Combining basic tool training and an introduction to physical sciences for freshmen engineering students

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Full Paper: Combining basic tool training and an introduction to physical sciences for freshmen engineering students

Abstract

The freshmen introduction to engineering course in the Department of Engineering at James Madison University is designed to introduce freshmen engineering majors to the tools and concepts used in engineering and reinforce the applications of math, physics and chemistry from the core curriculum.

Students taking the freshmen-engineering course at JMU were found to have significantly different levels of math, chemistry and physics backgrounds. One of the goals of the freshmen-engineering course was to provide a chance to practice the applications of fundamental math and engineering science. The fundamental properties addressed through the development of an integrated experiential-learning approach for tool training and engineering science included applications of force and weight, force distribution, density, specific gravity, and applied geometry. Additional course goals for the freshmen engineering course discussed herein included exposing engineering students to modern engineering tools and understanding and practicing appropriate safety protocols.

There are twelve objectives for the freshmen course, which address 10 ABET a-k topics. As part of the described module:

- Students calculate the volume and density of various materials
- Students interpret engineering drawings to relate principles and equations in geometry.
- Students perform a force balance to balance a hinged load.
- Students create an engineering drawing to design and build a balance for two objects.
- Students receive an orientation to basic tools and safety in the machine shop.
- Students must successfully complete a competency based lab and shop safety quiz.
- Students build and test the mechanism they have designed to balance the point and distributed forces.

As a result of this approach, students gained confidence in relating abstract drawings to physical materials. Students also gained hands-on experience relating basic engineering concepts about density, materials, statics and dynamics. Students expressed increased confidence in using basic tools and relating those tools to engineering science principles. Many students who had no previous experience with basic tools and shop techniques went on to apply and work as undergraduate teaching assistants in the shop after completing this assignment.

Background

The engineering programing at James Madison University was established in 2008.[1] New programs have many challenges, some of which include unknown characteristics of students and a lack of established norms for both students and faculty. Many pieces of the curriculum were still being developed. Due to these challenging and changing circumstances, an iterative approach was used to refine the program's freshmen introduction to engineering course, ENGR 112. Students taking the freshmen-engineering course at JMU were found to have significantly different levels of math, chemistry and physics backgrounds. One of the goals of the freshmen-engineering course was to provide a chance to practice the applications of fundamental math and engineering science. The fundamental properties addressed through the development of an integrated experiential-learning approach for tool training and engineering science included applications of force and weight, force distribution, density, specific gravity, and applied geometry. Additional course goals for the freshmen engineering course discussed herein included exposing engineering students to modern engineering tools and understanding and practicing appropriate safety protocols.

By year 3 of the JMU engineering program, knowledge gaps for some students began to become apparent to faculty teaching junior/senior courses.[3-4] Problems identified included a lack of comprehensive knowledge of some fundamental concepts. Many students consistently had difficulties relating mathematical and scientific theory to real products. Basic elements of engineering analysis including unit analysis, force, weight and mass caused great difficulty for some members of the engineering class. In particular, students could not intuitively related the properties of mass, density and force. For example, many students prior to the course did not intuitively understand that a similar sized piece of PVC has less mass than a similar volume of steel. Instructors also observed that students could “plug and chug” their way through force problems but lacked an intuitive understanding of the concept of weight as a force acting on an object when students were expected to apply the definition of a force in this course and subsequent statics and dynamics courses. Additionally many students experienced difficulty communicating engineering ideas, including interpreting and developing engineering drawings; and difficulties with algebraic problem solving. Grades on quizzes for two years prior to the discussed changes related to these key engineering analysis topics averaged 40% and 52%, well below the department target goal of a 70% or greater score on these problems. As a result of these observations, instructors from the freshmen course met with instructors of the subsequent Statics and Dynamics course to devise a method to illustrate these concepts using a project-based experiential methodology.

Development of an integrated freshmen-engineering module to apply fundamental concepts in engineering science

A video-based module was used to introduce students to the relationships between gravimetric forces and mathematical analysis. The video used was from the Mythbusters™ Bug Special episode that evaluated how many bees would be required to lift and average laptop computer. The video demonstrated and introductory physics using the relationships between the properties of density, specific gravity of materials, weight and force. An example was developed that utilized a spreadsheet for basic calculations and graphical analysis and introduced force principles and the concept of a distributed force, the data for the example is shown in Table 1.

The introduction to the fundamental relationships between force, mas and weight was reinforced with a hands-on design and build balance project. A balance is a simple mechanical device that illustrates many fundamental principles and can be easily built and assembled. Students were given a series of assignments to design, draw and build a simple mechanical balance. The principles incorporated into the assignment included:

- utilizing the density and specific gravity of solid and liquid materials to perform a force balance;
- utilizing the principles of geometry and algebra to calculate the weight and force acting on the balance beam;
- reading engineering drawings to relate numerical values to real parts and components of the balance; and
- reading and demonstrating an understanding of safety protocols and expectations in a manufacturing facility.

Table 1: Data required to evaluate how many bees are required to lift a laptop

Number of beads a bee can lift	8	beads
Mass of a bead	12	milligrams
Mass of a laptop	2216	grams
Question	How many bees does is take to lift the laptop	
Solution	{2216 x 1000/(8 x 12)} = 23,083	bees
Area of the laptop	234	Square inches
Bees per square inch	40 bees/4 in2	
Question	How many bees can fit on the laptop	
Solution	{234 x 40/4} = 2,340	bees
Busted	10 times more bees are needed than can fit on a laptop	

Assignment 1: Relating material density to weight and geometry: Given that water has a density of approximately 1000kg/m^3 and that the PVC from which the pipe and end cap on the attached drawings (Figures 1) are made has a density of approximately 1330kg/m^3: calculate the length of pipe required to contain 2oz. (weight) of water; calculate the weight of the pipe in ounces; calculate the weight of the cap in ounces; and calculate the weight of the complete assembly of the pipe, water, and two caps.

Once you have completed this work be sure to save the calculations and results as you will use this information for the next assignment and to produce the tool training project.

Considering the precision that we will be able to attain in building the tool training project, it is acceptable to disregard the dome shaped end of the cap and assume a flat shape for your calculations.

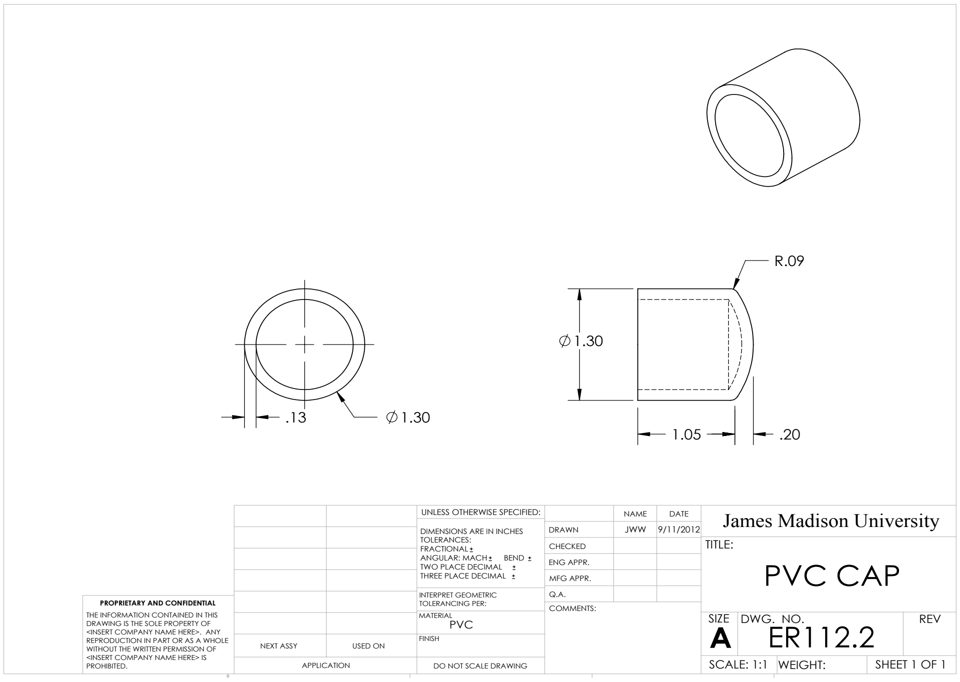

Figure 1: Engineering drawing of schedule 40 PVC endcap used to illustrate engineering drawing components and provide data for engineering calculations.

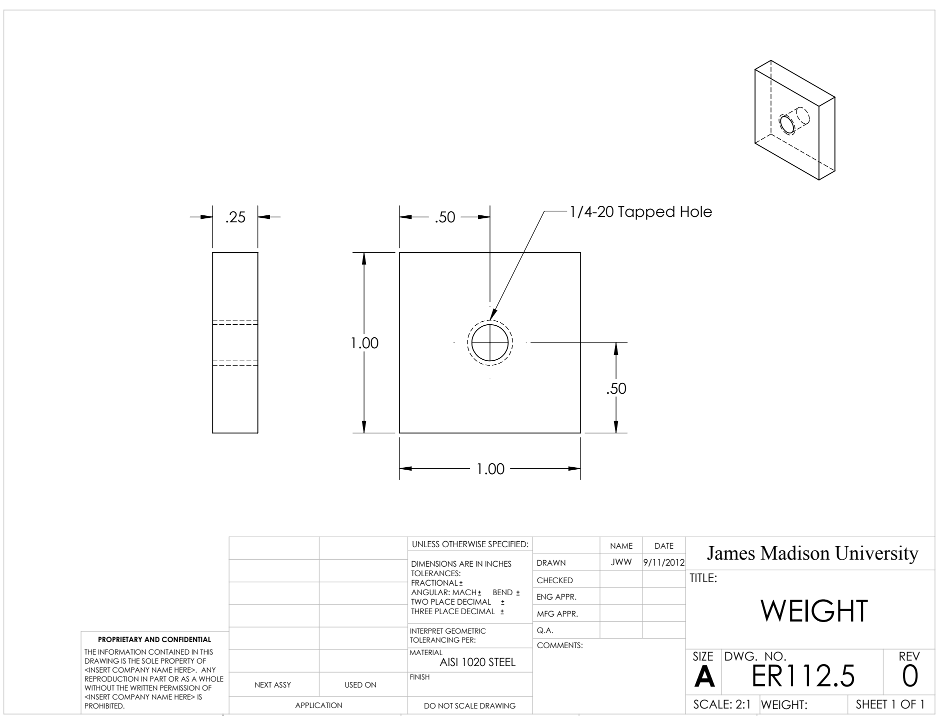

Figure 2: Engineering drawing of an aluminum counterbalance used to illustrate engineering drawing components and provide data for calculating the force acting upon the end of the balance beam..

Engineering Drawings and Communications: Students in higher-level courses had difficulty communicating their engineering designs, due to a lack of uniform ability to use engineering drawings to communicate ideas. Lecture were developed to introduce students to the fundamental types and functional components of engineering drawings, including line types (solid, hidden, etc.), orthographic projections, and scale. Figure 2 was one of several drawing used to demonstrate the purpose of engineering line types, such as hidden lines, used to communicate information to a machinist.

Demonstrating the use of algebra in problem solving: Through a combination of lecture, reading, and homework, students were introduced to the scientific relationships between density, weight, and forces. A second assignment required students to utilize their understanding of these principles, along with algebraic manipulation to find the centroid of their balance beam with two different loads acting on the beam.

Assignment 2: Using algebra to balance two forces: A piece of wood shown in Figure 4 is 1.75cm x 3.6cm x 20cm weighs 64.5 grams.

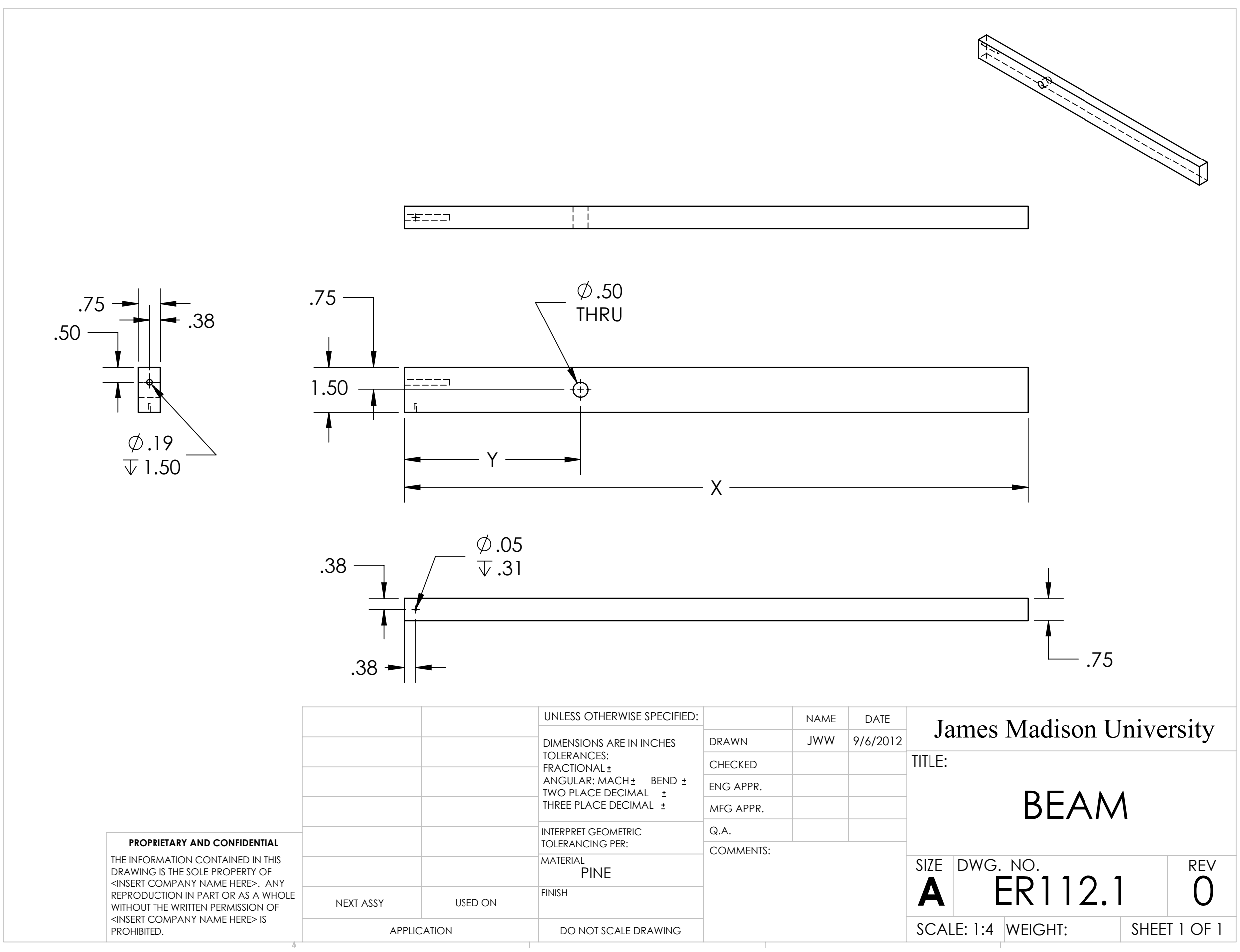

Figure 4: Engineering drawing of wood balance beam used to illustrate engineering drawing components and provide data to calculate the centroid of the weigh-loaded beam.

Calculate the length of a wooden beam that is 50cm + the last digit of your student ID number.

Example: Amy's student ID number is 100055446. The length of Amy's beam will be 50cm + 6cm = 56cm, since her ID number ends with the number 6. Calculate the weight of a wooden beam that is 1.75cm x 3.6cm in cross section whose length is 50cm + X cm, where X = the last digit of your student ID number. Add 47.5g plus the total weight of the components from Tool Training Homework 1 to find the weight of your counter balance assembly. Find the balance point of your beam and counter balance assembly using the formula:

(beam weight)(beam length/2) = (distance to balance point)(counter balance assembly weight)

Example: Amy's beam is 560mm long and weighs 180.6g, while her counter balance assembly weighs 145g.

- (180.6)(560/2) = (X)(180.6+145)
- 50568=(X)(325.6)
- X=155.3
- So, the balance point of Amy's beam and the counter balance assembly is 155.3mm from the end where the counter balance assembly will be mounted.

Save these calculations so that you can build your balance beam assembly during the hands on tool training lesson.

In year three, a pre-assessment on the key engineering analysis topics relating to mass, density and force calculations were administered. The pre-assessment score was 50%. The scores associated with the additional Mythbusters™ Bug Special exercise was 80%. The score associated with the development of the force balance was 95%. After completion of the additional modules, the engineering analysis quiz with similar problems to previous years was used to assess the objectives after implementing the hands-on active learning projects and quiz scores rose to 80%. Over a period of three years, engineering analysis scores averaged 40%, 52%, and 50% respectively. After implementation of the additional active learning activities the score for assessment of the engineering analysis unit rose to 80%, which was above the department target goal of a 70% for these problems. As a result the active unit modules were retained in the course to assist in meeting the learning objectives for tool-usage, and problem-solving skills related to unit analysis, force, weight and mass.

Summary

The benefits of team teaching are not optimized by individuals teaching different subjects in their individual are of expertise. The freshmen project was developed by multiple instructors from multiple background designing a student learning experience that integrated elements of applied mathematics, physics, engineering drawing and a hands-on laboratory experience to design and build a simple balance. The hope is that demonstrating the process of integration early in the curriculum will help students learn to integrate engineering fundamentals and design into applied practical projects throughout the remaining 6 semesters of project related course, and may also be beneficial in internships and future employment. The authors hope they may be able to track the impact of the integrated project as students' progress through the curriculum.

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