AC 2010-614: DEVELOPMENT OF A TECHNOLOGICAL LITERACY COURSE FOR NON-ENGINEERING STUDENTS: SCIENCE OF HIGH TECHNOLOGY

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Abstract

As citizens, we are confronted by many global and national issues such as the dangers of greenhouse gases and the best choices for energy sources. These questions are fundamentally technical in nature and many people feel ill-equipped to understand the variety of claims and counterclaims as to what is “the truth” on these and other important scientific issues. For many people, the reaction is to give up and accept that the modern world is too complex to understand. To address these issues and improve technological literacy, the College of Engineering (CoE) at San José State University (SJSU) has implemented a new lower division physical science General Education (GE) course for the university--Engineering 5, Science of High Technology.

Engr 5 was designed for non-engineering students. Many of the technologies discussed in this class are ones that students naturally wonder about. We cover electronic technologies and show the student the science behind these technologies. In this way, students use real objects (such as portable audio players or microwave ovens) to discuss physical concepts. This course serves two purposes: to increase the technological literary of undergraduate students, allowing them to become more effective and engaged citizens; and to provide knowledge about these technologies to non-engineering students who will work for technology companies in the Silicon Valley after graduating from SJSU.

Introduction

In 1959, in the midst of the technological explosion in the West, C. P. Snow published his influential essay *The Two Cultures*[1]. In his essay, he saw the Western society was “increasingly being split into two polar groups…at one pole we have the literary intellectuals…at the other scientists.” There is “a gulf of mutual incomprehension… but most of all lack of understanding” between these two groups. This lack in understanding that Snow portrayed has been exacerbated today by the increasing advances in technology and engineering, leaving the general public uninformed about the nature of technology and technological innovation.

Byars[2] summarized the need for technological literacy classes for liberal arts majors, particularly classes with an engineering-based approach. She emphasized that this need is based on the well-established lack of scientific and technological literacy among the American general public. Surveys[3] indicate that many Americans are unable to provide the correct answers to basic questions in science and do not understand the nature of experimentation or scientific inquiry. The Organisation for Economic Co-operation and Development (OECD)[4] noted that literacy had several components:

> Current thinking about the desired outcomes of science education for all citizens emphasizes the development of a general understanding of important concepts and explanatory frameworks of science, of the methods by which science derives evidence to

> support claims for its knowledge, and of the strengths and limitations of science in the real world. It values the ability to apply this understanding to real situations involving science in which claims need to be assessed and decisions made…
>
> Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity. (pp. 132–33)

This definition of scientific literacy encompasses technology. In this area, the colleges of engineering are uniquely poised to provide this type of literacy education to students from other disciplines. The Green Report-- Engineering Education for a Changing World[5], released in October 1994 as a joint project report by the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education (ASEE), challenged the deans of the colleges of engineering to work with colleagues across the university to promote technological literacy for all students. "Engineering colleges should accept responsibility for providing technical literacy programs to liberal arts students."

Many universities addressed this call for technological literacy curriculum by developing courses for general education under the general theme of science, technology, and society. Frostburg State University[6] offers an interdisciplinary course titled *Science Technology and Society* as a freshmen-level general education course for non-science and non-engineering majors. At the University of Denver[7], an interdisciplinary team including faculty from the Department of Engineering has offered a three-quarter long course called *Technology 21* for fourteen years with approximately 100 students each year. *Technology 21* is used by the non-engineering and non-science students to meet their university's science general education requirement.

A general education course titled *Technology and the Engineering Method* at the University of Dayton[8] also fulfills a science education requirement and is taken by a diverse group of non-engineering students. At California State University—Northridge, the Manufacturing Systems Engineering departments offers a general education breadth course in the GE area of Applied Arts and Sciences. Other universities that have engineering courses as part of the General Education programs at their institutions include Miami University[9], Penn State University[10], Old Dominion University[11], North Carolina State University[12], San Francisco State University[13], The University of Washington[14], and the University of Texas at Austin.[15]

Traditionally, the College of Engineering at SJSU has not offered many courses in the GE program. However, this stance has changed in the past two years as the CoE has embraced technological literacy as a critical area for all undergraduates, including non-STEM (Science, Technology, Engineering, & Mathematics) majors. SJSU is located in the heart of the Silicon Valley which has the highest percentage (13%) of its workforce in technological occupations among all regions in the nation. It has been the technology center of the world, known for advancing technology frontiers from semiconductors to networking to software to web technologies. Because of its location, most SJSU graduates are employed by Silicon Valley organizations. The CoE has embraced technological literacy as part of its commitment to the local community. The faculty in the CoE have technological expertise which can benefit the overall SJSU community through the GE program. This focus on technological literacy has led to the development of a new GE course in engineering, Engr 5—Science of High Technology. This course attracts students from all of the colleges and programs (see Figure 1). It is widely promoted in freshman orientation sessions and GE literature for undeclared majors. We have had great success in attracting non-engineering students to this course.

Figure 1. Number of declared and undeclared students in Engr 5, listed according to their college

	Fall 2008	**Spring 2009**	**Fall 2009**
Applied Sciences & Arts	**0**	**2**	**5**
Business	**9**	**5**	**19**
Continuing Education*	**4**	**0**	**0**
Education	**0**	**0**	**1**
Engineering	**5**	**1**	**6**
Humanities & Arts	**2**	**1**	**5**
Liberal Studies**	**0**	**0**	**1**
Science	**0**	**1**	**2**
Social Sciences	**3**	**1**	**1**
Undeclared Major	**7**	**3**	**10**
TOTAL	**30**	**14**	**50**

* The Continuing Education program does not belong to any particular college.
** Liberal Studies is a multidisciplinary degree program. It doesn't belong to any particular college.

Content of this Course

Engr 5 focuses on technologies used every day to teach scientific principles to students. This course deconstructs technologies to teach students the scientific foundations underlying these technologies. The main textbook chosen for this course ("How everything works"[16]) is used in many universities across the country to enhance the scientific literacy of students.

Most undergraduate students don't intend to become scientists or engineers but all of them will have to make decisions involving technological and scientific issues. Engr 5 helps the students understand several scientific concepts and see how they are applied in the world. Our goal is to educate students so that they *know* that they *can* understand scientific principles and they *can* understand how things work from a scientific point of view.

Much of the world around us and the technology we use is governed by physics principles. Once those principles are understood, the technologies we use everyday become understandable and predictable. Many of the technologies discussed in Engr 5 are ones about which students naturally wonder. We deconstruct technologies (including batteries, radios, television, portable audio players, microwave ovens, and computers) and show students the science behind these technologies. In this way, we use real objects to discuss physical concepts. In Engr 5, we demystify high technologies and, thereby, help the student understand the physical principles underlying the high technology artifacts.

The conceptual perspective in this course appeals to non-STEM students. This course emphasizes hands-on activities so that students have an experiential approach. The combination of lectures, demonstrations, and short laboratory activities is designed to give the students a more in-depth understanding of the material. Since much of the class is focused on electrical and electronic technologies, the students should be able, after the completion of Engr 5, to apply their knowledge to other technologies and technological situations in real life. Complete information and a detailed syllabus are available on the course website at http://www.engr.sjsu.edu/thowell/E5.htm.

Each unit has class activities, labs, and/or homework sets that require students to use quantitative and analytical techniques to solve problems in science. In addition, there are four student learning objectives for Engr 5. We expect that the students should be able to:

- Use scientific methods and gain scientific knowledge to understand how science is applied to the development of high technology devices and systems
- Describe how engineering and technology is influenced by the needs of society
- Describe how engineering and technology influences society
- Use quantitative and analytical techniques to solve problems in science

One of the most important messages for the students is that while science and technology can be complicated, they can be broken down into comprehensible pieces. We want students to leave thinking "I can understand this!" Our approach is to teach basic scientific principles at a level they can fully grasp. We then apply these principles to familiar situations in our daily lives and discuss how simple principles become building blocks for more complex technologies. We try to minimize time spent lecturing. Instead we build things, measure things, and take things apart to see how they work. In order for this approach to work, students need to read the relevant sections of the textbook *before* we talk about them in class. We encourage this by quizzing students on the reading at the beginning of each new unit rather than at the end.

Quantitative reasoning is important in science and engineering, but many of our students find complex mathematics intimidating. To deal with this, we emphasize the science and keep the math simple. We discuss vectors for forces and velocities using diagrams with arrows instead of more complicated coordinates. We encounter the relationship $F = m \times a$ when we study Newton's laws. Knowing two of the three quantities, students can calculate the third. We don't often need to get more complicated than this. Similarly, students learn that torque = force × lever arm. They can reason that doubling the lever arm with a constant force doubles the torque. This exercises quantitative reasoning while keeping the math comfortable. Our lab exercises involve similar relationships. For example, we measure the conductance C of Play-Doh™ cylinders of various cross-sectional areas A and try to discover σ in the formula $C = \sigma A$.

Analogy is a useful tool as our students study electrical devices. It is difficult to visualize flows of charges in circuits because the charges are invisible. However, water flowing in pipes is familiar and easy to visualize. We use this analogy to describe various electrical circuit components: resistors, capacitors, inductors, batteries, diodes, transistors. We compare a theater with empty seats and full seats in the orchestra and balcony sections with the semiconductor materials used in diodes, and transistors. This visualization helps students understand devices that many of them previously considered beyond their reach.

Experimentation is the path to scientific truth. We incorporate as many experiments and demonstrations as possible. Seeing nature do it is much more convincing than hearing the instructor talk about what *would* happen *if* you did it. We spend a large part of our class time demonstrating the simple scientific principles that form the basis of our technological devices. We drop things, spin things, bounce things, and swing things as we discuss Newton's laws and clocks. We dissect power adapters and test the diodes we find inside. Electromagnetic waves, being extremely important for technology, are hard for students to visualize. Many students enjoy doing experiments with microwave ovens to study the wavelength and polarization of the microwave radiation used to cook our food. This improves their understanding of all electromagnetic waves, not just microwaves.

Repetition is an important tool for teaching. We encounter harmonic oscillators early in the course when we discuss clocks. Later on, they reappear as tank circuits in radios and microwave ovens. We encounter the Lorentz force on a moving charge in a magnetic field as we dissect a disk drive actuator. The same force appears again in loudspeakers, in cathode ray TV tubes, and in the microwave oven. Each time a concept appears, the students' understanding of it is reinforced and deepened. This works well as we cover a wide range of technologies.

Assessment of this Course

Engr 5 is approved under the lower division science core of SJSU's General Education as a physical science (GE Area B1). Students are required to take courses in several different areas including physical science (B1), life science (B2), and mathematics (B4). They must also take one lab course (B3), either as part of the life or physical science class or as a separate one-unit class. The course goals and student learning objectives for the science core are shown in Figure 2 below.

SJSU's GE program is developed as an outcomes-based program. SJSU uses course-embedded assessment to determine the university's achievement of its GE learning goals. Each GE course must submit a yearly assessment report to document how students meet the specific learning objectives for the GE area. Course-embedded assessment[17] "uses instructor grading to answer questions about student learning outcomes in a non-intrusive, systematic manner. The process requires instructors to define learning objectives for each course, devise a rubric that measures these objectives, use the rubric to grade student work, record the data, and note needed changes for future course offerings."

For continuing certification in General Education, a department's GE courses are reviewed during the normal program planning cycle. There is a section in a department's program planning self-study that addresses GE. In this section, the department must include a comprehensive evaluation of the course that may include a focus on the GE Goals for its area or other course goals and changes that the department has made to try to improve student success with respect to the GE Student Learning Objectives (SLOs). Since the Department of General Engineering is the home department for Engr 5, the formal assessment reports for Engr 5 are due in Fall 2012.

Figure 2. Goals and Student Learning Objectives for Area B, SJSU General Education[18]

Core General Education: – SCIENCE
(B1, B2, B3)

A. Goals

Science is a continuous and adaptive process through which we discover and communicate how the natural world works, separate fact from inference, and establish testable hypotheses. All students should sufficiently master essential quantitative and qualitative skills that are necessary to understand scientific knowledge and methods. Students should be able to incorporate scientific knowledge into the workplace and everyday life experiences.

B. Student Learning Objectives

Students should be able to:

1. use the methods of science and knowledge derived from current scientific inquiry in life or physical science to question existing explanations;
2. demonstrate ways in which science influences and is influenced by complex societies, including political and moral issues; and
3. recognize methods of science, in which quantitative, analytical reasoning techniques are used.

For the yearly course assessment, departments were asked to focus on one GE SLO at a time. For the 2009-2010 academic year, we decided to focus on assessing the students' achievement of Area B GE SLO #3 (Students should be able to use the methods of science, in which quantitative, analytical reasoning techniques are used). The two other SLOs in this GE area will be assessed over the next two years (see Figure 3).

Figure 3. Assessment Plan for Engr 5

GE Student Learning Objective	When will this SLO be assessed?
SLO 1: Students should be able to use the methods of science and knowledge derived from current scientific inquiry in life or physical science to question existing explanations	AY 2011-2012
SLO 2: Students should be able to demonstrate ways in which science influences and is influenced by complex societies, including political and moral issues.	AY 2010-2011
SLO 3: Students should be able to use the methods of science, in which quantitative, analytical reasoning techniques are used.	AY 2009-2010

Three activities were assessed as part of the embedded course assessment for Engr 5 in Fall 2009: the pendulum exercise, Lab 1 Newton's Laws for Toy Trucks, and Lab 2 Conductance of Play-Doh. All of these activities are described in Figure 3 below.

Figure 4. Student Activities Related to GE SLO #3

Pendulum exercise--The pendulum exercise comes as we move from the unit on Newton's laws to the unit on clocks. The students, working in groups of 3 to 4 construct pendulums out of string and metal washers. Each group is assigned a different length. They time ten swings of the pendulums and compute its period. Then they shorten it by a factor of four and measure its period again. The instructor collects all the data and makes a plot of period versus length. The functional relationship is a square root, so the plot is curved. Then the instructor plots the period squared versus length and get a straight line. The students use their data and the plots by the instructors to discuss the scientific principles.
Lab 1 Newton's Laws for Toy Trucks--The students roll toy trucks down ramps of various heights and try to deduce the relationship between ramp height and distance rolled. They repeat the experiment with extra weight in the trucks if they have time.
Lab 2: Conductance of Play-Doh--The students make cylinders of various diameters out of Play-Doh™. They place the cylinders on a measurement fixture and measure currents through them and voltage across them. Their task is to deduce the relationship between conductance (current / voltage) and the diameter of the cylinder.

The pendulum exercise occurs early in the course as we move from the unit on Newton's laws to the unit on clocks. After the instructor plots the students' results of the pendulum exercise, students use the results to determine the value of g. Using a formula from the textbook, we expect the period to be 2 pi times square root of length / g, where g is the acceleration of gravity. All of the students' measurements taken together are usually good enough to determine g to within 1% of the accepted value.

The two lab activities are done in the College's Introduction to Engineering Lab. This lab was recently constructed to house this class and is a very attractive laboratory for the student's use. For Lab 1 (Newton's Laws for Toy Trucks), the students rolled toy trucks down ramps of various heights and tried to deduce the relationship between ramp height and distance rolled. They repeated the experiment with extra weights in the trucks if they had time.

The students wrote lab reports in which they described their experiments. The reports were graded on both technical quality and writing quality. The point values were 10% for hypothesis, 20% for procedure, 10% for raw data, 20% for plots, 20% for conclusions, and 20% for writing quality. The students generally did a good job on the reports; the class average score was 88% (see Figure 5).

Figure 5. Distribution of student grades for Lab 1 (Fall 2009)

A	67%
B	20%
C	9%
D, F	4%

The good results are partially due to the students following the instructor's outline for the report contents and some very explicit instructions for making simple plots using Excel. Engr 5 has been offered for three semesters. In the past semesters, the instructor expected the students to do the plots by hand, with only the most advanced students using Excel. When more students attempted to complete the plots with Excel, many generated poor results. Simple plotting instructions have become necessary in this lab.

The technical result of this experiment is to plot the relationship between ramp height and distance rolled. The students also investigated the effect of extra weight in the truck. Most students found a linear relationship: distance rolled was proportional to ramp height. Distance rolled was independent of the extra weight in the truck, although some students tried to attach too much significance to small variations. Neither of these results was easy to predict from theory. They depend on details of friction and air resistance. Our results are consistent with friction being proportional to the truck's weight and independent of its speed and with air resistance being negligible.

The second lab focused on electric conductance (Lab 2: Conductance of Play-Doh). The students made cylinders of various diameters out of Play-Doh™. They placed the cylinders on a measurement fixture and measured current through them and voltage across them.

The students wrote lab reports in which they described their experiments. The reports were graded on both technical quality and writing quality. The point values were 10% for hypothesis, 20% for procedure, 10% for raw data, 20% for plots, 10% for finding the slope of a plotted line, 10% for conclusions, and 20% for writing quality. The students generally did a reasonably good job on the reports but did not do well as they did on Lab 1. The class average score was 78%.

Figure 6. Distribution of student grades for Lab 2 (Fall 2009)

A	23%
B	42%
C	21%
D, F	14%

The instructions for this lab report were not as explicit as those for Lab 1 and not all students maintained the good discipline they showed on the earlier report. The technical results of Lab 2 were slightly more complex than those of Lab 1; the relationship between conductance and diameter was quadratic rather than linear. The students needed to determine that conductance was linearly related to the cross-sectional area of the cylinder. The instructions hinted strongly in this direction but purposely did not spell it out.

This experiment also required the students to read volts and milliamperes on digital meters. The fluctuating readings were difficult for some students to decipher. Also, the quality of the contact between the Play-Doh cylinders and the measurement apparatus was often inconsistent. Next semester, we will have one student hold the Play-Doh firmly in contact with the apparatus while his/her teammates take the readings.

The technical result of this experiment was a relationship between either diameter or cross-sectional area and conductance. Many students found the expected linear relationship between cross-sectional area and conductance, but many did not. Poor quality data was one obstacle, and poor data analysis was another. We need to improve the data taking methodology and give more explicit instructions for plotting and analyzing the data.

In the past semesters, the students computed resistance instead of conductance. In Fall 2009, the instructor changed this lab and had the students compute conductance so that the relationships to diameter and area would be quadratic and linear instead of inverse quadratic and inverse linear. This simplified the task significantly at the expense of having to deal with an unfamiliar unit: mho. This change was a net improvement, and we plan to continue using it.

Below are some student questions and the instructor's answers, which were posted while the reports were being written.

> Q: How do I find the area of my Play-Doh cylinders? Would it be 10 cm times the diameter?
> A: The area we need to calculate is the cross sectional area of the Play-Doh. It is the area of a circle with the given diameter. The length (10 cm) is not needed. The area is (pi/4) * diameter * diameter. If you are doing the plot in Excel, it can do the calculation for you. If not, (pi/4) = 0.785. For Excel users, if the diameter is in cell B2, the following formula in any other cell will compute the area. =PI() * B2 * B2 / 4
>
> Q: How would I determine the slope?
> A: To determine the slope, pick two points near the ends of your straight line. The slope is the difference in the y-coordinates (conductance) divided by the difference in the x-coordinates (diameter or area). For example, assume you plotted conductance versus area, and your two points are (area = 0.2, conductance = 25) and (area = 1.0, conductance = 105). Then the slope is (105 - 25) / (1.0 - 0.2) = 80 / 0.8 = 100 milli-mho / cm2.
>
> Q: How should I label the conductance?
> A: The proper label for conductance would be milli-mho if your currents are in milliamperes and your voltages are in volts. For example, if current is 100 mA and voltage is 5 V, the conductance is 20 milli-mho (or 0.020 mho). Don't worry too much about labels. Just use them to help you keep track of what you are doing.

Changes Based on the Assessment

The procedures and results for Lab 1 were quite good. We had several types of toy trucks. Some worked better than others. Next semester, we will get more of the types that worked best and retire the ones that gave inconsistent results. The instructor will expand upon the Excel plotting instructions and specify the contents of the report. This will delay the lab about one week so it will follow the in-class exercise on pendulums. This will give the instructor a chance to demonstrate some of the Excel plotting and data analysis techniques the students will be using.

Overall, Lab 2 did not work as well as Lab 1. Next semester, the instructor will give more explicit instructions for Lab 2, similar to the instructions for Lab 1. The students will make plots of conductance versus diameter and conductance versus area. They will compare the plots and determine which one has a linear shape, and they will find the conductance from the slope of the line.

Conclusion

From a college perspective, the success of Engr 5 has expanded our view of the role of the College of Engineering in General Education. As do many other colleges of engineering, we have several pre-college initiatives aimed at increasing the technological literacy of K-12 students. We believe that these efforts should be supplemented at the university level to promote technological literacy for non-STEM students at SJSU. Because of our location in Silicon Valley, we have the expertise to offer technological literacy courses that could provide all students with a greater understanding of the local high tech industries. As engineers, we have the expertise to base our "science" courses for non-STEM students on the analytical tools and traditions of engineering rather than theoretical science. Because we use hands-on activities in Engr 5, we give non-STEM students the opportunity to creatively problem-solve using electronics and engineering processes. This can demystify engineering for these students and should lead to a higher level of technological literacy.

Students with minimal mathematical skills present the biggest challenge in this class; they are often anxious about the coursework. This is often a problem with engineering GE courses that are designed for non-STEM majors[19 20]. Because many of the students take this class in their first or second semester of college, they do not have, in general, the mathematical skills to explore various functional relationships and search for the linear one as was expected in the labs. The students are generally more comfortable with computer software tools than with abstract mathematics. Therefore, over the four semesters, we have increased the reliance on spreadsheet programs with plotting capability, and we have provided more explicit instruction on their use. This improved student performance on Lab 1 in Fall 2009, and we expect similar results for Lab 2 in Spring 2010. This change has also caused significant improvements in students' course grades (see Figure 6). Students come out of Engr 5 with a good appreciation for the quantitative analytical reasoning techniques of science.

Figure 6. Distribution of student grades for Engr 5 (Fall 2008 to Fall 2009)

	Fall 2008	**Spring 2009**	**Fall 2009**
A+, A, A-	13%	29%	16%
B+, B, B-	37%	14%	48%
C+, C, C-	26%	36%	30%
D+, D, D-	17%	--	--
F, *WU	7%	21%	6%
*WU is an unauthorized withdrawal. For GPA purposes, it is treated as an F			

Our experiences in Engr 5 have taught us how to design courses that address the need for technological literacy among non-engineering students. Because of this positive experience, we are in the process of submitting two additional courses for GE certification in the College. These engineering-based general education courses address our desire to contribute to our university community. As Kelly notes, "the role of engineers in society needs to be discussed in universities beyond engineering programs […] Engineering schools should provide opportunities for the broader university community to understand and appreciate technology."[21]

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