

Incorporating the Impact of Engineering Solutions on Society into Technical Engineering Courses

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ABSTRACT

In the era of market and work-force globalization engineers need a solid understanding of the impact their products have locally as well as globally. This is why the US Accreditation Board for Engineering and Technology recently put a new spin on this requirement in engineering education. Specifically, outcome 3h of Engineering Criteria 2000 states that engineering graduates must have *“the broad education to understand the impact of engineering solutions in a global / societal context”*. This outcome may be one of the most difficult to achieve since it requires not only a strong technical understanding but also an informed societal and historical perspective that is particularly difficult to achieve. This paper identifies some of the skills students need to be able to evaluate the impact of their solutions in a global / societal context as well as methods used by some universities to address this issue outside of technical engineering courses. The main focus of this paper is the introduction of course design elements that help students master these skills that can be incorporated into required and elective engineering courses. Examples are presented from a variety of thermal/fluid courses where these skills are taught in the Mechanical and Aerospace Engineering Department at San Jose State University.

INTRODUCTION

Engineering solutions have always had a major impact on society. In some cases this impact has been clearly positive, such as in the case of house appliances and water purification. In others the impact has been negative, as in the case of bombs with ever-increasing destructive power. In many some cases the impact of engineering products has been both positive and negative, as in the case of the automobile. Engineers usually give the proper attention to the safety and cost of their products, two aspects that impact all users of engineering products and therefore society as a whole. More recently, engineers have also become more sensitive regarding the environmental impact of their products. On the other hand, there have been many cases where the engineers involved in the creation of a particular solution, constrained with a limited view of the situation they were trying to address, were not aware or could not possibly imagine the impact their product would later have on the society as a whole (for example, CFC's which caused destruction of the ozone layer).

In the era of market and work-force globalization engineers need to have a solid understanding of the impact their products will have locally as well as globally so they can make a sound evaluation of the pros and cons. The American Society for Engineering Education expresses the need for this global and societal perspective as follows: *“[E]ngineering colleges must not only provide their graduates with intellectual development and superb technical capabilities, but, following industry's lead, [they] must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental, and international context of their professional activities.”* [1]. Moreover, the US Accreditation Board for Engineering and Technology (ABET) recently put a new spin on this requirement in engineering education.

Specifically, outcome 3h of Engineering Criteria 2000 states that engineering programs must demonstrate their graduates have *“the broad education to understand the impact of engineering solutions in a global / societal context”* [2]. This outcome may be one of the most difficult to truly achieve since it requires not only a strong technical understanding but also an informed societal and historical perspective that is particularly difficult to achieve in curricula with few liberal arts courses.

There are numerous examples of engineering projects that have a major effect on society that illustrate this need. For example, students may work on the design of a dam to provide hydroelectric power. While hydroelectric power results in no pollution or greenhouse gas emissions, students must be encouraged to examine the greater environmental and social ramifications of creating a new dam in a community. For example, people may be displaced and farmland and cultural sites flooded. Negative environmental impacts may include ponding and eutrophication, and the fish population may be adversely affected. On the other hand, new dams may help control flooding. Many articles have recently been published about the expected positive and negative effects of the Three Gorges Dam project on the Yangtze River in China, which is displacing over a million people (See for example [3].)

HOW CAN ENGINEERING PROGRAMS INCORPORATE GLOBAL AND SOCIETAL PERSPECTIVES IN THEIR CURRICULA?

Universities seek to instill these global and societal perspectives into their students through a variety of methods. Worcester Polytechnic Institute has a project-based curriculum. Students must complete three large projects, and 60% of the students complete a project off campus, most often in an international setting. [4] Engineering students at Messiah College may work

on a multi-disciplinary team to complete a culturally-appropriate international engineering project. For example, in their water purification project, students from a variety of disciplines work with a local water company to develop innovative, economical water purification systems for impoverished communities. [5] Students at Calvin College can take a one-month interim course during January. Many of these courses are offered in foreign countries. Some engineering students take the course "Design for the International Market" which is held in several Western European countries. Students' desired course outcomes include discerning cultural differences, cultivating interests in non-technical fields, improving critical thinking, and increasing understanding of global markets. [6]

The College of Engineering at San Jose State University has established a one-million-dollar Global Technology Initiative, whose mission is to give American students a global perspective with a focus on technology and business developments in the Asia-Pacific region. The donors of the initiative are business leaders in the high-technology industry with strong business ties in the Silicon Valley and the Asia-Pacific region. In the inaugural program in 2004, twenty-five students and four faculty members visited a variety of industrial, academic, and cultural sites in China and Taiwan. A second program is planned for 2005. [7]

WHAT KINDS OF SKILLS ARE NEEDED TO EVALUATE THE IMPACT OF ENGINEERING SOLUTIONS IN A GLOBAL / SOCIETAL CONTEXT?

The first task in the design of a curriculum that gives students "*the broad education to understand the impact of engineering solutions in a global / societal context*" is a more precise definition of this understanding. A faculty discussion in the Mechanical and Aerospace Engineering Department at San Jose State University concluded that students have the kind of understanding described in outcome 3h if they are able to do the following:

1. Evaluate and describe accurately the environmental impact of aerospace / mechanical engineering products, including those they have designed in course projects.
2. Evaluate and describe accurately environmental and economic tradeoffs in aerospace / mechanical engineering products, including those they have designed in course projects.
3. Evaluate and describe accurately the health / safety and economic tradeoffs in aerospace / mechanical engineering products, including those they have designed in course projects.
4. Take into consideration the environmental impact when designing aerospace / mechanical engineering products.
5. Take into consideration the health / safety impact when designing aerospace / mechanical engineering products.
6. Speculate on large-scale societal changes that some engineering innovations may cause.

Although this list of skills is by no means exhaustive, it forms a good foundation upon which our faculty could build course elements to address outcome 3h.

COURSE DESIGN ELEMENTS TO ENHANCE UNDERSTANDING OF THE IMPACT OF ENGINEERING SOLUTIONS IN A GLOBAL / SOCIETAL CONTEXT

In order for students to thrive in the highly competitive global economy, it is critical for them to develop international perspectives and knowledge. The best way for students to develop a global or societal perspective is for them to spend time in foreign cultures. However, many students do not have the time or money for such a trip. Additionally, many engineering curricula do not have room for new courses focussed specifically on the goal of fostering students' global awareness. In these cases, this awareness of global and societal issues must be developed in courses throughout the engineering curriculum.

There exist few detailed suggestions of how to integrate these issues into engineering courses. Gunnink and Sanford Bernhardt [8] describe how they have changed civil engineering writing assignments to foster critical thinking and an awareness of global and societal issues. They have altered traditional lab reports in a soil mechanics course to help students think about environmental effects of their designs (among other issues). They have also added short essays to freshman and sophomore level classes asking students to discuss whether or not existing dams on the Snake River be removed and the future implications of the World Trade Center tower collapses on design, construction, and operation of skyscrapers.

Felder and Brent [9] suggest the incorporation of case studies, in-class exercises, and homework problems that involve current global/societal issues. They recommend that discussion of these issues be included as part of all major design projects. Examples of some issues include environmental/economic tradeoffs, movement of production facilities to countries with low-cost labour, and the pros and cons of government regulation of private industry.

The next section explains how mechanical and aerospace engineering professors at San Jose State University incorporate these issues into their thermal/fluids classes. While students must write several papers addressing environmental issues in their technical writing course E100W, the following section gives examples of how these topics can be integrated within technical engineering courses.

A generic assignment designed to address global / societal issues is given in several junior and senior level courses. Students:

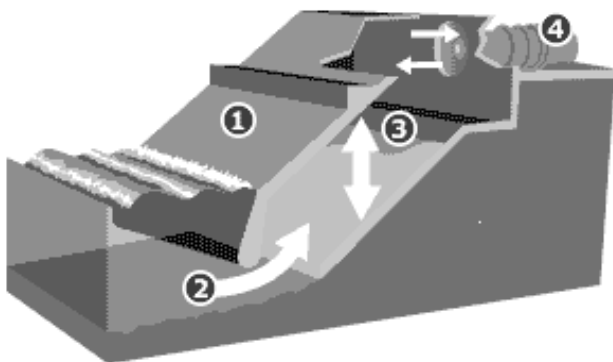
- a. Select a current application or problem related to the course content. They are advised to select a topic that includes not only the technical aspects of an application but also some related global / societal / contemporary issue as a result of the application or the problem. These issues may include one or more of the following: environmental, safety, human health and welfare, political and economic tradeoffs.
- b. Find several references (newspaper, magazine or journal articles) that discuss the application and related issues.
- c. Consult with the instructor and present a detailed (slide-by-slide) outline of their application and related global / societal issues several weeks before they start making their presentations to the class (for major presentations only). This is an important step in the success of this assignment; otherwise students may not have a good grasp of all the issues involved in a particular application.

- d. Write an analysis on the problem / application including the following elements: (i) How does this problem affect our environment or the society in general? (ii) What technical solutions have been proposed recently to address this problem? (iii) Which solution you think works best and why? (iv) What is your solution to the problem? (v) What is the cost involved in implementing these solutions? (vi) What are the economic tradeoffs? In other words, what will be the environmental / societal cost if these solutions are not implemented?
- e. Make a presentation to the class, followed by discussion. Several class meetings or lab sessions are typically dedicated to these presentations and discussions.

A. ME111 Fluid Mechanics

Fluid mechanics is a junior level course required for aerospace, mechanical and civil engineers. In the most recent offerings of the course, the following applications were discussed in the lecture and explored further by the students through their research papers:

- Wave power stations: Oscillating water columns in the world's oceans can be used as a renewable source of energy. In November 2003, the first commercial wave-power station went into service at the Scottish island Islay generating a peak power of 500 kW, enough to run about 400 island homes [10]. A schematic of this station is shown in Figure 1. Some research suggests that less than 0.1% of the renewable energy within the world's oceans could supply more than five times the global demand for energy, if it could be economically harvested [11].



1: Wave capture chamber set into rock face

2: Tidal power forces water into chamber

3: Air alternately compressed and decompressed by oscillating water column

4: Rushes of air drive the turbine, creating power

Figure 1. Schematic of the Islay wave power station [11].

- Hydraulic Hybrid Vehicles: Along the lines of the successful electric hybrid vehicles on the market today, some large US automobile makers are developing hydraulic hybrid vehicles that use the energy normally discarded during deceleration to compress an inert ideal gas such as nitrogen. The compressed gas is then used to generate power to assist the gasoline engine upon acceleration. The increase in fuel economy and ramifications to the environment are discussed.

- Down and drag force in automobiles. The airflow patterns resulting in down and drag force in automobiles are discussed in the context of engineering fuel economy and performance requirements. Down force is achieved through a spoiler that acts as an “upside-down airfoil” and/or the underbody that can result in a venturi-type flow. Down force results in a greater amount of control in sharp corners due to the increased friction on the road surface. Drag force results from skin friction at the surface of the vehicle and pressure drag from any blunt object in the system, such as mirrors, tires, and the car itself. Both forces reduce fuel economy. Although down and drag forces are most heavily optimized in high performance automobiles such as race cars, there are applicable modifications that could be considered for common commuting vehicles.

- Cavitation. Liquid flow patterns that result in pressures below the saturation pressure at that temperature result in cavitating flows. The prediction of the onset of cavitation and its consequences are discussed in the lecture and illustrated by the film, “Cavitation”, produced by the National Science Foundation in the United States. The examples illustrated by the film include damage caused to turbines, pumps, and other turbomachinery; destruction of lift and other desirable forces on hydrofoils, missiles, and other watercraft; and increased cleaning and mixing which is desirable in many industrial and household applications.

Additional topics selected by the students for their research papers included the global impact of waste water, water flow in fire systems, and hydroelectric power generation.

B. ME113 Thermodynamics

The thermodynamics course is favourable for introducing and discussing the global and societal impacts of engineering solutions not only because of the relevance of this topic but also its place in our curriculum. Thermodynamics is a required course for all mechanical and aerospace engineering majors at SJSU. This course is taken at the beginning of the junior year, after the lower division fundamentals have been completed, but before the advanced topics in these areas of specialty have been studied. The students, therefore, have an understanding of the basic analysis techniques and tools used in the field and are poised to not only learn more specific and advanced analysis techniques but also to evaluate issues in a broader context.

Various applications of thermodynamics and their global and societal impacts are discussed in the lectures concurrent with the relevant technical theory throughout the semester. Examples of these applications are listed below.

- Use of CFCs. Chlorofluorocarbon (CFC) compounds used to be commonly used as refrigerants in refrigeration and air-conditioning applications. Upon discovery that CFC's results in destruction of the ozone layer that protects us from harmful ultraviolet radiation, a ban was instituted, and less harmful refrigerants developed, such as R-134a. The Montreal Protocol, which was the initial global meeting to phase out the use of CFC's, is discussed along with temporary problems that arose in Europe when they tried to phase out the use of CFC's on a very fast schedule. Engineering opportunities that have resulted from new

governmental standards are raised in class. Recent measurements have shown that the ozone hole over the polar caps has been decreasing as a result of the ban. Students are tested on this information on an exam.

- Global warming. Global warming is an adverse consequence of an overabundance of carbon dioxide (and other gases) in our atmosphere, which is produced primarily by the burning of hydrocarbon fuels. Products of combustion and their consequences are discussed with the Rankine, Brayton, Otto and diesel power cycles. A technical discussion of radiation reflection and transmission and their dependence on wavelength is presented so that students can understand the reason for global warming. An overview of competing scientific theories about the prevalence of global warming is presented along with scientific and economic challenges that have been raised. The views of the most recent presidential candidates are presented, and in class the students discuss whether or not the United States should sign the Kyoto Protocol, legislating a reduction in these greenhouse gases. Some links giving an overview of the Protocol as well as arguments for and against the United States signing it can be found at [12-14].

Following the class discussion, in recent semesters students were given the assignment of writing a researched memo to the President of the United States advising him whether or not the United States should sign the Kyoto Protocol. The best memo on each side of the issue was read to the class, prompting more discussion.

- Pollution. Air and water pollution is an unfortunate consequence of many industrial applications including energy generation and transportation. Combustion by-products responsible for acid rain and smog are discussed as well as thermal and radiation pollution from nuclear power sources. A photograph documenting the effects of acid rain is shown in Figure 2.

In Spring 2003, the range of topics chosen for the research project discussed earlier included the following:

- Hybrid gasoline-electric vehicles
- Solar energy and solar powered homes/devices
- Fuel cells
- Alternative fuels for automobiles
- Liquification of natural gas
- Diesel engine improvements
- Gas turbine design
- Ultra-high temperature power plants

These issues deal with increase of efficiency and/or the reduction of pollution during power generation.



Figure 2 – A popular photograph showing the effects of acid rain on a statue, original source unknown [15].

For a variation, students may instead be asked to address an environmental/societal issue that is in the news in the area where the students live. In California where San Jose State University is located, the use of MTBE (methyl tertiary-butyl ether) as a fuel additive has been of recent interest. MTBE was added to fuels in the United States in 1979 to replace lead, which was used to prevent engine knock. In 1992, the Clean Air Act required increasing the concentration of MTBE in some fuels to help reduce air pollution due to its oxygenating properties. However, in recent years MTBE has been shown to possibly contaminate drinking water. Some communities in California have shut down some of their primary sources of drinking water following the discovery of increased levels of MTBE [16]. Incorporating issues of local interest can increase student awareness and concern of the effect of engineering solutions on society.

Both of these assignments generated interest and lively discussion during the lectures and gave the students an opportunity to be more creative than on the traditional problem sets and exams.

C. AE162 Aerodynamics

Aerodynamics is a junior level course following fluid mechanics. It is a required course for aerospace engineers and an elective for mechanical engineers. In the most recent offering of the course, students presented the following applications, which bring to light a variety of economic, environmental and safety issues:

- Formation flying: The added lift and reduced drag experienced when airplanes fly in formation can save fuel, boost range, and cut pollution emissions. Flight tests have demonstrated up to 20% drag reduction, resulting in an 18% fuel savings and a 100-130 mile range increase. A 10% reduction in drag on a commercial airliner travelling daily between New York and Los Angeles would translate into a savings of half a million dollars a year per aircraft.

Moreover, emissions of carbon dioxide and nitrous oxide greenhouse gases could be reduced by 10% and 15% respectively [17].

- Laminar flow wings: Laminar flow control promises up to 30% reduction in fuel consumption and is the only aeronautical technology that offers the capability to design a transport that can fly non-stop without refuelling from anywhere in the world to anywhere else in the world and stay aloft without refuelling for 24 hours [18].
- Winglets: Similar benefits to the ones described above have also been demonstrated with winglets (wingtips bent up to reduce vortex drag as shown in Figure 3). Moreover, aircraft with winglets can climb more efficiently, so they can get to their cruise altitudes faster and at lower thrust settings, both of which reduce aircraft fuel consumption and noise footprint, not to mention extended engine life [19]. Better climb performance can also translate into a higher allowable takeoff weight, which means more passengers and cargo, especially on hot days.



Figure 3 – A Boeing 737-700 jet showing the winglets, which provide increased range and improved climb performance [20].

- Wingtip vortices: Flying into the tip vortices of a large transport can cause serious accidents (ex. 1994 crash of USAir flight 427 when it encountered the tip vortices of Delta flight 1083). This problem requires adequate spacing of air transports at busy airports, often causing delays in departures and arrivals. In addition, buildings near busy airports suffer property damage from these vortices (Figure 4). In the Heathrow airport area houses had their roofs damaged by wake vortices, forcing local authorities to spend 5 million pounds to reinforce 2,500 roofs.

D. AE164 Compressible Flow

Compressible flow is a senior-level course, an elective for mechanical engineers and required for aerospace engineers. The following applications are discussed in the lecture and explored further by the students through their research papers:



Figure 4 - Roof damage from airplane tip vortices [21].

- High-Speed Civilian Transports: Students discuss the global warming, ozone depletion and sonic boom effects that may result from a large fleet of hypersonic vehicles, should they become mainstream in the future. They also look into passenger safety, as these vehicles may accelerate/decelerate rapidly and fly at very high speeds in extreme environments. The health risks from atmospheric radiation on passengers and crew at very high altitudes presents an additional concern [22].
- Space tourism: Students discuss current attempts to fly in space for very low cost and the vision to make space tourism affordable in the near future [23]. They also look into high altitude pollution, which may result from a large number of flights into space.



Figure 5 – The White Knight turbojet aircraft with Space Ship One attached to its underbelly. On October 4th 2004, it won the \$10 million Ansari X Prize. The competition challenged independent designers to safely put three people into space twice in two weeks with a reusable spacecraft [24].

- Helicopter noise: Students discover the primary sources of helicopter noise (Figure 6).

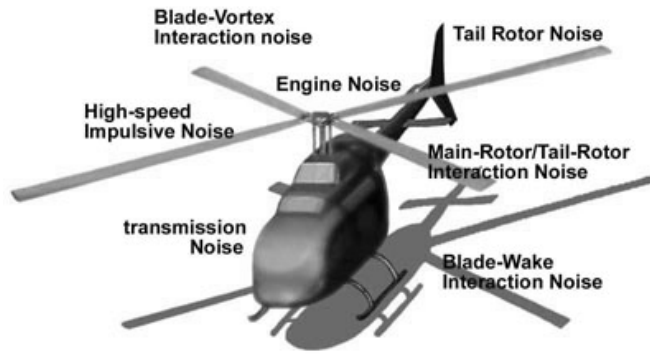


Figure 6 – Sources of helicopter noise [25].

E. AE167 Aerospace Propulsion

Aerospace propulsion is also a senior-level course usually taken in the same semester as AE164. It is a required course for aerospace engineers and an elective for mechanical engineers. The following applications, which bring to light a variety of economic, environmental and safety issues, are discussed in the lecture and explored further by the students through their research papers:

- Fuel consumption and pollution: Students explore the differences in fuel consumption, emissions, and noise pollution between the different propulsion systems used in aerospace vehicles, from reciprocating engine / propeller combinations, turboprop, turboshaft, turbojet, turbofan, unducted fan, propfan, ramjet and scramjet all the way to rocket engines.
- Engine noise: Jet engines are the primary source of noise during takeoff and landing. Most of this noise comes from the turbomachinery inside the engine (fan, compressor and turbine). However, in the high-speed transports of the future, additional noise will come from shock waves at the inlet and the exhaust. Students explore different ways to design engine components for reduced noise as well as to lower the exhaust velocities by cooling the gases with surrounding air.

F. AE170 Aircraft Design

AE170A&B is a two-semester senior design, capstone experience. In the first semester, students design full-size airplanes. In the second semester, they design, build and fly remotely controlled (RC) or autonomous airplanes for a specific mission. One or more teams participate in the International Society of Automotive Engineers (SAE) heavy-lift Aero Design West competition [26]. In addition to the technical aspects, students are required to address the following issues in their proposed designs:

- Economic / political issues: The first design report describes the mission specification for their proposed airplane and includes a comparative study of airplanes with similar mission requirements. Students also discuss the motivation for their proposal. For example, if they propose a civil transport, they discuss the possible market for this new airplane. If they propose a military airplane they discuss the national defense requirements or other political reasons which may dictate a new airplane design.

Moreover, they discuss the technical and economic feasibility of their airplane. For example, can it be manufactured with off-the-shelf components or will it require the development of new technologies? If the technologies are already available, is the cost to implement them acceptable? Two publications, which help the students address these issues include *Aviation Week & Space Technology* and *Flight International*.

- Environmental and safety issues: In their final design reports students discuss environmental and safety issues related to their proposed airplane designs and the cost involved in implementing any design solutions that alleviate environmental or safety problems. These issues may include air and noise pollution, including sonic boom for supersonic airplanes, energy consumption, controlled flight into terrain, pilot decision-making, weather, loss of control, survivability, and runway incursions. Again, students are required to use and cite several references.

In addition, each student makes a class presentation on a current global / societal issue related to airplane design. For example, the following topics were presented in academic year 2003-2004:

- Safety aspects of very large air transports (VLA): A new generation of VLA weighing more than one million pounds will soon begin service (Airbus A380 will have a takeoff weight over 1.2 million pounds and the stretched version of Boeing's 747X will be close to this number). These aircraft present additional challenges, such as more powerful wingtip vortices and their associated problems discussed earlier, difficulties in ground manoeuvring and emergency evacuations. For example, can passengers from the upper deck be evacuated in 90 seconds [27]?
- Airport expansion and redesign to accommodate VLA: Students explored the environmental and economic impact of all the modifications needed to accommodate VLA. Although allowing the airplanes to oversteer (by design) is one way to help VLA pilots turn on the ground, fillets – edging at runway / taxiway intersections – may have to be added to keep the main landing gear from rolling off the paved surface. Moreover, runways have to be expanded, and obstacle-free zones for balked landings must be provided. These modifications could cost millions of dollars in construction costs to airports [27].



Figure 6 – An Airbus 380 (mock-up) at the gate. Note the relative size of the Boeing 747s [28].

- Airplane design to guard against possible terrorist attacks: In light of recent attacks on civilian airplanes with

shoulder-fired missiles, students presented and discussed ideas on how to incorporate safety features to guard air transports against such attacks [29].

- Fuel dumping: Many air transports are designed with a landing weight much lower than the takeoff weight. The reason behind this practice is to reduce landing gear weight. However, should an emergency occur immediately after takeoff forcing the pilot to return for landing, several thousands of gallons of fuel must be dumped, usually in residential areas, in order to reduce the weight for a safe landing.
- The promise of new generation, single-engine airplanes to provide safe and economic air transport.
- Environmental effects of de-icing fluids and run-off pollution from airports.

G. ME182 Thermal Systems Design

At SJSU, mechanical engineering students must choose a design course in one of three areas. ME182 is the “capstone” course in the thermal / fluids option. Each student in this course must make a 20 minute presentation on an alternative source of power or a particular method of energy conservation. No two students are allowed to address the same topic.

The presentations must address the following issues, as appropriate:

- An overview of the technology
- How the technology works
- Where it currently is used
- Potential new applications
- Any obstacles in the way of wide-spread utilization
- Issues relating to human health and welfare, society, politics, economics, and the environment
- Summary discussion their views on the future potential of the technology

Early feedback given to the students based on their detailed outlines shows that many students must be encouraged to pay increased attention to issues relating to society, politics and economics (although a truly complex evaluation cannot be undertaken in 20 minutes). With this early feedback, the presentations in ME 182 have been excellent. Typical topics and issues for this course include ocean thermal energy conversion (OTEC), fuel cells, the future potential of nuclear fusion, biomass, hybrid vehicles, solar and wind power, and power sources for microsystems.

The final exam in this course is worth only 10% of the final grade. Half of the final exam is based upon the student presentations, which forces the students to pay as much attention as to a standard lecture. The Powerpoint presentations are also uploaded onto the course website. In a recent course offering, the questions on the final exam related to these presentations were split into two sections. The first, worth 34 points (out of an exam total of 100), included factual questions only. The second, worth 16 points, required an essay answer to the question, “Of the alternative fuel technologies discussed in class, which do you believe will have the greatest effect on our society in the next 50 years? What major obstacles must be overcome? Support your answer.” The average score on the factual questions was a 74% while that number rose to 89% for

the essay. The most common weakness on the essays was the lack of sufficient support for their conclusions. Fuel cell technology was most commonly chosen by the students for their essay.

CONCLUSION AND FUTURE WORK

Universities have used a variety of methods to instill in their engineering students an awareness of the global and societal effects of their designs. These methods range from encouraging students to complete some courses or projects in foreign countries to requiring separate courses devoted to this topic. This paper presented examples of how the faculty members in the Mechanical and Aerospace Engineering Department at San Jose State University have attempted to educate students in this area by incorporating lectures and assignments throughout their courses. Needless to say, there is still more work that needs to be done to assess student understanding of the impact of engineering solutions on society, and in particular, to increase their sensitivity to environmental, safety, political and economic issues as they come into play in the design of engineering products.

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