pencil and paper, that involve surface identification, construction of multiview drawings from an isometric, creation of missing views, construction of an isometric from multiview drawings, and creation of sectioned-views of parts. Solid models were used to help students visualize complex parts. Examples of some classroom activities are shown in Figure 2, and many additional activities can be found in the workbook by Sorby and Wysocki (2003).

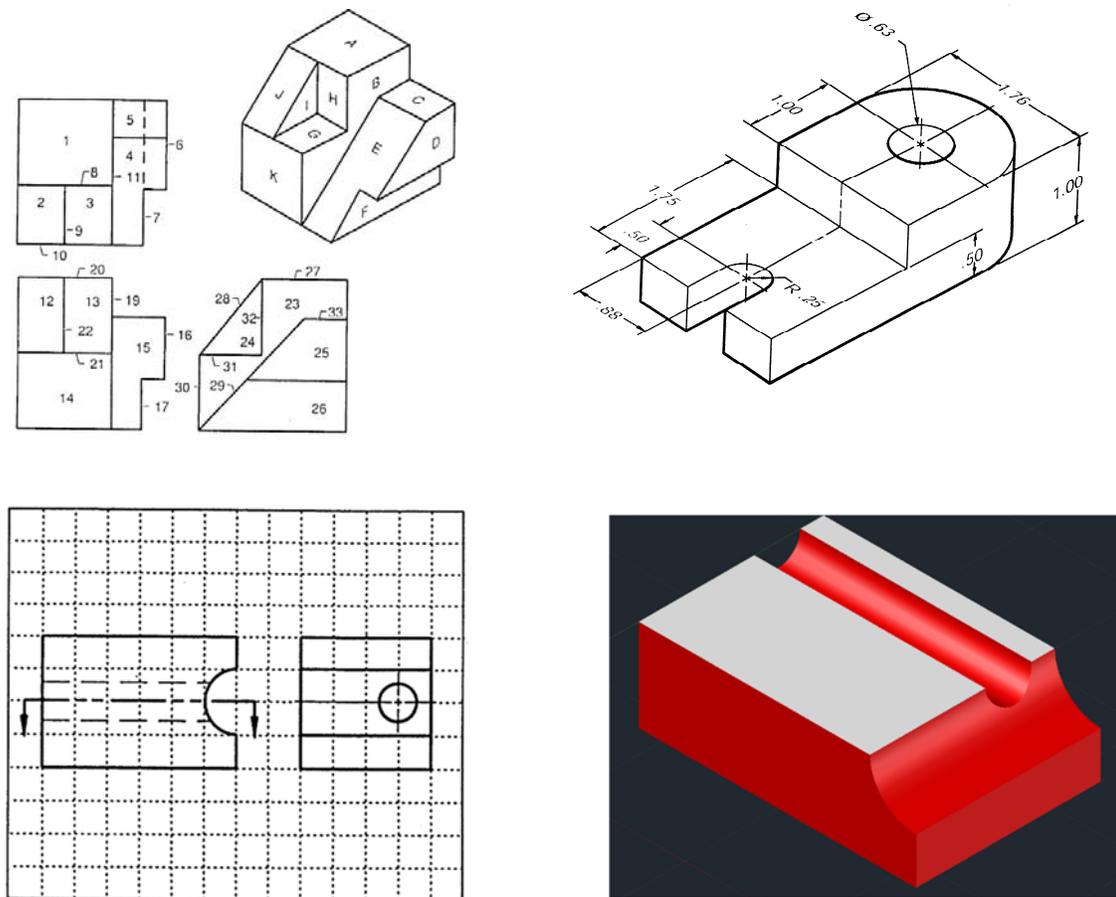


Figure 2: Sample activities in ENGR 127 to improve spatial visualization skills.

Next, the coordinator of the ENGR 127 computer lab (Mueller) and the coordinator from ME 160 (Bi) worked together and developed activities and exercises to help students to better transition from ENGR 127 to ME 160. Both classes teach CAD, but the modeling techniques and software packages are different. With close coordination, the instructors developed activities and exercises to be used in both classes—specifically at the end of ENGR 127 and at the beginning of ME 160. Instructors of the two classes must be willing to cooperate and use the common activities.

Requiring students to work the same problems using two different approaches, allows them to compare and contrast and develop a much deeper understanding of the different modeling techniques. This approach is based on one of the central implications of Gardner's Multiple Intelligences Theory, viz. *Pluralization*.<sup>2</sup> Pluralization refers to the idea that important material should be taught in several ways.

The purposes of common activities and exercises are to compare the outcomes of two courses in terms of the *accuracy of models* and the *productivity of the modelling process*. The 2D drafting methods and 3D methods are taught in two different classes. Three modeling exercises/quizzes will be assigned in both classes to evaluate the students' performances. Examples of the exercises are given in Figure 3. At the end of the semester, an anonymous survey was given to assess students' attitudes and opinions about 2D and 3D modeling methods.

<sup>2</sup> See for example [https://howardgrdner01.files.wordpress.com/2012/06/faq\\_march2013.pdf](https://howardgrdner01.files.wordpress.com/2012/06/faq_march2013.pdf)

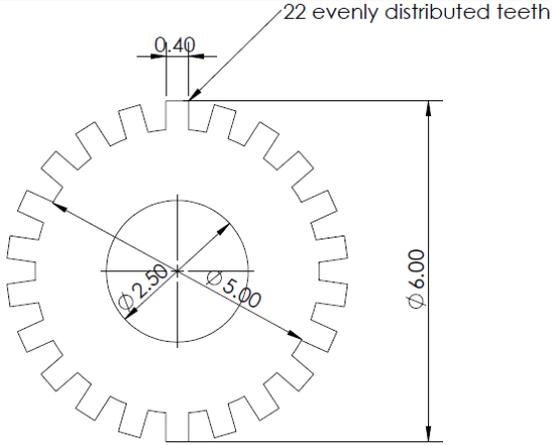
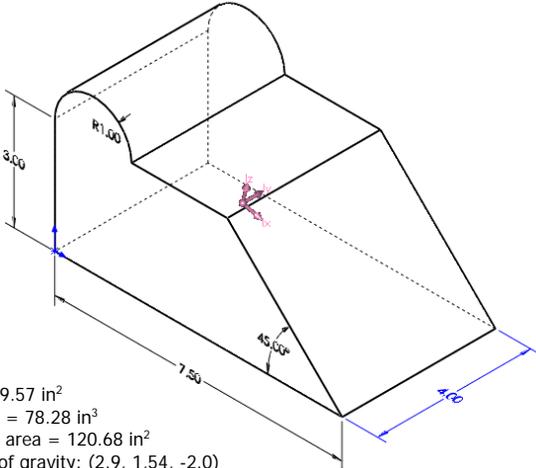
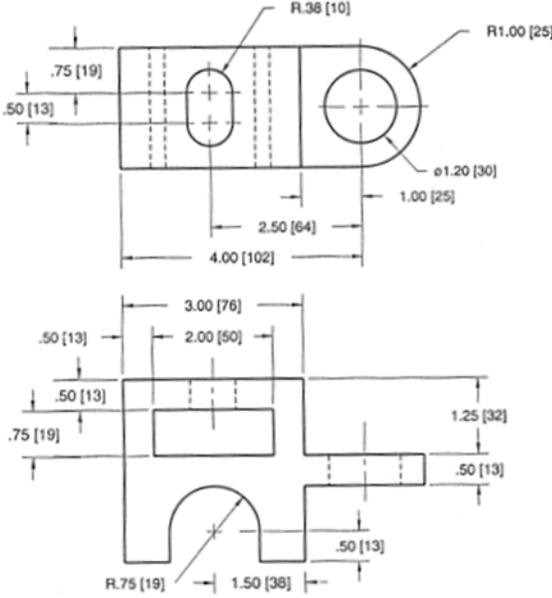
Example	Purpose	SolidWorks/AutoCAD
1	Use relations and dimensions to reflect the design intents	 <p>22 evenly distributed teeth</p> <p>0.40</p> <p><math>\phi 2.50</math></p> <p><math>\phi 5.00</math></p> <p><math>\phi 6.00</math></p>
2	Understand the completeness of solid model (find volume, surface area, and the center gravity with respect to give coordinate system)	 <ul style="list-style-type: none"> <li>• Area=19.57 in<sup>2</sup></li> <li>• Volume = 78.28 in<sup>3</sup></li> <li>• Surface area = 120.68 in<sup>2</sup></li> <li>• Center of gravity: (2.9, 1.54, -2.0)</li> </ul>
3	Use feature-based modeling and generate 2-D drawing automatically	 <p>R.38 [10]</p> <p>R1.00 [25]</p> <p><math>\phi 1.20</math> [30]</p> <p>1.00 [25]</p> <p>2.50 [64]</p> <p>4.00 [102]</p> <p>.75 [19]</p> <p>.50 [13]</p> <p>3.00 [76]</p> <p>2.00 [50]</p> <p>.50 [13]</p> <p>.50 [13]</p> <p>.75 [19]</p> <p>1.25 [32]</p> <p>.50 [13]</p> <p>R.75 [19]</p> <p>1.50 [38]</p>

Figure 3: Sample activities common to ENGR 127 and ME 160.

The second innovation is the development of the module “solid models in product life cycles” in ME-160 using everyday examples of engineering items when possible.

The lecture on solid models in product life cycles was enhanced, and a number of concepts were covered in one class meeting. The subjects include (1) the Interface of CAD tools with Other Software Tools, (2) the available tools in SolidWorks for Product Data Management, (3) the basics and procedure in using Rapid Prototyping, (4) CAD modeling tools for CAM, (5) CAD modeling tools for process planning. During the class, everyday items were used to show how solid models are utilized for engineering analysis, motion simulation, mold design, parametric design, and manufacturing

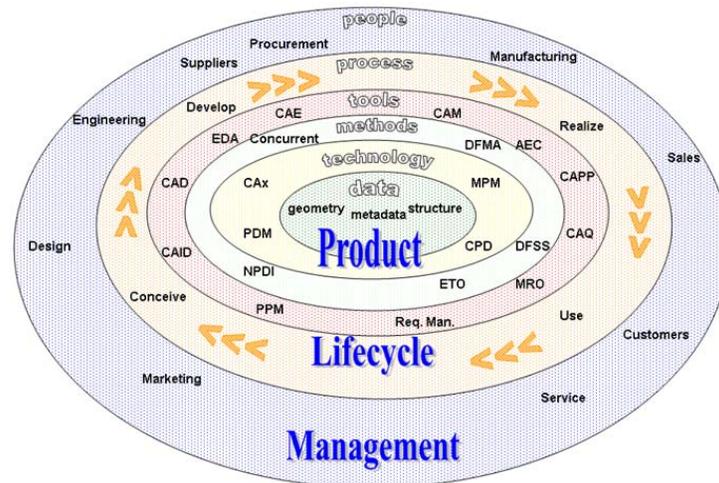


Figure 4. Solid models in product life cycles



Figure 5. Use of everyday examples to show product design. Photo is on the left and student-generated model is on the right.



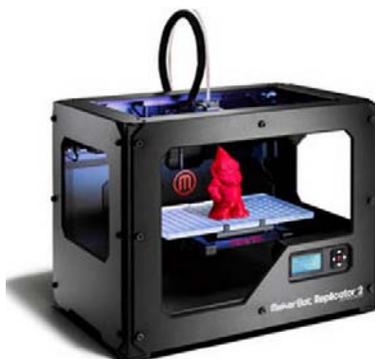
Figure 6. Use of every day examples to illustrate concepts of motion simulation (robot) and design tables (toolbox).

The use of everyday examples in this manner was described in a recent paper by Bi and Mueller, viz.

Zhuming Bi and Donald W Mueller Jr. (2016) "Integrating everyday examples in mechanical engineering courses for teaching enhancement," *International Journal of Mechanical Engineering Education*. DOI: 10.1177/0306419015625562.

The third innovation is to use additive manufacturing (3D printing) in ME 160 projects.

Over the summer and fall of 2015, an additive manufacturing lab was established in ET 342. In this lab, two 3D printers have been placed for student use. Since 3D printers differ from conventional printers in terms of calibrations, set-ups, and time of operation, students have to follow the instructions to use devices adequately. The department hired and assigned a technician (Jason Moyer) who worked with Mueller and Bi to establish policies and procedures to manage the lab and schedule time using the printers. The requirements of the ME 160 course projects included generation of one or two parts by 3D printing. Figure 7 shows the two 3D-printers available to students, and Figure 8 shows two mechanical engineering students using the printers and a few of part samples made by students in the ME 160 class during the fall 2015 semester.



MakerBot Replicator 2



Dremel 3D Idea Builder

Figure 7. Two 3D printers available to students in ET 342

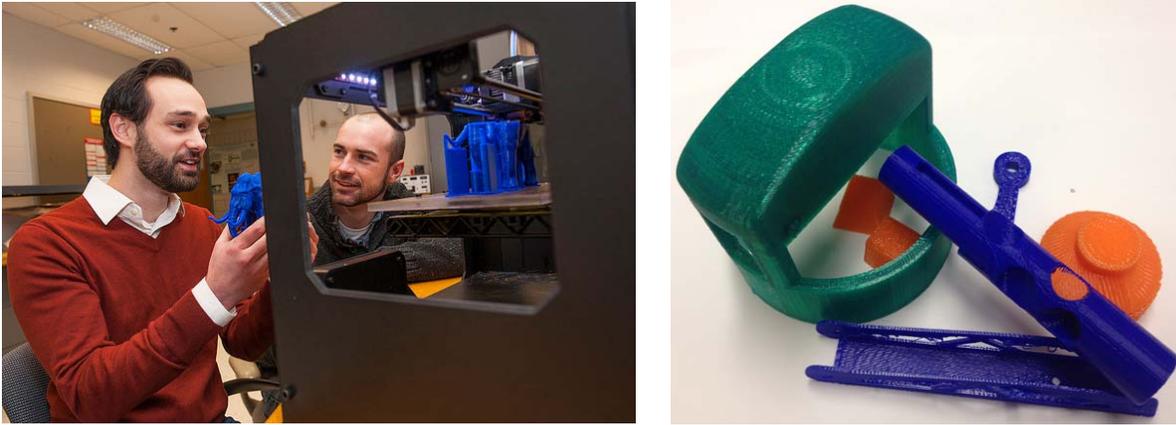


Figure 8. Two mechanical engineering students working with the 3D printer and sample 3D-printed parts by ME 160 students.

The fourth innovation as a result of this project is to use the certified SolidWorks Associate (CSWA) exams for student evaluation.

SolidWorks provides free access for us to use the certified SolidWorks (CSWA) exams for student evaluation. Students in ME 160 now take the CSWA exam as part of the final exam. Prior to the exam, a class meeting was spent reviewing solid modeling concepts and learning the procedure for online testing. In the fall 2015, ME 160 students took the CSWA as part of their final exam.

#### 4. Results and discussion

In this section, we report some of the preliminary evaluations of our work and give a possible framework, with some instruments, that may be useful to more rigorously study the innovations described in the report in the future. Our intention is to involve Dr. Scott Moor, Coordinator of the First-Year Engineering Program (affiliated with the Department of Electrical and Computer Engineering) and the soon-to-be-hired (search is currently underway) counterpart that will be affiliated with the Department of Civil and Mechanical Engineering with these efforts.

##### ***Instrument: PSVT:R***

The Purdue Spatial Visualization Test: Rotation (PSVT:R) consists of 30 multiple choice questions that require the test-taker to match representations of solid objects to rotated versions. (See e.g. Figure 9.) The PSVT:R is a well-researched testing instrument first developed in 1977 at Purdue University (Guay, 1977). The exam has been used in hundreds of studies and there is a large amount of comparison data, parsed in many different ways, available in the published literature.

During the first week of the fall 2015 semester the PSVT:R was given to the students (N=141) in the computer lab of ENGR 127 (all sections, i.e., sections 01-06) and to the students (N=15) in ME 160. Students were instructed that the test would not be used for grading, but would be shared with them for their own awareness, if interested. In addition, the scores might be used, on an anonymous basis, to better understand our students' abilities and improve our programs. After a review of the instructions, students were given 25 minutes to complete the test.

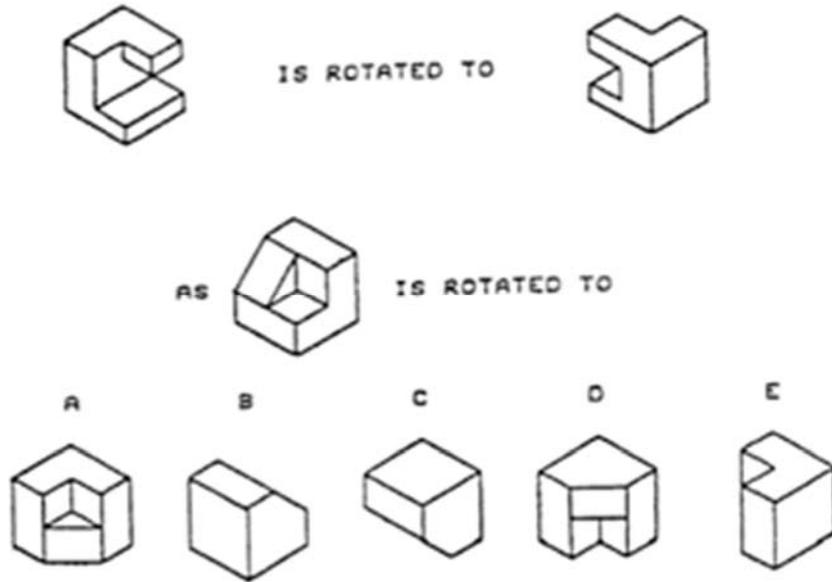


Figure 9. Sample question in PSVT:R

The average scores for each of the six sections of ENGR 127 and one section of ME 160 are shown in Figure 10. In addition, scores from three other engineering schools (Metz et. al., 2011) are shown for comparison. The overall average score for students in ENGR 127 was 23.6/30 or 78.8% correct. The average score for the 15 students in ME 160 was 24.0/30 or 80% correct. These scores compare very favorably with those from first-year engineering students at other universities (Metz et. al., 2011). Note: According to the literature, scores have shown to improve based on level in the engineering program, i.e. sophomore, junior or senior compared to first-year, and average male scores are typically higher than average female scores. Many different variables have been shown to have an effect on the PSVT:R scores.

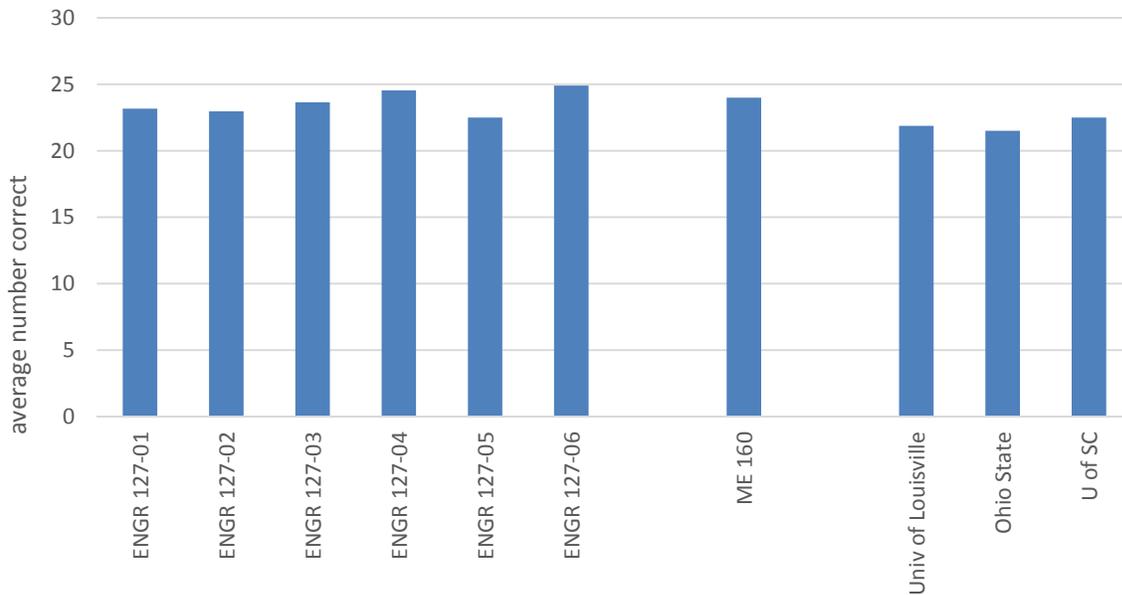


Figure 10. Class average scores for the PSVT:R for students in ENGR 127 and ME 160.

A closer look at the data for the ENGR 127 students reveals interesting results. The literature indicates that a score below 20/30 (or 67%) on the exam indicates a spatial visualization weakness that can be improved. In many studies, an intensive, “short-course” was given to improve the students’ spatial visualization abilities (e.g. see the work of Sorby), while in other cases improvement strategies were incorporated into an existing course (Dong, 2012). (Note: In some studies the demarcation between acceptable and weakness was set at 18/30 or 60%; we used the cut-off of 20/30.) Out of the 141 first-year engineering students tested, 24 students or 17.0% scored below 20 on the test, while 117 or 83.0% scored 20 or above. These results are summarized in Table 1.

Table 1: Distribution of ENGR 127 student scores

	N	%
Number of scores below 20	24	17.0%
Number of scores 20 or above	117	83.0%
	141	100%

A closer look at the scores for the ME 160 students also shows interesting results. Figure 11 shows the scores for each question and the distribution of the individual scores. Improved spatial visualization skills among ME 160 students (compared to ENGR 127) is expected because ME 160 students have some CAD experience and scores have been shown to increase as a student progresses in an engineering program.

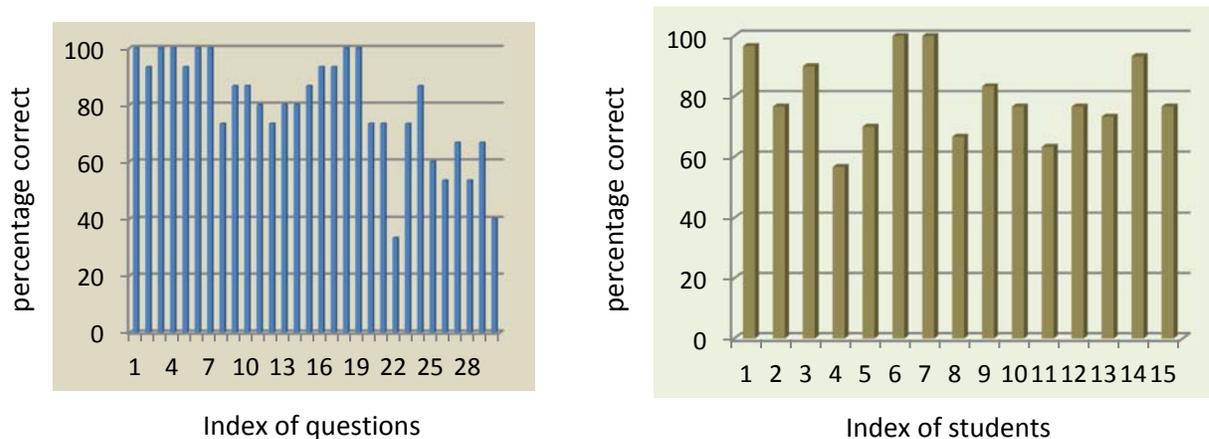


Figure 11. Average scores for each question and each student on the PSVT:R given to ME 160 students in fall 2015.

During the first week of the spring semester 2016, the PSVT:R was given to the students (N=24) in ME 160. Students were instructed that the test would not be used for grading, but would be shared with them for their own awareness, if interested. In addition, the scores might be used, on an anonymous basis, to better understand our students’ abilities and improve our programs. After a review of the instructions, students were given 25 minutes to complete the test.

The average score on the test is shown in Figure 12 with a comparison to the average score of ME 160 student in the fall 2015. The average score for spring 2016 ME 160 students was 2.1/30 or 7% higher in comparison to the scores in fall 2015.

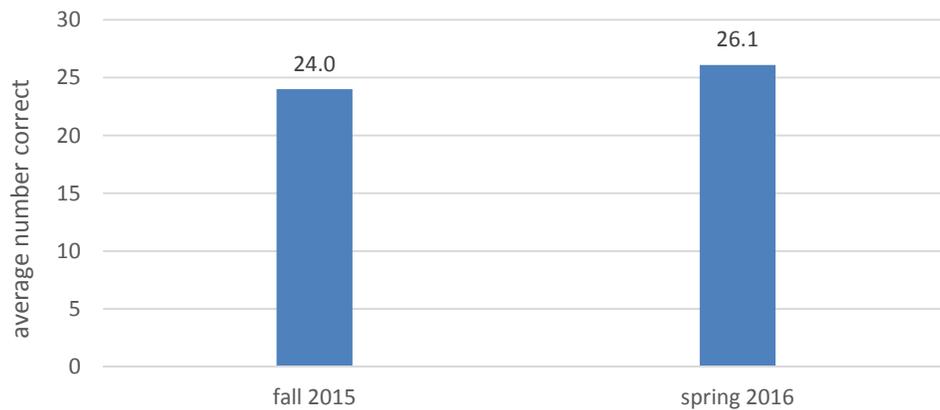


Figure 12. Class average scores for the PSVT:R for students in ME 160 (fall 2015 and spring 2016).

Of the 24 ME 160 students taking the exam in spring 2016, 17 had taken the exam in fall 2015 as an ENGR 127 student. This allowed us to examine the improvement for repeat test takers. The increase in the raw score from the fall 2015 to the spring 2016 is shown in Figure 13.

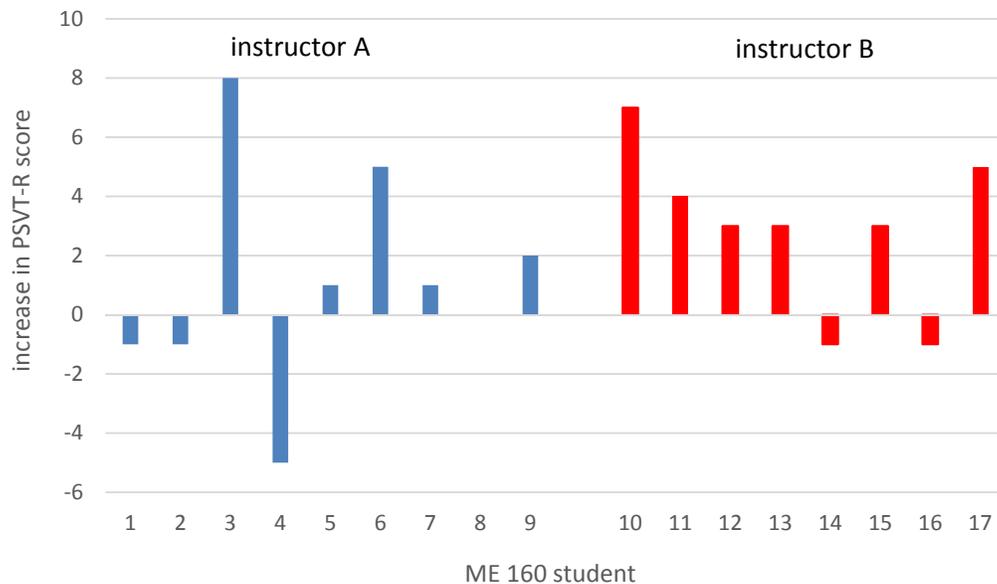


Figure 13. Increase in PSVT:R scores for ENGR 127 students (fall 2015) to ME 160 (spring 2016).

Overall average improvement of repeat test takers was 1.94, with the average improvement for students with instructor A = 1.11 and the average improvement instructor B = 2.88. Five students had lower scores on the retake. It is interesting to note that Instructor A has not taught a CAD class before and did not have much experience with CAD software. Instructor B has taught multiple

sections of CAD for several years. In addition, Instructor B used many multiview assignments and several spatial visualization improvement exercises similar to those detailed in this report.

***Instrument: Survey of ENGR 127 students***

During the last week of classes in the fall 2015 semester, an anonymous survey was given to first-year engineering students (N=56) in three sections of ENGR 127 lab. The survey was voluntary, administered while the instructor was not in the room, and collected by a student. This survey was administered in a manner similar to our standard assessment procedures. Results were not examined until after final grades for the fall semester were submitted. The purpose of the survey was two-fold:

1. To determine the student's impressions of the utility of AutoCAD software and improvements in their spatial visualization and problem-solving abilities due to working with AutoCAD
2. To ascertain how much first-year engineering students are utilizing resources for help in their classes.

Table 2 shows the students attitudes and opinions concerning multiview drawing and AutoCAD. The data in Table 2 reveals that students believe that they can create multiview drawings and feel comfortable using AutoCAD.

Table 2: First-year engineering students (N=56) attitudes and opinions concerning multiview drawing and AutoCAD

Question	average
I can create multiview drawings in AutoCAD.	3.61
Working with AutoCAD has improved my spatial visualization abilities.	3.27
Working with AutoCAD has improved my problem solving abilities.	3.05
Creating drawings with AutoCAD is easy.	3.27
Creating drawings with AutoCAD is fun.	3.35

Note: 4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly disagree

A second purpose of the survey was to determine how many students were taking advantage of university-provided academic resources. Table 3 show the percentage of ENGR 127 students who took advantage of some type of university-provided academic resource—the majority of the students (59%) took advantage of some kind of help. The type of resource and the number of visits was also a topic of the survey. As shown in Table 4, the type of help used by most students was instructor office hours, and most students use the resources more than once. Note that the percentages do not add to 100% as students may have used multiple resources.

Table 3: Percentage of first-year engineering students (N=56) using university-provided academic resources.

	N	%
Student who did use university-provided academic resources	33	33/56 = 59%
Students who did not use university-provided academic resources	23	23/56 = 41%

Table 4. Type of university-provided academic resource used by ENGR 127 students (N=33 of 56)

	N	%
Instructor office hours	26	26/33 = 79%
ETCS Success Center/Help Corner	12	12/33 = 36%
Math MALL	12	12/33 = 36%
Center for Academic Support and Achievement (CASA-TutorTrac)	13	13/33 = 39%

Students were also asked if they did not use a certain resource to circle the reason why not: *not aware, not needed, no time*. The most popular answer was *not needed*, by a large margin, followed by *no time*. It appears that most students are at least aware of the help resources that are available on campus.

### **Instrument: CSWA exam**

In the fall 2015, 13 ME 160 students took the CSWA as part of their final exam. Figure 14 shows the percentage of scores in five categories including 'basic part modeling', 'intermediate part modelling', 'advanced part modeling', 'drafting theory', and 'assembly modeling'. Due to the introduction of solid modelling in product design; students understand better about the applications; thus, achieving better scores in the categories of 'assembly modeling' and 'advanced part modelling'. The average percent of scores is 74.5% and the pass rate is 9 out of 13, i.e., 70% success rate.

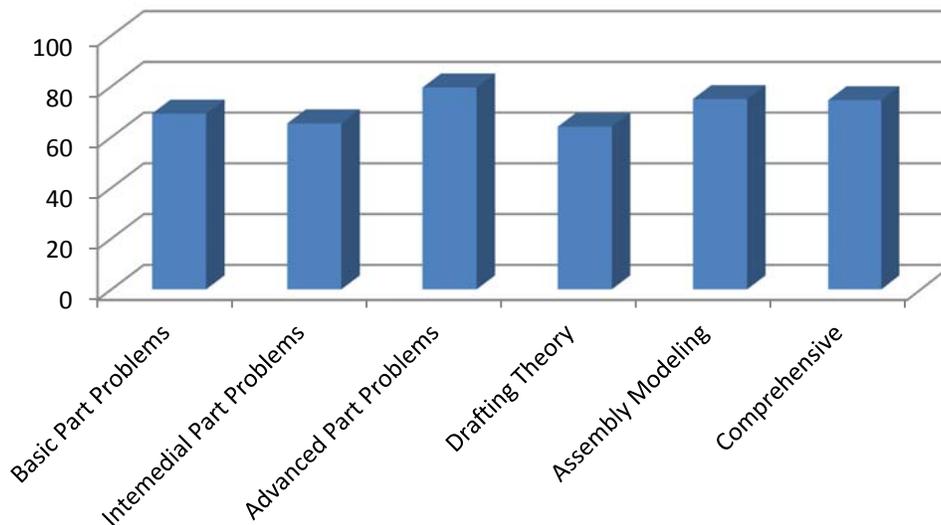


Figure 14. Averages of fall 2015 ME 160 student (N=13) scores of CSWA tests

### **Instrument: Survey of ME 160 students**

We designed a survey to collect the responses from students about the improvements we made through this SID project. Table 5 shows the five questions in the survey and Figure 15 shows the averages.

Table 5. Survey to assess attitudes and opinions of ME 160 students

No.	Questions
1.	In comparison with your previous experience in learning a computer-aided design tool (e.g. AUTOCAD), how do you rate your experience in ME-160 solid modeling course? Please comment on the most significant things you learn in ME-160?
2.	I expanded the introduction on how to use Solid Models for engineering analysis; for example, using motion simulation, conducting stress analysis, and creating molds for parts. Do you think these introductions increased your interest in using SolidWorks to support your junior or senior level mechanical courses?
3.	I assigned the course project for you to <i>reverse engineering</i> everyday example products and rapid-prototype sample parts from 3D printing. Do you think this project and 3D printing is a good learning experience for you?
4.	I adopted Certificate SolidWorks Associate (CSWA) in the grading system to measure your skills in solid modelling. Do you think CSWA could be helpful to increase your confidence level of solid modeling and grow your career development?
5.	We are making our efforts to make a continuous improvement semester by semester. What are the most significant changes you would suggest?

**Note:** students are asked to (1) give their ranking as 'excellent', 'good', 'fair', and 'poor' and (2) provide the comments to support or explain their ranking.

Figure 15 gives a summary of students' feedbacks on the improvements through our SID projects. It shows that students responded very positively (all scores excellent or good) about the changes in all four areas.

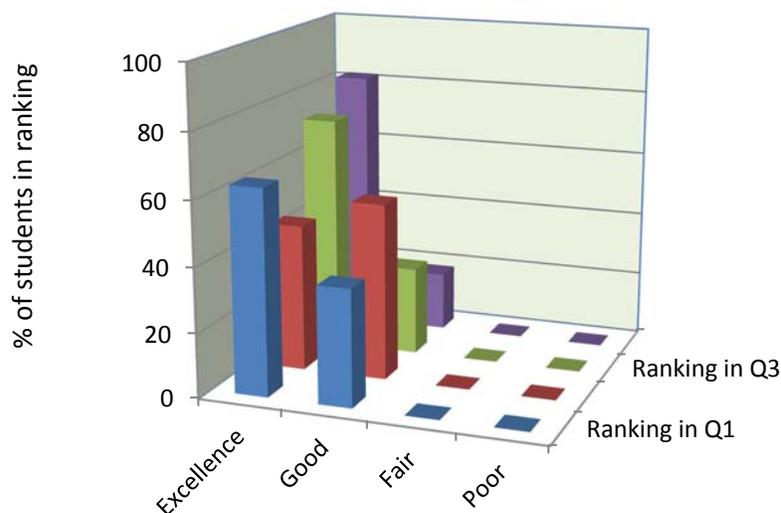


Figure 15. Students' rankings on the improvement by SID projects

## 5. Outcomes and concluding remarks

The goal of this project is to enhance students' spatial visualization and solid modeling skills through modifications to two courses: ENGR 127 *Fundamentals of Engineering I-Computer Lab* and ME 160 *Solid Modeling*. To accomplish this goal, four specific innovations were developed and implemented, viz.

1. We devised new activities and assignments to enhance spatial visualization skills and to better bridge the gap between 2D wireframe modeling taught in ENGR 127 and 3D, parametric solid modeling taught in ME 160. *These material are available to other instructors of the courses to use as they wish.*
2. We developed the module "solid models in product life cycles" in ME 160 using everyday examples of engineering items when possible. *This material is available to other instructors of ME 160 to use as they wish.*
3. We used additive manufacturing (3D printing) in ME 160 projects. As of fall 2015, the lab is functioning with policies and procedures established for 3D printing. *Other instructors may use this facility as they wish.*
4. We used the certified SolidWorks Associate (CSWA) exams for ME 160 student evaluation. *The procedure to access and administer this standardized certification exam has been established and has been and will be shared with others teaching the course.*

The innovations from this project have resulted in new course materials being developed and existing course material being refined as well as new evaluation methods being proposed and implemented, at least on a pilot basis.

In addition to the four specific innovations of the project listed above, we have

- Outlined a procedure and methodology, using the PSVT:R, that can be used to continually assess our incoming first-year engineering students' spatial visualization abilities, improvements in our students' spatial visualization abilities, and use of university-provided help resources. Future work can correlate this data to student performance in subsequent classes, as well as student retention.
- Developed an advising worksheet (see Appendix A) that can used to help make students aware of a spatial visualization weaknesses, potential for improvements, and possible resources for help.
- Assisted with the development of the 3D printing lab which will serve as resource for all civil and mechanical engineering students.
- Documented, in a published journal article, examples of how to use everyday examples in a solid modeling course.

Our intention is for this work to continue, and possibly expand, under the direction of Dr. Scott Moor, Coordinator of the First-Year Engineering Program (affiliated with the Department of Electrical and Computer Engineering) and the soon-to-be-hired (search is currently underway) counterpart who will be affiliated with Department of Civil and Mechanical Engineering.



Figure 16. Students using the new 3D printing lab.

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<sup>3</sup> References are just a sample of many studies related to spatial visualization.

## Appendix A – PSVT:R score report sheet

### Spatial Visualization Diagnostic Report

ENGR 127

Spatial visualization is considered to be one of the basic human intelligences. According to the research, well-developed 3-D spatial skills are critical to success in STEM fields, including engineering, mathematics, physics, chemistry, architecture, and computer science. Some individuals naturally possess excellent spatial abilities and some have spatial skills that can be improved. ***The important thing to remember about spatial skills is that they are skills and can be developed through practice, just like any other skill.***<sup>1</sup>

In order to assess the spatial visualization abilities of our engineering students we give a standardized test (PSVT-R) during the first week of ENGR 127. Students who score less than 67% (20 out of 30 questions) are advised to be aware and make an effort to improve their spatial visualization abilities. Your score, out of 30, and typical average scores for *first-time* test takers are shown in the table below.

Student Name: \_\_\_\_\_

	student score	IPFW average score	national average scores	
PSVT-R Scores	/30	23.6 / 30	first-year students: overall:	19 / 30 22 / 30

Note that IPFW offers many opportunities for help, e.g.

**Course instructors and TAs:** Please ask questions, in class, at office hours, and via email. Courses builds; make sure you understand things as they come up—you will encounter the material again.

**ETCS Student Success Center (ET 233):** Drop in when you have questions about IPFW procedures, need to know where to get help with your classes, for a place to study, or to take a break. For more information, visit their website at [ipfw.edu/etcs-student](http://ipfw.edu/etcs-student).

ETCS tutoring in **The Help Corner (ET 151):** Free, drop in tutoring by upper division engineering students is available in ET 151. See schedule by the room, online at [ipfw.edu/etcs-help](http://ipfw.edu/etcs-help), and around the ET building. For more information, visit the website at [ipfw.edu/etcs-help](http://ipfw.edu/etcs-help).

**Tutoring Center (KT G23):** Free tutoring is available in the Learning Center. You are entitled to two (2) free hours per week, per class, of one-to-one, course-specific help in understanding concepts, practicing the application or explanation of material being learned, and developing effective test-taking strategies. Make appointments through TutorTrac (<http://www.ipfw.edu/offices/casa/tutoring/tutortrac.html>). If you don't see a tutor available for your class, contact them in Kettler G18! Call 481-5419. Hours: Monday-Thursday 9 a.m. to 5 p.m.; Friday 9 a.m. to 3 p.m. After hours and weekend tutoring may be available in the Learning Commons (Helmke Library). Check the schedule in TutorTrac for additional times and places.

**Disabilities:** If you have a disability and need assistance, special arrangements can be made to accommodate most needs. Contact the Director of **Services for Students with Disabilities** (Walb Union, Room 113, 481-6658) as soon as possible to work out the details. Once the Director has provided you with a letter attesting to your needs for modification, bring the letter to your instructor(s). For more information, please visit the web site for SSD at <http://www.ipfw.edu/ssd/>.

For specific **help improving your spatial visualization abilities**, consult your instructor for practice exercises and take a look at *Introduction to 3D Spatial Visualization: An Active Approach* by Sorby and Wysocki (2003).

<sup>1</sup> See S. Metz and S. Sorby, "Implementing engage strategies to improve retention: focus on spatial skills-engineering schools discuss success and challenges," ASEE paper AC 2011-438 and reference therein.