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Public Policy and Engineering Design Education*

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Both the ABET 'Conventional Criteria' and 'Engineering Criteria-2000' require engineering design education to include considerations such as the environmental, health, safety, ethical, social, and political impact of engineering design. This paper focuses on public policy as a proposed umbrella framework for consideration of these issues, and advances three propositions. First, that the public policy process has a lot in common with the engineering design process; second, that engineering design activities are becoming increasingly entwined with public policy considerations; and third, there are a wide variety of practical approaches to incorporating public policy considerations into engineering design education. The paper begins with well-known models of the engineering design process and the public policy process to establish the similarities between the two. In addition, several popular myths regarding the relationship between these two processes and their practitioners are explored. Next, the paper enumerates different classes of public policy activities engaged in by federal, state, and municipal governments that have implications for engineering design decisions. Included are generic issues such as: environmental, health, and safety regulations; professional licensing and registration; government support for basic and applied research, development, and exploration; defense weapons and other government procurement activities; patent and other policies to support technological development; and government collection, analysis, and dissemination of technical information and data. The third (and primary) part of the paper describes many ways in which public policy issues can be introduced as an integral and logical part of design education, rather than being perceived by either the students or teachers as diversions. This includes lecture and classroom discussion topics and activities, case studies, homework assignments, in-class and take-home quizzes and exams, mini-design projects that extend from one class-session to several weeks in length, and capstone design projects. Also, web-based and other resources on public policy for design instructors and students are described.

INTRODUCTION

BOTH THE ABET Conventional Criteria and Engineering Criteria–2000 require engineering design education to include considerations such as the environmental, health, safety, ethical, social, and political impact of engineering design [1]. This paper offers public policy as an umbrella framework for considering these issues, and advances three propositions:

1. The public policy process has a lot in common with the engineering design process.
2. Engineering design activities are becoming increasingly entwined with public policy considerations.
3. There are a wide variety of practical approaches to incorporating public policy considerations into engineering design education.

We begin by exploring several popular myths regarding the relationship between engineering design and public policy. Next, we argue that incorporating public policy criteria into engineering design is a logical continuation of an existing trend, rather than a radical departure from tradition. Then we enumerate different classes of public policy activities that have implications for engineering design decisions. After that we describe many ways in which public policy issues can be integrated into design education, rather than being treated by either the students or teachers as ancillary activities or diversions. We conclude by arguing that inclusion of public policy issues should be done in an intellectually rigorous fashion and that proper preparation for doing so implies serious examination of the humanities and social science stems of the engineering curriculum.

THE ENGINEERING DESIGN PROCESS

The Accreditation Board for Engineering and Technology (ABET) defines engineering design as [2]:

> Engineering design is the process of designing a system, component or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

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ABET describes the nature of the design element of the engineering curriculum as follows [3]:

> The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

Most of ABET's 'realistic' constraints establish a basis for the engineering/public policy connection. Further, ABET states that while engineering design relies on mathematical and scientific analysis, it is also a creative art that includes many subjective considerations. This may seem contrary to the engineering image of cold, hard, objective analysis. Actually, engineers have to do both; good engineering design has been described as a form of controlled schizophrenia—alternating during different stages of the design process between left-brain (analytic) and right-brain (creative) modes of thought [4]. We reinforce this characterization by exploring several myths regarding the relationship between engineering design and public policy [5].

Myth A: Engineering design and public policy are fundamentally different processes

Figure 1 displays well-known models of both processes, each extracted from their respective specialized literature [6, 7]. At first glance, the similarity between the two models is quite remarkable. Upon reflection, what is really remarkable is that most engineers and policymakers do not recognize this close resemblance.

Figure 1 stimulates us to replace a few choice words in the ABET definition of design and transform it into a definition of public policy that many policymakers might be quite comfortable with:

> Engineering design Public policymaking is the process of designing a system, component or process to meet desired needs. It is a decision-making process (often iterative), in which the basic social sciences, mathematicslaw, and engineering sciences design concepts are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design policy process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. Central to the process are the essential and complementary roles of synthesis and analysis.

Myth B: Design engineers are unbiased while policymakers represent special interests

Design engineers have their own biases and special interests. Figure 2 shows eight different versions of a proposed airplane design, each one

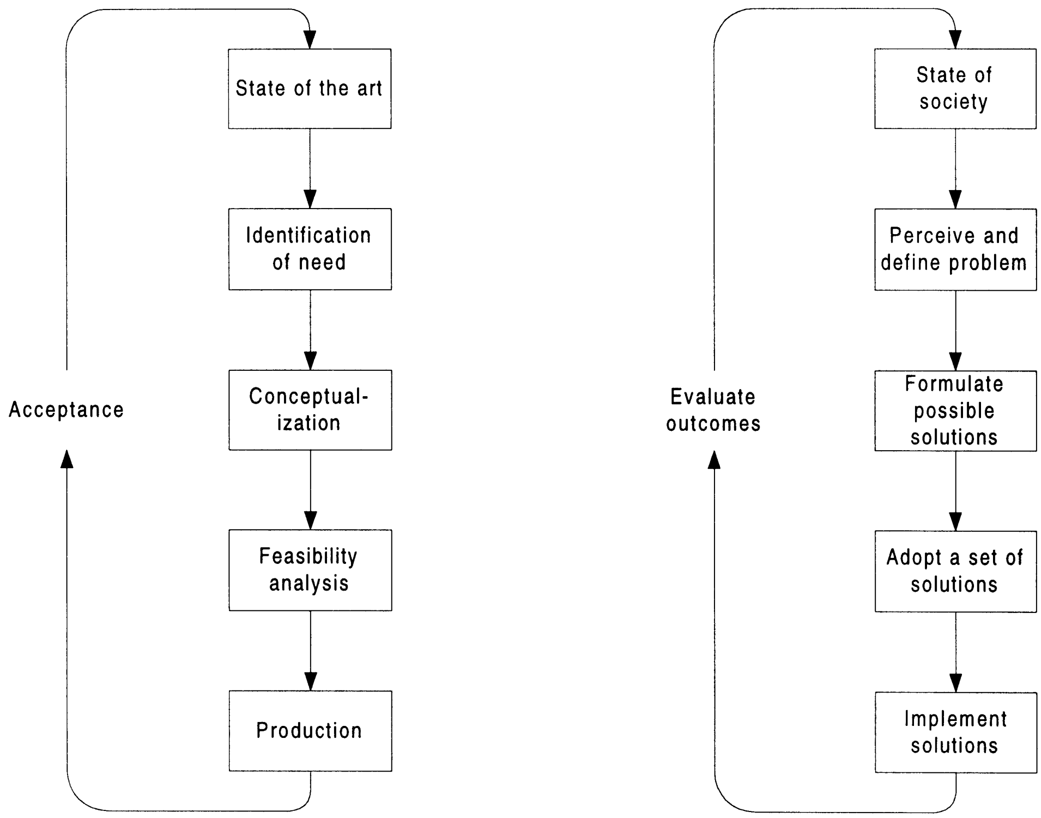

Fig. 1. Models of the engineering design and public policy processes.

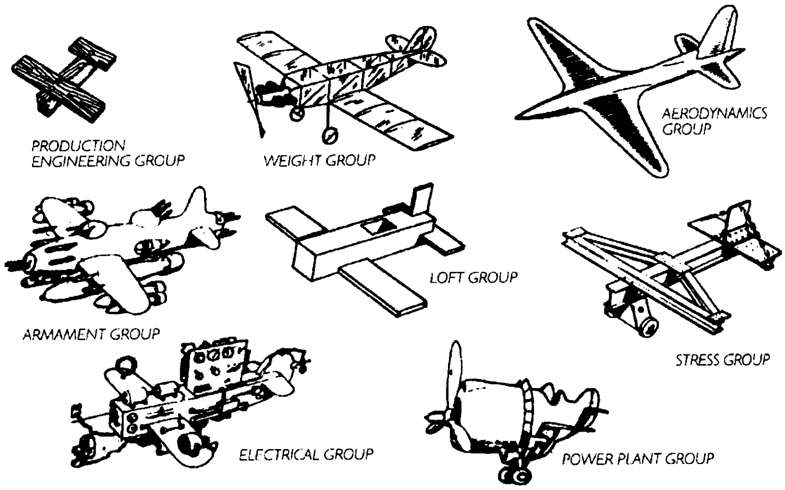

Fig. 2. Aircraft design by special interest groups of engineers.

representing what the plane would look like if it were designed by: an aerodynamics engineer, a structural engineer, a propulsion engineer, etc. [8].

The cartoon's depiction of the vastly different concepts of airplane design only slightly exaggerates the reality that design engineers are the ultimate special interests. Design engineers, like all people, approach problems from a perspective derived from their own experience and expertise. Each tends to value their own knowledge and believes that their own specialty is important. The debates among engineers within a given project or between competing projects can be as lively and as emotional as those between members of Congress who bring strong differences in political ideology to their debates. But like members of Congress, each specialized design engineer knows that 'the plane will never fly' unless they are willing to compromise with their colleagues who see the same design problem from a different perspective. Successful engineering design, like successful public policy, is the art of the possible.

NEW CRITERIA FOR ENGINEERING DESIGN

We now explore the incorporation of social criteria into engineering design as the logical continuation of an existing trend. We also discuss the new skills required of engineers in order to obtain creative design solutions in light of these changes [9].

From the earliest applications of technology, engineers have had one criterion by which to evaluate a design: did it meet the need? An 'engineer' craftsman designing a water wheel or a grindstone for oxen to turn was interested only in getting the device to work. With advancing technology and the rise of engineering schools in the 19th century with analytically oriented engineering curricula, a new criterion emerged: the design should be arrived at systematically. This new criterion required new skills of engineers (mathematics and science) in order to find acceptable design solutions. The new criterion did not require a sacrifice of the old criterion or of the old skills of creativity and imagination; it just added a new one on top of the old.

Engineering design criteria expanded again when economics began to explicitly affect design decisions in the late 19th century [10]. Economic criteria are now an integral part of modern engineering design and good contemporary design is not just the 'technically best', but the best at a given cost. For example, a relatively straightforward application of engineering techniques allows an engineer to specify the wall thickness needed in a pipe to withstand a given internal pressure. But the ready availability of low cost piping in standard stock sizes provides the engineer with the choice between low cost piping that is stronger than it needs to be and piping of exactly the required strength but which is more expensive since it must be custom made.

This evolution of engineering design criteria from purely technical considerations to include economics did not require any slighting of the technical criteria. The latter still had to be satisfied, but engineers had to acquire new skills in cost analysis in order to generate creative engineering designs that met these broader criteria.

Thus, it is not unusual for new design criteria to evolve from changes in the social environment within which engineers operates. In the last several decades, vastly increased public sensitivity to the impacts of technology has fostered the concept that engineering should consider societal concerns as part of the design process. Many of these social concerns have been articulated as public policy decisions that have become engineering design criteria. Such criteria are embodied in numerous federal, state, and municipal statutes and regulations such as energy efficiency regulations, worker safety standards, building codes, and limits on environmental emissions. In some cases, these criteria take the form of specific design requirements, such as those that require automobiles to achieve a minimum fuel economy. Other socially driven design criteria are derived from court decisions, especially in the area of product safety and professional liability. These criteria, while less prescriptive, hold engineers responsible and financially liable for design decisions that cause personal injuries and property damage.

As was the case with the earlier incorporation of technical and economic design criteria, engineers must understand engineering design criteria that are the result of public policy decisions. And without any diminution of their technical talents, engineers must develop the additional skills needed to exercise design judgments that satisfy these new criteria.

CATEGORIES OF PUBLIC POLICY/ ENGINEERING DESIGN INTERACTION

Here we describe seven generic classes of public policy activities that have implications for engineering design decisions. This typology is offered as a mechanism for structuring efforts to incorporate social criteria into design education.

Regulations and standards

Many engineering designs must satisfy environmental, health, and occupational, public, and consumer product safety regulations. Examples are emission standards for cars, safety guards for industrial machinery, and impact resistance requirements for bicycle helmets.

Technology innovation policy

Article 1, Section 8 of the US Constitution is the basis for a federal patent system that has successfully stimulated technological innovation. Engineers clearly embrace the system as a crucial mechanism for protecting design concepts embodied in patented devices. The Bayh-Dole Act of 1980 allowed universities and other institutions conducting federally funded research to secure patent rights and retain licensing royalties. Companion legislation, known as the Stevenson-Wydler Act, established technology transfer missions for federal laboratories. Both laws have had major impacts on fostering technological innovation and represent recent refinements of patent policy that began over 200 years ago.

The patent system is also a valuable source of design ideas and a tool for reducing the need to 'start from scratch' or to 're-invent the wheel' in the early stages of the design process.

Research and development

Executive branch agencies of the federal government operate some of the best engineering research laboratories in the world, such as the civilian laboratories operated by NASA and NIST, and the military laboratories such as the Naval Research Lab. Similar activates occur at the world-renowned national laboratories such as those at Argonne, Brookhaven, and Oak Ridge. In addition, many government agencies support research and development projects within academia and industry via an extensive system of grants and contracts. The governmental R & D mission has a significant impact on engineering design by ensuring a continuous flow of new knowledge and technologies for use in design activities.

Procurement

The federal government is the sole customer for most military weapons and space systems. Thus, it has an enormous impact on this segment of the engineering design profession. Public policy to fund design and construction of vehicles such as the Stealth fighter-plane, the Space Shuttle, and the Osprey tilt-rotor aircraft has a huge influence on engineering design decisions that push the envelope of technological capabilities. But government's influence is not limited to defense weapons and aerospace systems. Many local, state, and federal agencies have adopted policies to purchase products that are more environmentally friendly. Because government agencies are large customers in many markets (e.g., copy paper), government specifications for those products (e.g., minimum % recycled fiber in copy paper) have a big effect on the design of those products.

Incentives and subsidies

Public policy has been used historically to provide direct support for the development of engineered systems that are perceived to be in the public interest. The commercial success of Robert Fulton's steamboat would not have been achieved without the help of the New York State Legislature which granted Fulton exclusive rights for 20 years to operate steamboats on the Hudson River and other New York waterways [11]. Another example of a product of public policy is the civilian nuclear power industry in this country. When utilities resisted federal pressure to build nuclear power plants, the government passed the Price-Andersen Act in 1957 that capped utilities' liability in the event of a major nuclear accident. Price-Andersen made commercial nuclear energy possible in this country [12].

Analysis and dissemination of technical information

Government agencies analyze and disseminate a wide range of technical information. This includes the US Census Bureau and other units of the US Dept. of Commerce that publish detailed data on manufacturing activities. In another arena, the Environmental Protection Agency and the Department of Energy publish key data on energy consumption and environmental emissions, including the characteristics of energy conversion and pollution control equipment. Many engineering design decisions rely on this information.

Regulating the practice of engineering

Public policy also addresses issues of professional competency and behavior of engineers through professional licensing and regulations. All 50 states, the District of Columbia, and the US territories of Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands have engineering licensing boards. In addition, many states have enacted codes of ethics for licensed professional engineers.

INTEGRATION INTO ENGINEERING DESIGN EDUCATION

ABET requires that engineering curricula involve students in design problems that incorporate social criteria. In order for such efforts to be successful, public policy considerations need to be integrated into engineering curricula, not just tacked on as adjuncts in order to satisfy a social-sciences requirement. ABET provides a boost for an integrated approach by requiring that all engineering curricula culminate '. . . in a major design experience . . . that include(s) most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political' [13]. Here are examples from my teaching experiences of design activities that accomplish this integration. Included are capstone design projects, pre-capstone design projects that last several weeks, and homework and test questions.

Capstone design projects

Over the past 15 years, I have had many engineers from public institutions serve as clients for capstone projects, including engineers from Bonneville Power Administration, Seattle City Light, Seattle Dept. of Engineering, Snohomish County Public Utility District, Tacoma Public Utilities, Washington State Energy Office, and the Washington State Ferry System. This is a logical extension of the widely accepted practice of using industry-based engineers as clients for capstone projects. It is also very easy to implement, requiring only an expansion of the network of potential clients. Using government engineers and their agencies in this capacity automatically integrates a public policy element into the capstone design experience.

Short design projects

Part of the preparation for the ABET culminating design experience can be short design projects conducted within an introductory design or analysis course. Here, from my own teaching experience, are three examples of such design projects that incorporate public policy issues.

The first example asks students to design a refrigerated container for shipping perishable food products using dry ice as the refrigerant. The engineering science component of this project involves elementary thermodynamics and heat transfer. The economic component involves a life cycle cost analysis for different foods and insulation levels. The public policy component involves utilizing the design criteria embodied in an existing multinational treaty. Understanding the treaty and the social forces that led to it (reconstruction of Europe after World War II) raises students' awareness that no infrastructure exists in developing countries for maintenance and repair of refrigeration equipment, so the 'low tech' option of dry ice is particularly appropriate for those markets.

A second project involves designing a mile-long pipeline to deliver refinery waste-gas to a reprocessing facility. The engineering science component of this project involves elementary fluid mechanics and strength of materials. In one variation, I also include probabilistic considerations. The public policy component enters because the pipeline has to traverse a public thoroughfare. That means the pipeline design has to satisfy certain federal safety regulations. In the course of examining the federal requirements, the students learn that the federal regulation requires the pipeline be made of materials that meet ASTM standards. After chasing down the ASTM specifications, the students discover that commercially available pipe sizes are prescribed by an ASME standard. So in the course of doing a legitimate design problem, the students gain insight into the standards and regulatory system, and particularly the partnership between government and the engineering community in the standards arena.

My third project example involves assessing the merits of three competing desktop fans being considered for purchase by the General Services Administration (GSA), the centralized purchasing agent for the federal government. The students are told that GSA has decided to purchase 5,000,000 oscillating desk fans for use in federal offices, and it wants to include ease of recycling as an important element in deciding which fan to purchase. GSA has narrowed the choice down to fans produced by three different companies. The students' assignment is to evaluate the three options in terms of their relative suitability for recycling. This is a project dissection activity incorporating several elements of design methodology including functional analysis, formulating criteria to measure 'recyclability', and using decision analysis techniques to identify the best option. The public policy component consists of learning about the government's procurement practices and its capability, via its market presence, to encourage certain design practices via the way it writes its procurement specifications.

Homework assignments and test questions

Below is an assortment of questions I have used in a pre-capstone design course. They are designed to address the generic categories of public policy/design interaction described in the previous section:

- Identify three agencies of the federal government whose primary responsibility is safety. Briefly describe the mission of each.
- What is the most recent federal regulatory activity dealing with bicycle helmets?
- Under the Americans with Disabilities Act, many regulations have been adopted to make buildings and facilities more accessible to individuals in wheelchairs. According to those federal regulations, what is the minimum ground space required to accommodate a single stationary wheel chair in a building or facility?
- You are designing a ventilation system for a new 30,000 ft^2 general-purpose warehouse to be in conformance with the State Energy Code. How much outdoor air (ft^3/min) must your ventilation system be capable of delivering to the interior of the warehouse?
- As part of your design efforts for an improved automobile bumper, you are considering using an inexpensive, easily replaced, crushable honeycomb structure to absorb the impact of low-speed collisions. Before going any further, you decide to conduct a patent search:
  a) Using the Index to the US Patent Classification System, what classes and subclasses appear to be the most appropriate for your search?
  b) Use the Manual of Classifications to refine the list of classes and subclasses developed in part (a). What is your refined list?
  c) Select one of the class/subclass categories from part (b) and use CASSIS to search for all patents in that category. How many patents are on that list?
  d) Using the results of part (c), what is the patent number and title of one patent on that list?
  e) Use the Patent Office Gazette to find the abstract of the selected patent. Provide a copy of the appropriate page(s) from the Gazette that contains information on that patent.
- You are designing new energy-efficient equipment for manufacturing glass jars and bottles. In order to assess the potential environmental benefits of your design, you decide to consult the Annual Survey of Manufactures (ASM) published by the US Census Bureau. According to the latest available ASM, how much electricity was used nationwide to produce glass jars and bottles in the most recent year for which the data is available?
- Should all engineering professors be required to have a PE license? Explain.
- Compare the language in the ABET Code of Ethics with the Rules of Conduct required of all registered professional engineers in your state.

RESOURCES FOR LEARNING ABOUT ENGINEERING DESIGN AND PUBLIC POLICY

In this section, we describe several readily accessible resources to help engineering faculty add a public policy dimension to their design instruction activities.

WISE

The Washington Internships for Students of Engineering (WISE) is a highly visible summer academic program in engineering and public policy in Washington, DC. Nation-wide competitions are held annually for both the Faculty-Member-in-Residence and the 15 undergraduate engineering student participants. Its four main objectives are [14]:

1. Increase understanding of the public policy process among future leaders of the engineering profession.
2. Sensitize large numbers of engineering professionals, faculty and students to the relationship between engineering and public policy.
3. Improve the visibility and strengthen the image of the engineering profession among key public decision-makers.
4. Supplement the public policy activities of the engineering societies.

In the 1980's, each WISE student produced, under guidance of the Faculty-Member-in-Residence, an engineering and public policy case study for use in engineering courses. Seven of these cases were peer-reviewed and are available (with Instructor's Guides) through the Engineering Case Library administered jointly by the American Society for Engineering Education (ASEE) and Rose-Hulman Institute of Technology [15–22]. Drafts of eleven WISE cases were also class-tested in engineering courses on eight campuses. Analysis of the student responses to their use showed that the cases were very effective in sensitizing engineering students to the public policy aspects of engineering [23].

More recently, each WISE student prepares a policy analysis paper on a topic of interest to his/her sponsoring professional engineering society. Those papers are published in an electronic journal linked to the WISE website. Recent examples include papers on reform of military specifications and standards [24], commercialization of fuel cells [25], and licensing of low-power FM radio stations [26].

Because each of these cases and policy papers are authored by undergraduate engineering students with guidance from a professional engineering society, and reviewed by an engineering faculty member, they have a high degree of credibility with engineering students and faculty. They can serve as a focused entryway for discussion or design activities on a wide variety of technical topics that are intertwined with public policy issues. For example, the refrigerated food container short design project described earlier is drawn from an unpublished WISE case.

WISE links

The WISE website also contains links to the government relations sites of seven of the engineering societies that currently participate in WISE (AAES, AICHE, ANS, ASCE, ASME, IEEE, NSPE). Thus, it is easy for both students and faculty to identify the public policy issues of concern to the various engineering disciplines. Many of the societies have already taken positions, or are in the process of formulating positions, on these issues. These materials can serve as a further stimulus for classroom discussion and design activity.

In addition, many links are provided to various legislative and executive branch agencies and information resources that provide lots of grist for the design mill. For example, the May 2, 2001 lead story on the NASA homepage (www.nasa.gov) describes the new space shuttle main engines that eliminate welds by using a casting process for the housing, and contain an integral shaft/disk with thin-wall blades and ceramic bearings.

ASME WEB module

ASME is currently developing a web-based educational module designed to expose engineering students to the interface between engineering and public policy. The module will include case studies that illustrate governmental structure and processes used in policymaking, emphasizing the roles of engineers and engineering professional societies in public policy. While still in its early stages of development, this tool has significant potential value for integrating public policy considerations into design education.

Websites on engineering ethics

Given inclusion of codes of ethics into engineering licensing laws and regulations, the topic of engineering ethics naturally falls under the public policy umbrella. Two online resources are the websites for the National Institute of Engineering Ethics (www.niee.org) and the Online Ethics Center for Engineering and Science (http://onlineethics.org). These both contain a wealth of materials, including case studies and suggestions for teaching activities.

Popular media

Finally, popular media regularly cover new technological developments and events that have a public policy dimension. I first heard about the Bellingham pipeline explosion from the morning paper. Similarly, with the recent announcement of the Boeing sonic cruiser airplane concept. (Commercial aircraft design is one of the most highly regulated of all engineering design activities via the FAA certification process.) Since most popular media have websites with more details and related links, they are a convenient way to demonstrate to students the social significance of engineering design decisions.

CONCLUDING REMARKS

Many engineering faculty members do not have both the background and motivation to fulfill the ABET mandate to incorporate social criteria into engineering design education. Hopefully, the approach described in this paper of collecting these criteria under the umbrella of public policy provides a focus and framework for such efforts. In addition, the resources described above can facilitate the integration process, simplifying the task for individual faculty members, curriculum planning committees, and students.

The broad-based integrated treatment of social criteria in the culminating design experience cannot be meaningful if it is the first exposure students have to most of ABET's enumerated considerations. A capstone course should provide students the opportunity to synthesize the tools and skills previously learned. Most engineering faculty wouldn't dare suggest using a capstone design course to first introduce the concept of a vector cross-product. Issues of safety, ethics, environmental impact, etc., also deserve respect as legitimate fields of intellectual inquiry. To believe that engineering students can learn these fields on the fly during a capstone project is at best naive, and at worst, extremely arrogant. A good faith effort to meet this new ABET requirement requires many engineering schools to re-examine the humanities and social sciences stems of their curriculum. In the same way we currently require students to first study math and science in order to do engineering science, we may someday establish courses in ethics, sustainability, and political science as prerequisites for doing engineering design.

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