2006-1046: PUBLIC POLICY AND ENGINEERING DESIGN: A CREATIVE PARTNERSHIP IN ENGINEERING EDUCATION

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Public Policy and Engineering Design: A Creative Partnership in Engineering Education

1 Introduction

A 2004 study by the National Academy of Engineering (NAE) addressed the nation's need for rising engineering leadership in policy formation by the year 2020. The NAE justified its argument by citing the growing role of technology in society. As a result, engineers will need to play strong roles in creating and administering public policy.[1] Current engineering curricula, however, provide little preparation for engineering students to provide this essential leadership. Knowledge is divided into distinct "disciplines" which constrain the ability to address complex real-world problems. Engineering professors, with little public policy experience, emphasize the technical aspects of their subjects without examining the social implications of the technology. The NAE followed its 2004 publication with an education-specific document emphasizing a shift in both materials and methods presented in a more interactive and interdisciplinary approach.[2]

This paper describes the efforts of the School of Engineering and Applied Science (SEAS) at the University of Virginia (UVa) to meet the need called for in these NAE reports and prepare students to understand and participate in the public policy process. The approach emphasizes the potential for engineering design to inform the development of public policies. One of the authors of this paper (Tramba) was a student participant in the activities discussed here, addressing the need for affordable, energy-efficient housing and the necessity to coordinate public policy development with engineering design in order to reach major societal goals. Home-energy efficiency and her particular role in projects related to it serve as case studies in effective policy-design integration.

2 Political Applications of Engineering

In an increasingly technology-driven society, engineers are needed for an increasingly wide variety of decision-making roles. This is particularly true in the public policy sector where a growing number of sound decisions require an understanding of technological capabilities, limitations, costs, and collateral impacts. Without collaboration, the scientific and government communities may exist as "two disparate worlds,"[3] promoting conflicting or counterproductive policies and regulations. For example, in the construction industry, the enormous impact of buildings on national energy consumption, environmental health, and human safety has brought scientific knowledge and design practices to the fore. Emerging materials and systems may improve quality of life and reduce both cost and environmental impacts of new and existing construction. In contrast, outdated building codes may inhibit the spread of new technologies, to the detriment of owners, occupants, and industries. As a result, policy planners and building code writers must be informed of advanced design capabilities, and designers working on building projects should have meaningful backgrounds in public policy.

Engineering is an "applied science," making it particularly relevant to the policy-making process. In the building industry, government programs supporting affordable and energy-efficient housing must rely on engineering improvements in methods. The U.S. Department of Housing and Urban Development (HUD) supports the Partnership for Advancing Technology in Housing

(PATH), a program that implements systems engineering methodologies.[4] Developing a relationship between engineering design and public policy serves the public interest and business opportunities, and provides significant opportunities for improving engineering education.

3 Current Engineering Education Practices

Engineering is primarily taught using the 'engineering science' model, consisting of loosely-connected lecture courses dealing with technical subjects germane to the respective disciplines. Knowledge is transmitted in narrow specialized units: the NAE states, "Students are still largely assigned to and educated in a single department, and, as engineering disciplines have proliferated … clearly delineated specialties within those subdisciplines have evolved."[5] Graduates and employers frequently discover that this academic background has not prepared students well with some skills needed for the interdisciplinary, collaborative, and cost-driven environment of the professional engineer.[6] Engineering design projects can bridge this gap between theory and reality and develop both analytical skills taught in lecture and professional skills such as communication, interdisciplinary teamwork, creative, open-ended problem solving, and ethical evaluation. These latter skills are difficult, if not impossible, to impart by lecture; rather, they require an active learning approach in which the student develops the required habits in the context of engineering practice.

Practical design, product development, and project management skills require a synthesis of knowledge from engineering, business, and humanistic disciplines. Too often, research-based academic settings do not integrate these practices effectively to communicate the societal impact of technology. Undergraduate engineering students study humanities and social science in required classes that do not relate the humanities to relevant engineering applications. As an example, an economics class might discuss the effects of rising oil prices, but generally will not expound on the technical ways in which builders can reduce home-energy use and costs. Still, engineering graduates enter professional worlds where success depends upon critical judgment informed by an understanding of the interactions among technology, the economy, and society. Leadership in engineering, business, government, and society at large increasingly depends upon an understanding of the context and consequences of technological development.

4 Engineering in Context Educational Methods

Calls to better address such "contextual" issues in engineering education are not new. In 1989, an MIT Commission on Industrial Productivity singled out curricular reform in higher education as one key to arresting the nation's declining industrial competitiveness. The Commission called for the creation of a new cadre of students and faculty that function in interdisciplinary teams to apply practical knowledge to actual problems.[7] In the Fall of 1993, an American Society for Engineering Education (ASEE) task force of engineering deans and industry leaders observed that social conditions limit engineering design more than technological considerations do.[8] Three years later, in 1996, the IEEE Spectrum convened an "Employment Roundtable," concluding that the "non-engineering context" plays heavily into engineers' careers and that they must actively participate in decision-making processes.[9]

In spite of these and many other admonitions, engineering instruction has changed slowly. Course and curriculum integration such as that initiated at Drexel University almost 15 years ago remain isolated examples.[10] Extensive research shows the ineffectiveness of the lecture method of instruction. The noted engineering educator Richard Felder noted, "Of all instructional methods, lecturing is the most common, the easiest, and the least effective." However the delivery of engineering education continues in discrete, specialized modules by individual instructors in a lecture-based format.[11] In particular, studies of engineering analysis and design continue to occupy a separate world from the consideration of "contextual issues" such as social and environmental impacts, ethics, regulatory, and economic considerations. Although more than 30 percent of all engineers now occupy managerial positions in industry and government, undergraduate engineering education poorly prepares them for these leadership challenges.[12] For many years, engineering programs have acknowledged the importance of a liberal component in the education of engineers, but in practice that component has usually led to students taking courses with no apparent relevance to the major technical component of their curriculum.[13]

The Accreditation Board for Engineering and Technology (ABET) has led initiatives pushing engineering programs to incorporate ethical, communication, and other contextual issues into engineering instruction.[14] These laudable goals fall short, however, if topics are approached piecemeal with little integration into the engineering science courses that constitute the bulk of the curriculum. ABET addressed this danger with a capstone-design requirement that combines economic, social, environmental, and other considerations realistically.[15] If students are to experience engineering in context, that context must be integrated into the overall experience, not offered as a series of separate issues.

Understanding that policy and technology constantly influence and constrain one another becomes significant in preparing engineering students for the conflicting problems and opportunities within our society. The immediate challenge lies in finding projects in which the outcome heavily depends on both engineering development and attention to policy regulations. As a current and significant application, building energy efficiency offers a promising outlet to achieve the desired integration. To encourage students with varied interests, however, any program must have a broad base that fuses a variety of engineering science topics with relevant policy considerations.

5 Engineering Design and Public Policy Programs at The University of Virginia

The University of Virginia's School of Engineering and Applied Science (SEAS) recognizes the need to introduce engineering students to policy applications for their technical backgrounds. In response, programs now provide relevant and interdisciplinary academic environments and real-world, hands-on experiences both at the university and in Washington, D.C.

5.1 Science and Technology Policy Minor

The UVa SEAS created a minor in science and technology policy in the spring of 2005. The minor requires six courses: three core courses and three electives. The core consists of courses in politics, macroeconomics, and science and technology policy. Examples of electives include

Human Genetics, Ethics, and Technology; Natural Systems and Environmental Planning; and Justice and Health Care. This minor alone does not address all the issues needs identified in the NAE report. Some of the courses are based on the lecture method, and the SEAS is still working to integrate theory and practice more closely. But many of the courses rely on team projects for major parts of the instruction, and the minor creates a coherent focus on the intersection of policy and engineering.

5.2 Washington Internship Program

The Engineering School operates its own internship program in science and technology policy. The program began in 2000 when Richard Miksad, then SEAS Dean, teamed with James Turner, Chief Democratic Counsel for the US House of Representatives Science Committee. A few years earlier, Mr. Turner had begun placing students from MIT in science and technology policy internships in Washington. UVa joined forces with MIT's program in 2000 by sending a single intern to the office of Representative Virgil Goode (R-Va). Since then over 50 UVa undergraduate engineering students have participated in the program.[16,17]

To participate, students must be undergraduates in the Engineering School (all majors are eligible), in their second or third years, and in good academic standing. Admission is competitive and requires a written application and an interview. The program pays for housing in a dormitory in Washington and a stipend for living expenses; funding comes from the University of Virginia Engineering Foundation, the dean of the engineering school (now James Aylor), and a private donor. Administrators are now looking to endow the program.

The program now places eleven interns each summer in Congress, executive agencies, think tanks, and non-government organizations. Examples of placements include the White House Office of Science and Technology Policy, National Science Foundation, National Academy of Engineering, National Institutes of Health, House of Representatives Science Committee, Senate Small Business Committee, Federation of American Scientists, Electronic Privacy Information Center, Woodrow Wilson Center for Scholars, Environmental Protection Agency, International Relief and Development, and offices of members of Congress from both sides of the aisle.

During their ten-week internships, students learn about science and technology policy in several ways. Each writes a research paper, which ensures that students develop in-depth knowledge of some aspect of science and technology policy relevant to their host offices. (The papers are available on our web site-- http://www.student.virginia.edu/~ecouncil/wip/default.html--under "Alumni and Friends.") UVa and MIT interns learn from each other's experiences while rooming together in a college dorm; they also attend a speaker series organized by Mr. Turner. Past speakers include the White House Science Advisor, Director of the National Science Foundation, President of the National Academy of Engineering, and a Justice of the Supreme Court.

Students prepare for the internship in a dedicated course taught the spring term prior to their time in Washington. The course (STS 300: Science and Technology Policy) examines the history and structure of the federal government, science and technology policy, methods of policy analysis, and strategies for successful internships. *The Washington Post* serves as a text for the course, heightening student awareness of science in political arenas. The program director (Russell) teaches the course.

Alumni of the program have raved about their experience. In end-of-summer surveys, all ten 2005 interns reported that they felt prepared for the summer, had a placement that fit their interests, enjoyed the atmosphere of their office, benefited a lot from the internship, would recommend the internship to others, and would make the same choice to do the internship again. Nine of the ten said they worked on substantial issues of science and technology policy during much of the workday and learned things they could not have learned in a course. Seven were introduced to careers they had not known or thought much about, and five changed their career plans as a result of their experience. One wrote that the experience "has restored my faith in our government and made me interested in politics. I also now want to get a job after school rather than go right to graduate school…" Another commented, "I have become more poised and mature by working in a professional environment, living in the city independently, and getting to know other driven students." A third wrote, "I have a broader understanding of engineering, of policy, of Washington D.C., and of life in general."

The interns have had an impact. In 2003, Ahson Wardak wrote a report on regulation of nanotechnology that the Woodrow Wilson International Center for Scholars published as a white paper.[18] Danielle Fallon, an intern in 2004 at the Competitiveness Council, wrote a paper that the Navy is drawing on as it develops its policy on open source software.[19,20] Daniel Bowman, another 2004 intern, helped write a report on security of shipping containers for the Government Accountability Office that since has been classified. While interning at the Electronic Privacy Research Center in 2005, Dhruv Kapadia helped prepare a critique of a Department of Defense database policy that made the front page of the *Washington Post.*[21,22]

One 2005 intern (Tramba) worked on a project that she has carried on since returning to UVa. She spent the summer at the Federation of American Scientists, a small think tank primarily focused on nuclear disarmament and security, involved in a housing technology project. The original intent was to build affordable, high-quality homes in Afghanistan, but a lack of ground support in the region forced the project back to the United States. Tramba gained valuable project management experience and exposure to the construction industry, an environment completely new to her as a systems engineer, by working with a variety of contractors, specialists, and energy analysts. She left Washington at the end of the summer intent on pursuing this line of work and the policy-technology relationship emphasized by the internship program. The design-build concept was an ideal means of continuing such a politically-driven engineering project.

5.3 The Design-Build Experience: The ecoMOD Project

Preparing engineering students for leadership in the public policy arena requires not just an exposure to that arena, but also the experience of how policies are actually implemented and how they impact stakeholders. The engineering design-build process engages students with customers' needs and with the material and technological enablers and constraints required to render public policies into desired societal changes. The NAE's *The Engineer of 2020: Visions* *of Engineering in the New Century* stressed the need to balance economic, social, environmental, and military factors.[23] Policy regulation plays an integral role in achieving this balance.

As Tramba discovered, home-energy efficiency in new construction requires a significant connection between new technologies and policy regulation. She joined the ecoMOD Project to continue the subject of the work that she began in the summer; appropriately, two students who will intern through the Washington Internship Program in the summer of 2006 also joined the project team.

The ecoMOD initiative ("eco" stands for economic and ecological and "MOD" refers to the modular building technique employed) is an interdisciplinary research and design/build project focused on creating well-designed and well-built, modular homes that cost less to live in, minimize damage to the environment, and appreciate in value. ecoMOD strives to create ecological, modular houses for low-income families in central Virginia. Over the next several years, UVa architecture and engineering students and faculty will design and construct a minimum of three modular houses. Through a partnership with Piedmont Housing Alliance (PHA) of Charlottesville, the 1000- to 1250-square-foot homes will sit in low-income neighborhoods. Families eligible to own the homes will make down payments with financing assistance from PHA. The first house, named OUTin, was designed in 2004 and 2005, constructed during the summer of 2005, and assembled on a lot in the Fifeville neighborhood of Charlottesville. Sale and occupation are expected in March 2006. Among the energy- and resource-conserving features in the house are structural insulated panels (SIPs) instead of conventional framing, cisterns and a water purification system to collect and utilize rainwater, and a solar thermal water-heating system.

During the 2005-06 academic year, teams of engineering, architecture, business, and environmental science students are monitoring the home's performance to evaluate its sustainability, making a full life-cycle analysis. The engineering team has designed and installed an energy-monitoring system throughout the house. Data from temperature, humidity, current, voltage, and flow sensors are being monitored remotely by a National Instruments LabView system. Using these data, the team will develop an energy model of the house, evaluate the costs and savings of the energy conserving technologies, and generate recommendations for the next design iteration. Students are working with engineers, architects, landscape architects, affordable housing experts, modular housing manufacturers, builders, planners, government officials, building scientists, electricians, plumbers, and HVAC consultants to understand and quantify the energy fluxes in the house. Students will also perform a post occupancy evaluation and a modular housing market analysis. The houses will eventually be prototypes of a modular house system, with many variations and options.

The ecoMOD project offers a real-world, hands-on application of engineering technologies in the business and political realms. Part of ecoMOD's funding comes from a P3 grant from the Environmental Protection Agency (EPA). Consequently, standards must comply with the EPA's expectations. In addition, the homes must follow all regional building codes and PHA's typical regulations. With such restrictions, the policy aspect of construction enters heavily into the project.

Finally, ecoMOD lends itself to integration with federally-sponsored building programs, such as the Department of Energy's Building America program[24] and HUD's PATH program. Because these agencies have already set up research-oriented green building initiatives, it benefits the ecoMOD team to learn from existing design techniques and technologies. Conversely, the OUTin design and features may introduce elements of low-cost, green construction to the federal programs that they have not previously seen. The benefits of developing a working relationship between government agencies and UVa's interdisciplinary team perfectly demonstrate the significance of integrating technology and policy.

6 Implications for Engineering Education

Engaging engineering students in the analysis and design of public policies provides an effective means of integrating social, cultural, economic, environmental and other contextual issues into technical-based educations. When presented in the form of policy options, these issues relate to the experience of engineering students in a way that likely enhances learning, retention, and the ability to make connections with other spheres of knowledge. The relevance of these issues is especially obvious in the context of realistic, open-ended design projects. Engineering design is an active learning experience which lends itself to interdisciplinary transfer of information, as called for by the National Academies' Commission on Behavioral and Social Sciences and Education. Decision making and evaluation of feedback become easier in a more active learning environment.[25] Participation in engineering projects with a social purpose increases the likelihood that students will remain in the discipline.[26] Perhaps most importantly, the multi-disciplinary, experiential learning approach advocated here can attract students to and retain them in the study of engineering by making it more relevant to their lives and their aspirations to make the world a better place.

At the University of Virginia, the activities described in this paper form part of a comprehensive effort, called Engineering in Context, to address social, economic, ethical, and sustainability issues throughout the curriculum. Other activities include an Engineering Business minor, a multidisciplinary capstone design course, building our first year Introduction to Engineering course around meaningful semester-long projects, and providing equipment, support and space for student design projects. Increasingly, instructors are supplementing lecture material with team project assignments that require students to demonstrate the resourcefulness and initiative to define problems and design solutions. As is happening in engineering schools across the country, a realization is dawning that students cannot learn to be engineers simply by listening to lectures and working textbook problems. Ninety years after the publication of *Democracy and Education*, in which John Dewey laid out a case for the importance of education in preparing young people to participate in public life and "alter conditions," engineering education is beginning to recognize that experiential learning is the core of true education.[27]

Tramba's personal experience reflects the potential impact of creatively integrating hands-on experience into the engineering curriculum. During her summer in Washington D.C., she entered the energy-efficient housing field with little previous knowledge of construction or building codes. She realized that this was an appropriate application for her Systems Engineering background, however, and conversely found that engineering methods benefited the project's management and research. At the end of the summer, she determined that she wanted to further pursue the application of green building technologies in the affordable housing market. The ecoMOD project allowed her to apply and expand on her experience at the Federation of American Scientists. These programs now motivate her post-graduation goals, as she has an appreciation for both the science behind sustainable technology and the societal considerations that play into housing policy. The programs have demonstrated the use of Systems Engineering in an environment that is not generally associated with the major, but profits considerably from such skills.

7 Implications for Public Policy

Just as the education of engineers can benefit from the introduction of public policy considerations into engineering curricula, so the process of developing sound public policies can benefit from the application of engineering design principles. Like computers and airplanes, policies are designed. Good policy design, like good engineering design depends on a well-constructed design process. The problem to be solved must be fully understood. The stakeholders must be identified and consulted. The objectives and specifications must be clearly explicated. Divergent thinking, to identify the full range of possible approaches to the problem, must be followed by convergent thinking based on well-defined selection criteria. Research, judgment, and creativity are essential to identify optimal approaches. Models and heuristics must be developed and simulations conducted to investigate alternative scenarios. A systems perspective is necessary to recognize interdependencies among different components of the design.

Achieving the ends of public policies depends upon an understanding of the means available to achieve them. Often these means are technological. Addressing these means in the policy arena enhances the quality of regulations both in content and construction. Education which integrates the public policy aims and the technological means provides engineers the capabilities and training to develop their leadership potential and impact public policy formation.

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