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# **AC 2011-2023: SKETCHING, DRAFTING, & DEVELOPING ENGINEERING VISUALIZATION SKILLS**

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# Developing Engineering Visualization Skills

## introduction

In the fall semester of Academic Year 2000, the Mechanical Engineering Department at the United States Naval Academy introduced a new course required for all students entering the Mechanical Engineering major. The course is run through a 16-week fall semester and currently is scheduled for one lecture session and two two-hour lab/workshops per week for a total of three credits. Consistent with many “freshman support” programs at other universities, the goals of the course are to introduce the midshipmen to the “big picture” of the major for context; to introduce the midshipmen to each other and develop a mutual support network; and, to provide “tools” for success in follow-on courses. These tools include technical writing, critical thinking, design process, project management, computer programming and software, and engineering drafting skills. There is a significant project-based learning (PBL) component to the course. The assignments include both individual and team submittals. The double “lab” schedule allows much of the project work to be progressed under the mentoring eye of the instructor. This paper traces the course’s visualization skills thread of sketching, drawing interpretation, computer aided drafting, and construction of parts from drawings. Examples of the types of visualization-related exercises and ten year’s worth of assessment data are provided.

## background

The Mechanical Engineering Department of the United States Naval Academy typically enrolls between 80 and 130 Midshipmen (out of approximately 1150 in a class year group) into the Mechanical Engineering major every year. With some variation due to course validations and foreign language programs, the freshman year at the Academy is a common core curriculum that includes courses in science, mathematics, humanities and social science. This common core program feeds to any of the Academy’s 22 academic majors. Midshipmen select their choice of majors in the spring of their freshman year and then commence courses in their major program in the fall semester of their sophomore year.

## course design

The overall 75-hour course time budget is summarized in the table below:

	<b>Topic or Subtopic</b>	<b>Hours</b>
1	Course Orientation and Administration	2
2	Engineering Drawing – Hand Sketching and SolidWorks <sup>1</sup>	8
3	Intro to Thermal Fluids w/ Lab	5
4	Intro to Mechanics w/ Lab	5
5	Intro to Material Science w/ Lab	5
6	MATLAB	15
7	Design Process Overview and Exercise	5
8	Research Skills; Critical Thinking; Engineering Ethics	5
9	Professional Writing; Documenting Formal Calculations	5
10	Course Design-Build Project	20

Visualization-related elements are included in all topics except #6 and are estimated to total about one third of total course time. The textbook used for early basic drawing knowledge and skills development and then later in the semester for sectioning and dimensioning is *Freehand Sketching for Engineering Design* by Duff and Ross.<sup>2</sup> The lab-related activities also incorporate system sketches and free body diagrams.

Current course outcomes include the following statements:

- Create, dimension and interpret orthographic, isometric, and section-type engineering drawings.
- Demonstrate basic proficiency in the SolidWorks software package.

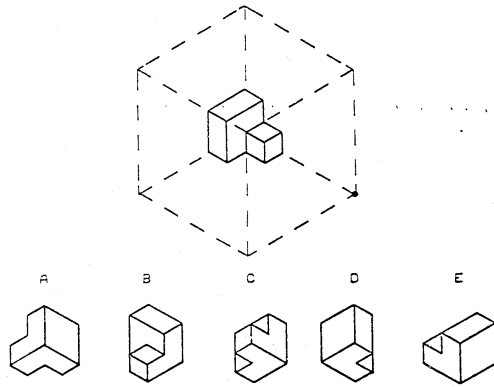
Students sit in groups of three to four, facing each other around tables during the semester. These groups are changed out at least three times at various breakpoints in topical coverage and students select with whom they will work. However, after the first group formation, they can not team up with anyone with whom they have worked in the past. Instructor-assigned groups of four or five are used for the end of semester design-build project. A team self-analysis is submitted by each person for improved feedback on individual contribution to team performance.<sup>3</sup> The attributes in this assessment are meant to identify desirable personal traits when working in teams.

To establish a baseline for measurement, a preliminary visualization test (PVT) is administered on Day 1. This is based upon the Purdue Spatial Visualization Test.<sup>4</sup> Only rotations and views test questions are used. The students are given twelve of each type of problem with an average of thirty seconds to answer each. Other problems of the same form are then included in the first exam, which is administered six weeks into the semester and includes the same time restrictions.

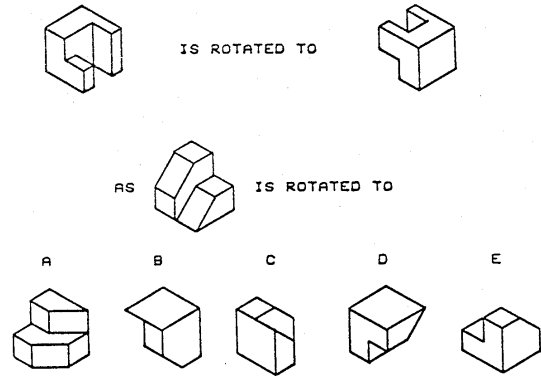
At this point in the course's history, the assignments are fairly mature and stable. The assignments tend to be very prescriptive with detailed instructions and provide specific directions regarding form and format of the submittals. A grading rubric is included with the more substantial assignments. Underlying expectations for sketching and drafting activities include that all drawings are to be checked and annotated by a peer prior to submission to the instructor. This helps to incorporate peer-instruction as well. If the drawings are fixed and flawless, then the peer reviewer may sign and include a statement that all discrepancies have been corrected. The specific activities are described by the week in the semester in which these activities are conducted.

## **week 1**

Preliminary Visualization Test. Figure 1 shows examples of the Views and Rotations used in this baseline assessment. The total time allowed is six minutes for each section of twelve problems. The view problem shows a dot in corner (in this case, the lower right) from which the object is to be viewed.

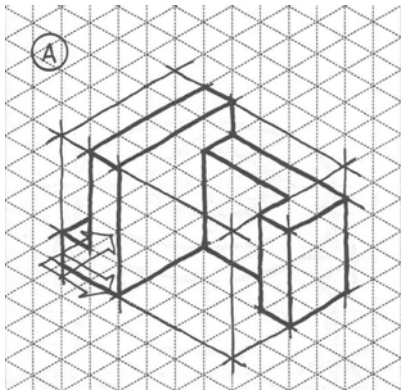


**Figure 1 - Example PVT View Problem**

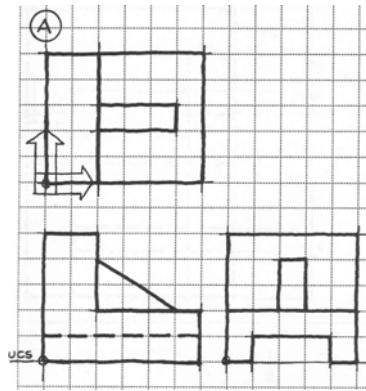


**Figure 2 - Example PVT Rotation Problem**

**Orthographic & Isometric Sketching.** Create three-view orthographic drawings from four different isometric source sketches. Create an isometric drawing from four different orthographic source sketches. Complete a surface definition and identification worksheet. Complete a worksheet that involves interpreting a three-view orthographic source sketch and reinforces surface definitions. All source drawings and worksheets are from Duff & Ross. Examples are shown in Figures 3 and 4.



**Figure 3 - Example Isometric Source Sketch**



**Figure 4 – Example Orthographic Source Sketch**

**Reverse Engineering Design Assignment.** Assemble a Lego™ pullback racecar from a kit. (The kit’s instructions have graphics suitable for a grade schooler, yet they reinforce developing the visualization skill set.) Then, disassemble, analyze and reassemble a gearbox. (This typically takes the students into new territory – not too many have actually seen the internals of this type of mechanism.) One person per lab team is to sketch the gears in the gearbox showing the gear ratios and direction of rotation for each pair of gears in each of the three operating modes (charging, discharging, coasting). The peer reviewer critiques the sketches for clarity and presentation. The group collectively authors a memorandum report describing the full operation of the gearbox. The box from one of the racer models and the interior view of the gearbox are shown in Figures 5 and 6.



Figure 5 - Lego™ Racer Kit

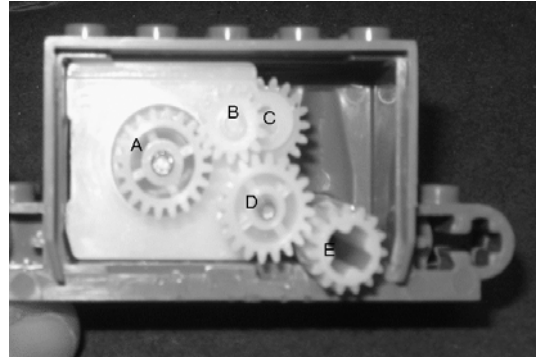


Figure 6 – Lego™ Pullback Gearbox Internals

Ortho & Iso Extra Credit – Each source drawing has three non-assigned sketches on the same sheet. Extra Credit is offered for preparing and submitting additional drawings. Many students avail themselves of this offer. There is no restriction upon when during the semester that they can submit these extra credit drawings. This serves to induce more engagement.

#### week 4

Build an Operating Engine Kit. Over the years, USNA has used a number of kits for this exercise. Some have been operating model steam engines and a variety of Stirling kits. Besides the graphics in the assembly instructions, the assignment includes the requirement to sketch the mechanics of the engine. For the Stirlings, the students are to show the timing between the displacer and the power diaphragm. This past year, the INPRO Solar Hand Stirling 6565 kit, shown in Figure 7, was procured. The cost of this kit from the manufacturer was about \$33 per kit. Each student built and kept the engine that they assembled. While this kit has the potential to operate on the temperature of a human hand, an electric hot plate with a beaker of warm water (~60 °C) was used to make the kit less susceptible to minor friction issues. Extra credit was awarded for obtaining reliable operation. About 80% achieved operation.

**Inpro Solar**  
**HAND STIRLING 6565**  
Instructions for Assembling and Operation

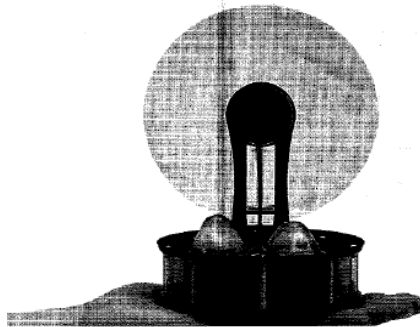


Figure 7 - Stirling Engine Kit

## week 6

Mid-Term Exam involving views and rotations in the same format as the PVT. Over the years of running this course, the same problems have been used for consistent grading. The exam booklets are collected after each use to prevent compromise by current students passing it to future students. The historic average over this ten year period is an increase of 13.4% in correct answers on this measurement of visualization skills.

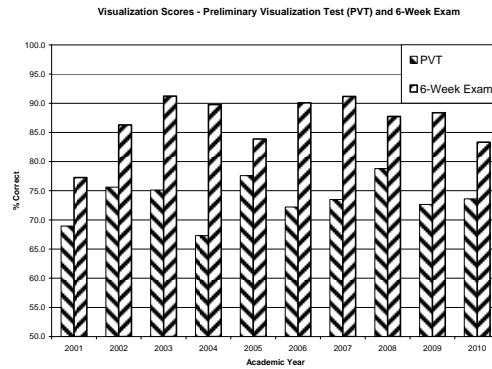


Figure 8 – Views and Rotations Preliminary and 6-Week Exam Averages

## week 7

Sectioning & Dimensioning. Complete two sketches involving sectioning and two worksheets involving dimensioning from the text. Examples are shown in Figure 9.

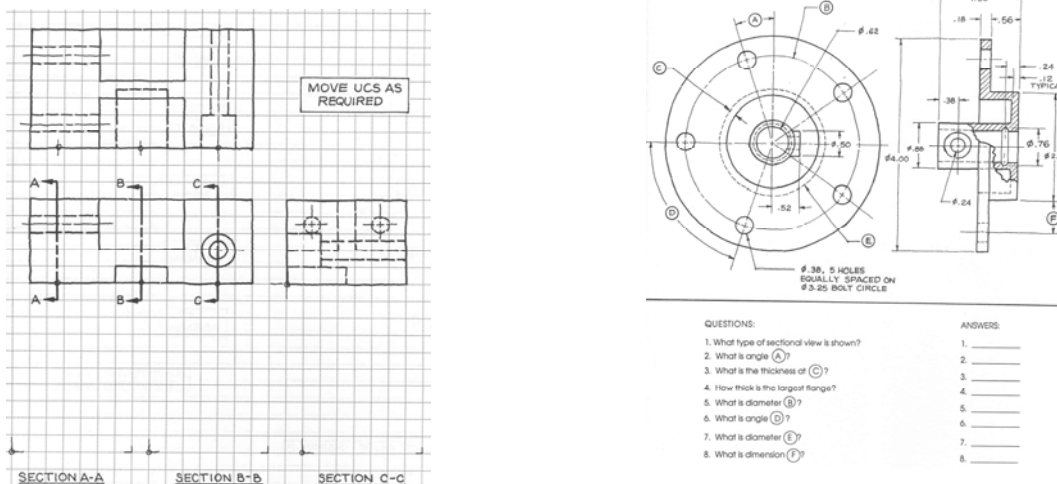
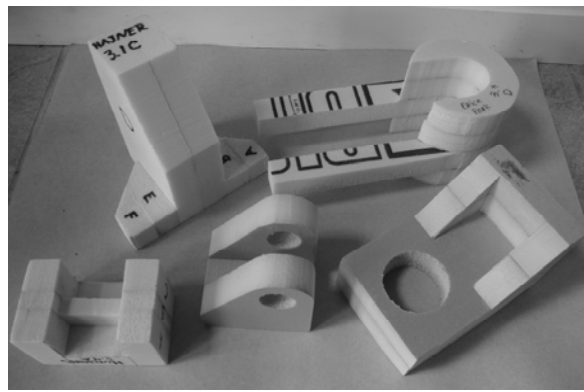


Figure 9 – Example Sectioning & Dimensioning Exercises

Introduction to SolidWorks in a computer lab. Complete the SolidWorks “Getting Started” tutorial and submit the final drawing with the student’s name printed by SolidWorks somewhere on the result. Download instructor-prepared SolidWorks orthographic views that show the same views as the worksheets used in the Sectioning & Dimensioning assignment, two of which are shown in Figure 9. Have the students use SolidWorks to section and dimension the drawings using SolidWorks.

## **week 8**

**Sketch to Foam/Wood Block to Sketch.** This exercise provides wood blocks of various shapes, cutouts and protrusions and has the student render by hand in both orthographic and isometric views. Then these hand sketches are rendered using SolidWorks. A second part of this activity is to take one of the shapes provided on the original orthographic source sheets (see Figure 4) and cut out this shape using one inch thick foam slabs as a material. The choice of shapes is coordinated by signup sheet so that not too many of the same shapes are produced. The students must plan a cut sheet as if this were going to be a mass production scenario and calculate the foam usage and cut efficiency. All shapes are scaled to require some lamination of multiple pieces. Examples of some of the student foam products are shown in Figure 10.



**Figure 10 – Student-Fabricated Foam Blocks**

## **week 11**

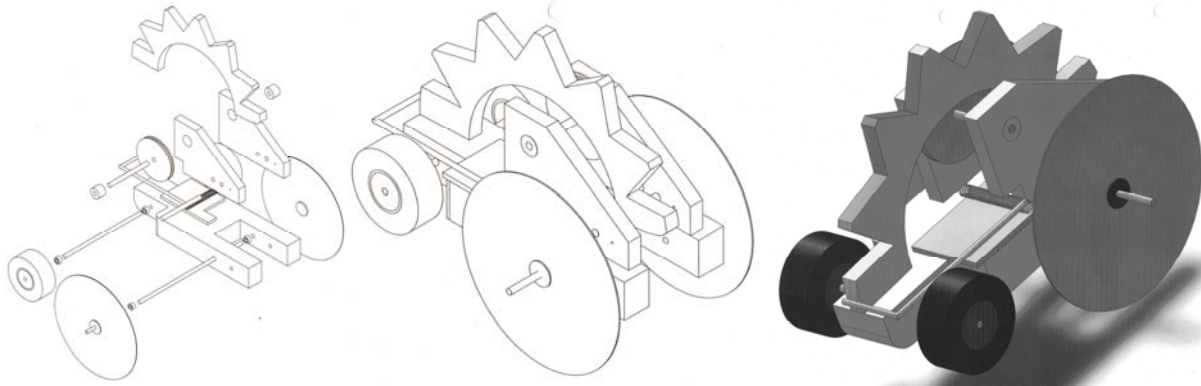
**SolidWorks Assembly Tutorial.** Students submit the final sketch from this tutorial and have SolidWorks print their name in the title block of the drawing. This assignment is preparatory to the mousetrap vehicle project. Most students take between one and two hours to complete this tutorial.

## **weeks 12 through 16**

### **Mousetrap Vehicle Design/Build Project.**

The basic task is to produce a mousetrap-powered vehicle that can compete in distance, drag race, and chain pull events using the energy available in one standard Victor mousetrap. The vehicle must fit inside a 6 x 6 x 8 inch box, weigh less than 250 grams, and cost less than \$30. This combination of events and design constraints is a good challenge even to those who have participated in some sort of mousetrap design challenge in the past. With respect to drafting, the design teams are to show hand-drawn design concept sketches during project intermediate submittal #1. Power transmission drawings are specifically required. Final design binders are to have orthographic and isometric views of the vehicle and an exploded view isometric drawing, all drafted in SolidWorks. The vehicle should have alternate configurations optimized for the other competition events. Drawings of these configurations are expected in the final design binder. The student team's final design presentation is to include SolidWorks drawings of the

vehicle in the PowerPoint slide show. Extra Credit is available for teams who figure out how to animate a SolidWorks drawing of their vehicle. An example of the SolidWorks graphics associated with one of the more novel recent vehicles is shown in Figure 11.



**Figure 11 – SolidWorks Drawings of a Student-Designed and Built Mousetrap-Powered Vehicle**

The isometric assembly to the right has been shifted to grayscale for this article. As produced by the students, it is in color and is quite impressive in its clarity of presentation. The borders and title blocks have been removed from these drawings, but overall, the total package presents quite professionally. Several groups even achieved the SolidWorks animation function to work.

### **conclusions**

The combination of formal presentations, leading to immediate practice with the combination of peer instruction and instructor mentoring is assessed to be effective. The spiral of “learn it and then apply it” in a variety of exercises keeps the development going. The formal assessment using the Purdue Spatial Visualization Test consistently shows improvement in the students’ abilities. Secondly, the use of teams stimulates peer instruction wherein students see each other’s work and learn from the better examples. Lastly, the semester project gets at least one member of each group to take their competence with SolidWorks to the next higher level. The skills that are developed are used in subsequent mechanical engineering courses. The anecdotal feedback regarding student visualization skills from these course directors is positive and reinforces the belief that this is an effective scope and sequence to achieve improved performance.

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<sup>1</sup> Dassault Systèmes SolidWorks Corp., [www.solidworks.com](http://www.solidworks.com).

<sup>2</sup> Duff, J.M. & Ross, W.A., *Freehand Sketching for Engineering Design*, PWS Publishing, Boston, 1995.

<sup>3</sup> Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS), University of Maryland, <http://www.enme.umd.edu/labs/BESTEAMS>.

<sup>4</sup> Guay, R., *Purdue Spatial Visualization Test* Purdue Research Foundation, 1976.