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Sustainable Technology / Development and Challenges to Engineering Education

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New ideas may require decades to find mature adoption. The organizations that implement innovations often must undergo painful restructuring before their benefits can be applied in novel and appropriate ways. For the electric dynamo significant productivity gains required as much as forty years, during which old manufacturing systems based on steam and water power had to be discarded and new ways of using electricity in manufacturing were developed (David, 1990).

A lag also appears in the integration of environmental concerns with technological development. Since publication of Rachel Carson's *Silent Spring* in 1962, environmental groups have become political forces, a multitude of environmental laws and regulations have been enacted, and the limits to growth, global warming, and overpopulation have been debated. Yet the relationship between environmental protection and technological change has not matured but remains largely adversarial, with the developers of technology often characterized as willfully negligent about the impacts of their work, treating the environmental and social consequences of technological change as messy, impossible to model, and therefore outside the design considerations of engineers.

Recently the debate about technological development and the environment has been changing. Technological change has not slowed in spite of concerns about its environmental effects and many environmentalists have discarded their calls for an end to development, advocating instead a new type of growth guided by new principles: *sustainable development*. At the same time, scientists and engineers are recognizing the important relationship between their work and environmental concerns, with *sustainable technology* emerging as a guiding principle that many hope will permeate engineering.

The objectives of sustainable development and sustainable technology seem to be symbiotic, yet many of the problems of sustainability have their roots in traditional practices of engineering, particularly the short-term maximization of technologically- or market-driven objectives through innovation and increases in the productivity of labor. Engineers have generally practiced and taught under the assumption that engineering solutions are, for them, complete. Concepts such as intergenerational equity, nonmarket public values, and impacts on ecosystems have been treated as exogenous, if at all. If old ways of thinking about engineering have contributed to unsustainability, then what changes in approaches to engineering must occur for development to be sustainable? Many engineers recognize that sustainable technology (or "industrial ecology," or "environmentally conscious design and manufacturing") is not only socially desirable and perhaps politically inevitable, but also can serve traditional objectives of technological and market advantage. But it is unclear whether engineering will rely on new environmentally-responsive applications of traditional epistemologies and techniques, or embrace and incorporate new principles of design and implementation.

Science and technology studies have shown how the dynamics of disciplines and technical professions resist deep redefinition. The rhetoric of sustainable technology may be sincere but the agendas, methods, and objectives of engineering will not be changed easily. Sustainable development raises questions that can be answered only by a dialogue that includes physical scientists, life scientists, engineers, social scientists, and ethicists, as well as the lay public, policy makers, and business leaders. Bodies of scientific and technical knowledge are separated by disciplinary boundaries that reflect not only cognitive and methodological differences, but also political forces within the disciplines. These are manifested in the articulation, aggregation, and representation of each discipline's interests within systems of professional rewards that are resistant to change. Disciplinary forces are also exhibited in the influence of disciplines and their formal organizations on research practices, and in the curricula and textbooks by which researchers are trained and socialized into their professions.

To understand and anticipate the progress of sustainability it is necessary to examine the processes by which technologists are trained, particularly their education about the scope of their profession: whether, and how, the social, economic, cultural, and ethical aspects of sustainability can be integrated into engineering.

The Evolution of Engineering Education

How amenable is engineering education to change? A series of self-examinations and calls for reform over the past century have been intended to distinguish engineering professionals from technicians, to strengthen the scientific basis of engineering education, to make engineers more well-rounded citizens, to improve their communications skills, and to make them better team players. Such proposals for reform continue: "the key parameters of the new context of engineering are globalization, 'sustainable development' replacing 'development,' continuous change in both practice and education, rise in the social value accorded to nature, the environmental focus on an increasing number of new technologies, greater technological choice, and the need to monitor the relationship between technology and society" (World Federation of Engineering Organizations, 1993).

Not only is the social role of the engineer changing, but lifetime career patterns indicate a need to reassess some aspects of engineering education. At age 30 about seventy percent of those with at least one engineering degree are still practicing engineering, but the proportion drops to about sixty percent in their mid-30's, forty-five percent by their mid-40's, and plateaus at about forty percent by their late 50's (*Engineers*, Oct. 1997: 6). About one-fifth of all engineering graduates are employed in management (but this is not new: at the beginning of the 20th century engineering educators were noting the tendency for their graduates to become managers). In response, there have been repeated calls for undergraduate engineering curriculum to prepare students for their entire careers, not just their first technical job. "The engineer is being transformed from an 'answer-giver' alone to a *problem-architect*" (Kulacki and Vlachos, 1995), and "the laws of politics are replacing the laws of nature as the principal factor establishing the feasibility of many engineering projects" (Augustine, 1996).

> "In the average engineering project, the first 10 percent of the decisions made effectively commit between 80 and 90 percent of all the resources that subsequently flow into that project. Unfortunately, most engineers are ill-equipped to participate in these important initial decisions because they are not purely technical decisions. Although they have important technical dimensions, they also involve economics, ethics, politics, appreciation of international affairs, and general management considerations. Our current engineering curricula tend to focus on preparing engineers to handle the other 90 percent, the nut-and-bolt decisions that follow after the first 10 percent have been made. We need more engineers who can tackle the entire range of decisions" (D. Allan Bromley, in National Research Council, 1995: 20).

The Board of Engineering Education has recommended changes in the undergraduate engineering curriculum that included "a first-year course on the transformation of society by engineering, giving concrete examples" (National Research Council, 1995). The Board did not recommend a course on the transformation of engineering by society, however.

In 1990 the National Science Foundation established the Engineering Education Coalitions program to "stimulate bold, innovative, and comprehensive models for systemic reform of undergraduate engineering education." Sixty colleges have participated in eight such groups, receiving nearly $100 million in grants from NSF and other federal agencies. But undergraduate enrollment in engineering has dropped by 20 percent since 1985, and programs report growing difficulties in recruiting women and minorities and retaining students. At the same time that employers' demand for engineering graduates is growing, the interest of students in the topic is shrinking. Thus, any innovations in engineering education will occur in a context of self-examination and other reform initiatives.

Sustainability Education for Engineers

What is meant by "sustainability," and therefore "sustainability education"? We may endorse the current standard definition -- "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987) -- but there is no common body of knowledge or method that encompasses the implications of each of the concepts in the definition. After all, sustainable technologies can be used in wasteful or environmentally harmful ways, and they may have long-term or secondary consequences that make it impossible to confidently pronounce a product or process to be absolutely "sustainable." In practice, it may be more useful to define and identify "unsustainability": practices which pretend to violate the second law of thermodynamics, which assume that there is an infinite supply of resources to be consumed or technologically substituted, or pretend there is an "away" in which to dispose of wastes. Supreme Court Justice Potter Stewart once remarked about obscenity, "while I can't define it, I know it when I see it" (*Jacobellis v. Ohio*, 378 U.S. 184, 1964); we may not be able to operationally define sustainability, but we should recognize its absence when we don't see it.

There are several general paths that sustainability education for engineers could take. First, sustainability could be defined narrowly as sustainable technology, full stop. In their engineering courses students would be taught to respond to forces external to engineering such as political demands, market pulls, or legal restrictions, with sustainability implications of their problem selection or design work treated as any other exogenous variables, as another form of constraint parameters in a design project. Sustainability technologies would be pursued because they are smart technologies, intellectually challenging, of interest to many companies, or perhaps mandated by "take-back" legislation. Sustainable engineering would be mostly another manifestation of the trend in educational reform toward problem-based learning and teamwork. This is the "*pure sustainable technology*" design. To a civil engineering student: how should a professional respond to regulatory mandates affecting the design and construction of a highway through an environmentally-sensitive area?

Second, sustainability education could be provided via courses taught on the other side of the campus: designated requirements or electives taught by social scientists, planners, or ethicists. As part of their humanities and social sciences requirements, engineering students would venture into foreign territory, reconnoiter a few alien ideas, add some new forms of intelligence-gathering or useful code phrases to their professional tool kits, then return to the familiar homeland. The concepts and methods of sustainability studies as practiced by non-engineers would be woven into the practices engineering in the same way as current curricula relate the study of government or the history of the Enlightenment to engineering questions -- by osmosis or by the student's own initiative. In this "*pure sustainable development*" design, sustainability would be something that social planners and ethicists worry about and that engineers may wish to consider and adapt to their primary interests. To the civil engineering student: what types of complaints might "they" (community groups, lawyers, politicians) voice about a proposed highway project?

Third, sustainability could be emphasized by integrating the fundamentals of sustainable technology and sustainable development. Social, ethical, economic, and cultural aspects of engineering design would be built into existing engineering courses and curricula, while core principles of engineering practice would be brought into courses on policy, communications, economics, and government. For example, mechanical engineering courses in heat transfer, tribological design, or polymer science and engineering would relate issues in transport coefficients, machine lubrication and wear, or the design and use of polymers to environmental impacts such as energy consumption, waste generation, substitutability, and consumer demand. Equally important, the engineers' perspective on the possibilities and limitations of technology would be addressed in courses on environmental policy, economic development, the sociology of work, and international relations. To address these issues accurately, engineering and liberal arts faculty would need to work together, not simply broadening the syllabus or team-teaching, but explicitly identifying common ground and conflicts between approaches to problem-solving. For engineering, the goal would be to suffuse the content of a liberal education into students' perspectives of what they will do as engineers. The civil engineering student would ask: instead of minimizing the impact of building a highway through a wetlands, are there other alternatives -- transportation, economic incentives, land-use planning -- that achieve the same objectives but at smaller social or environmental costs? The "*integrated sustainable technology and development*" option presents many imposing challenges, but it must be the preferred option.

Is "Sustainable Technology" Sufficient?

In 1993 the Georgia Institute of Technology launched a project to develop new curriculum initiatives in sustainable development and technology. A three-course sequence of courses was developed and taught by faculty from various engineering and non-engineering programs. Importantly, the sustainability initiative at Georgia Tech came from the engineering faculty. The current dean of engineering, Jean-Lou Chameau, has been an energetic advocate of introducing sustainability to the education of engineering students -- to "change our mind-sets, not just our problem-sets." One of the objectives of the sustainability program in Georgia Tech's curriculum was to permeate a wide range of undergraduate and graduate courses with the principles of sustainability, but the faculty have seen that goal as evolutionary, being realized as faculty discover the relevance of the topic to their particular interests. Chameau has acknowledged that incremental "tweaking" of the environment, and of engineering programs, will not lead to sustainability, but that curricular change requires time: to motivate faculty, to change their sustainability mind-sets, and for them to interact with those with other perspectives (Chameau, 1999).

As an evolutionary effort, not everything can be done at once. It is understandable that the initial impetus at Georgia Tech has been on sustainable technology, emphasizing engineering design considerations that employ renewable resources and minimize material and energy consumption. However, "technology for a sustainable society" was separated from "social considerations for a sustainable society," delaying the task of integrating into engineering the messy processes of determining the needs of current or future generations, the social and political consequences of shifts in technological paradigms, or the willingness of consumers or the public to bear higher costs, substitute products, or alter their style of living (if not their quality of life). At an early stage of change when the issue is still being framed for the engineering curriculum, it is risky to exclude or postpone the social parts of sustainability. The challenge for the engineering profession (including universities who train engineers) is whether to rely only on new applications of traditional epistemologies and techniques to new problems, or to incorporate new principles of design and choice.

Particularly when words have ambiguous yet ambitious meanings, labels are important. At some universities "environmental" has become a distinct field of engineering that attracts large numbers of students, although "environmental engineering" is often an addition to civil engineering rather than a broad commitment to sustainability with all of its implications. "Whenever we use 'environmental' to stand for all the positive and untroubling aspects of sustainability, we are making it more difficult to achieve a shared set of understandings within our own discourse, let alone in a wider context" (Johnston, 1997). Studies by the Wuppertal

Institute and Dutch Sustainable Technology Development Programme have concluded that "purely technological solutions to reach ecological sustainability cannot be expected." Environmentally efficient technologies must be combined with "policies which aim at changing environmentally detrimental economic structures and lifestyles"(Coenen and Klein-Vielhauer, 1997). If engineering students are taught that sustainability means only the application of familiar practices to environmental issues, engineering universities will not have changed mind-sets. The environmentally conscious engineering graduate of the future will need to be able to choose benign technologies and argue convincingly for their adoption; anticipate obstacles to their implementation; disagree with employers who prefer unsustainable alternatives; advise governments on the development and use of sustainable technologies; and substitute social, political, or economic solutions for technological solutions when appropriate (Beder, 1996).

In some ways the integration of engineering and non-engineering considerations in a curriculum is not as revolutionary as it may sound. Scholars of technology have observed that as they are developed machines pass through three stages: what works, what is useful , and what is marketable (Alois Riedler, discussed in Bryant, 1976). Engineers traditionally have embraced the first two concepts, and the idea of marketability is certainly familiar to them. But the question of whether a product is marketable mixes technological questions -- how it performs and relates to other products (technological compatibility or superiority) -- with issues such as consumers' tastes (values) and willingness to pay (economic interest), social and political acceptance (ethics), and legal restrictions. Engineers have already stepped outside their field of technological expertise when considering the marketplace; taking into account nonmarket social forces may be conceptually more complex but not logically different.

Tensions

Engineering education has always had an uneasy relationship with the liberal arts. The president of MIT stated in 1891: "Too long have our schools of applied science and technology been regarded as affording an inferior substitute for classical colleges. Too long have the graduates of such schools been spoken of as though they had acquired the arts of livelihood at some sacrifice of mental development, intellectual culture, and grace of life.... I believe that in the schools of applied science and technology is to be found the perfection of education for young men" (Noble, 1977: 25). More recently, an engineer wrote just as proudly that "When it is not buildings alone that are being planned, but entire communities, states, river basins, even continents, then the engineer bows to no one... there is no mistaking the fact that the planning of environment is in great measure the planning of life, and such planning is an art far more than a science. Yet it is an art for which, in this complicated and overpopulated age, only the engineer has learned the essential techniques" (Florman, 1968: 198). Nevertheless, early in the 20th century engineering faculty began to include humanities and social sciences courses into the undergraduate curriculum. As the social sciences began to be recognized as valid sources of understanding, the broadening of the engineering curriculum was seen to have a utilitarian objective as well as a culturalization purpose.

Engineering tends to be centripetal, relating coursework and experiential learning to established techniques and indicators. Sustainability is centrifugal, pushing students outward to complex questions with multiple answers, requiring knowledge from diverse fields and applying a range of methods and criteria of justification. Sustainability presents new types of problems which are largely unbounded in space and time and which do not lend themselves to reductionist analysis or the optimization of sub-systems. The sciences and engineering are compact disciplines (with a "sufficiently agreed goal or ideal, in terms of which common outstanding problems can be identified"), while the social sciences and emerging fields such as sustainability studies are diffuse or "would-be" disciplines, characterized by an "absence of a clearly defined, generally agreed reservoir of disciplinary problems, so that conceptual innovations within them face no consistent critical tests" (Toulmin, 1972). Gibbons and colleagues (1994) describe engineering disciplines as somewhere between Mode 1 (compact disciplines, such as the natural sciences, with clear norms about what constitutes good practice and relevant problems) and Mode 2 (transdisciplinary, applied and context-aware, socially accountable and reflexive, performed by a heterogeneous array of academics and practitioners). Sustainability will push engineering much more toward Mode 2.

Sustainability requires the use of large numbers of factors and techniques. Is it a science at all? Bowden (1956) wryly noted that "an art may become a science if it is concerned with less than about seven variables" (cited in Ravetz, 1996: 48). With far more than seven variables, if sustainability is not a science, then are we to judge its claims as empirically testable generalizations, as appeals to aesthetics, or as statements of moral justice? This is not a unique challenge: neither efficiency nor profitability are derived from compact sciences, yet they are fundamental concepts which traditionally have guided engineering practice. The integration of sustainable technology and sustainable development is also challenged by time scale. Product designers have very near planning horizons. Environmental impact time frames are much longer, and because sustainability is explicitly intergenerational the most crucial attribute for judging the validity of its knowledge claims is patience (although unsustainability is easier to demonstrate). But even with patience, strict standards for judging the verifiability of sustainability knowledge claims are fragile because sustainability studies are expected to alter the course of events and negate the conditions that they predict or upon which they are premised.

An engineering solution is based on the determinability of the problem, the empirical rigor of techniques of analysis, the hierarchical decomposability of design problems, a common language of specialist engineering communities, and the potential to determine an optimal outcome. "In technology, ambiguities which affect total systems performance are not tolerated; disagreements among members of specialized sub-communities or doubts about some aspect of design must be resolved, by empirical experiment if nothing else, for the total system to work" (Constant, 1984). Sustainability is far less determinable. Unlike technological systems, where the well-designed whole is functionally more than the sum of the parts, social systems appear to be increasingly dysfunctional at the very broad level. A carburetor, an engine, an automobile may work precisely as designed but a highway system is less designable and less efficient. An entire urban system with social, cultural, and political determinants of land use, modes of transportation, and lifestyle choices seems far too complex, multipurpose, and unmanageable for traditional engineering standards to be solely applicable. If engineering thinking dominates the relationship between sustainable technology and sustainable development, there will be disappointment in attempts to create a standard analytic structure that spans the complete domain (Thurston, 1999).

On the other hand, the homogeneity of engineering, as a profession and as a course of instruction, is not as great as the simple label "engineering education" would suggest. Some areas of engineering are more likely than others to depend on communities of practitioners while some are more theoretical, and they may differ significantly in scope and methodologies. Yet because of shared technique, language, educational experiences, self-selected personalities, professional attitudes and values, and acculturization, engineers from various fields are more likely to be able to work with each other than with humanists. Similarly, grouping scholars and subject matter from the social sciences and humanities into one common category carries the risk of inappropriate generalizations. For example, in examining teaching concepts and validation processes, Donald (1990) found that science professors underscore the importance of empirical evidence while those in the humanities favor peer judgments, but that social scientists are more similar to natural scientists in emphasizing empirical observation and testing of hypotheses. Broad characterizations of engineers, social scientists, or others disguise the complexities that offer possibilities for common language, approaches, and techniques between sustainable technology and sustainable development.

Latour (1993) observed that in the modern world there is a strong but doomed drive to separate the social and the technical by defining them as incommensurable. But definitions of sustainability always include attending to the needs and values of people. How are these design parameters to be discovered? Market processes alone cannot describe human values. Political processes are also incomplete and seem to be in conflict with engineering approaches, for which direct public input into choices of research problems or design considerations is alien. In practice, formal public participation processes usually have consisted of procedures by which public concerns are voiced late in the evolution of a technology when a decision is being made whether or how to use it, not whether or how to develop it. The public responds in the predetermined context of scientific/ technical analytic processes of policy making. Because "by both inclination and preparation, many engineers approach the real world as though it were uninhabited" (Wenk, 1996), the educational interface between sustainable technology and sustainable development must incorporate the essentially democratic context of planning for sustainability, and the vital role of public participation processes as objectives apart from their content.

Another implicit barrier to the integration of sustainability and engineering education may be an assumption that different types of people are compatible with different fields of study. Few engineers are drawn to the profession by their interest in people or public service and many are "uncomfortable with the ambiguities of human behavior" (Wenk, 1996). If it is true that for people of comparable intelligence, those with education in the humanities have stronger leadership skills than those educated as engineers -- better able to "reason verbally, communicate their ideas to others, and furnish leadership" (O'Neal, 1990) -- then education for sustainable technology must address this need among engineering students. Psychological studies of students and faculty have found a diversity of learning styles (e.g., abstract/concrete and active/reflective); we are most comfortable intellectually when studying in fields closely allied with our personal style. But one of the purposes of education is to challenge students to think differently, even if -- especially if -- it makes them uncomfortable.

Compatibilities

Engineering is about developing a new thing, or doing something in a new way or under new conditions. Sustainability, with its enabling policy and market mechanisms, has largely the same objectives. Small-systems thinking has been at the core of engineering (e.g., how to get two parts of a circuit or a machine to work together). Larger-scale systems have been considered primarily as technological systems composed of parts manipulable by engineering technology. For example, a highway system would be treated as a network of materials (concrete, vehicles), structures (roads, bridges), and functions (entrance and exit mechanisms, drainage), but the non-engineered aspects of the highway system (commuters' tastes and values, social norms and housing patterns, obligations to future generations) would be treated tangentially if at all. "Social systems have societies as their main structural components; people as their main functional components; cultures as their main organizational components; and human interactions as their main dynamic components. This is as opposed to a physical system... which has physical materials for its structural components, machines as its functional components, and mechanical and electrical interaction as its dynamic components" (Ottenberg, 1994). With the recognition that technological development occurs within large-scale, socially- and technologically-complex adaptive systems, these distinctions between types of systems begin to reveal similarities more than differences.

The increasing complexity of society that has accompanied technological growth also makes it more difficult to calculate all of the intended and unintended consequences of that growth; it seems that the more we try to control our fate, the less control we have (Beck, 1992). "[T]he equation of knowledge with certitude has turned out to be misconceived. We are abroad in a world which is thoroughly constituted through reflexively applied knowledge, but where at the same time we can never be sure that any given element of that knowledge will not be revised" (Giddens, 1990: 39). Sustainability problems cannot be interpreted simply as technological anomalies, as unintended consequences of underspecified engineering design processes that honor professional tradition by excluding relevant exogenous variables such as social values. If sustainability problems are construed only as failures of analytically reducible larger systems, then sustainable technologies, as corrections to technological anomalies, will be incomplete. The modern approach to engineering has been to deal with contextual complexities by avoiding or modelling them away, so engineering for sustainability must become more embedded in social systems. Taken to one extreme: must engineering become postmodern to be sustainable? The postmodern engineer would not be, in principle, "judged according to a determining judgment, by applying familiar categories" to the work (Lyotard, 1984: 81). Or are we all modernists at 30,000 feet?

Technology is a distributed social process, involving multiple organizations and social networks; innovation derives from local cultural values, communities of education and practice, and knowledge that is generated and used by organizations. "Technologists pursue the lines of research they do largely because they share the values of the wider community that benefits from their work; and the desires of the wider community depend importantly on the instrumental possibilities developed by technologists. Accordingly, the idea that the distinction of means and ends is mirrored in the distinction of technologists from the wider community is not viable. The essential point can also be put in this way: although there is a sharp distinction between the questions 'Is M the best means to E?' and 'Is E a good end?', there is no correspondingly sharp distinction between the questions 'Should I develop M as a means to E?' and 'Should I desire E as an end?' (Gutting, 1984: 60). This means that the distinction between sustainable technologies and social and cultural development problems is also not viable.

Donald Stokes (1997) pointed out that our conception of the relationship between science and technology has been artificially constrained by a prevailing one-dimensional model with basic research at one end of a flat continuous line and applied technological development at the other end. But by putting pure research on one axis and applied research on another, the space between (where Louis Pasteur worked on both basic research and practical questions at the same time) becomes much more enriching. The same criticism can be levelled at how we have thought of engineering and the liberal arts. By conceptualizing the two realms as opposite ends of a single line, there has been only one type of largely adversarial interface between the two essential aspects of technological development: right brain vs. left brain, analytical vs. reflective, quantitative vs. "soft," scientific/technical vs. value-laden. The issue of sustainability insists that we work in "Pasteur's Quadrant," where we fold the line and see engineering and the liberal arts as interwoven rather than opposed.

Barriers To Curricular Innovation

Technological systems develop constituencies which include manufacturers, workers, suppliers, research institutions, and educational institutions that have a vested interest in resisting significant changes (Hughes,1983). These constituencies define a technological paradigm that establishes legitimate questions and procedures, while at the same time leaving those who develop technology "blind" to possibilities outside the normal practice (Dosi,1982). In curricular innovation, these constituencies appear in several forms.

Disciplines   In higher education the disciplines are significant institutional barriers to an intermixing of sustainable technology and sustainable development. Academic disciplines, after all, impose discipline. They define accepted common bodies of knowledge and method, and they structure the education and training of new professionals seeking the disciplinary badge. There are engineering disciplines (although they have less obvious boundaries than those in science; Constant, 1984; Watson, 1990), but there is no established discipline, no set of scientific axioms, no theories--no "narrative"-- of sustainability that provides the authority for determining what is valid knowledge. Authority in scientific and technical knowledge derives from tradition, hierarchy, consensus, or institutionalization of a discipline. The field of sustainability studies is too new to have traditions of accepted knowledge. It is too interdisciplinary for there to be dominant individuals who are generally recognized as reliable judges of knowledge claims across all of the relevant bodies of knowledge and methods. The breadth of the field rules out any chance of being able to reliably define who is qualified to claim membership in the discipline of sustainability, and without an operational definition of who is a relevant practitioner it is difficult to assess a claim of consensus regarding sustainability knowledge. And the field is too new and too broad for it to have developed institutions (associations, journals, academic departments, textbooks, curricula) that can be recognized as definers of boundaries or arbiters of quality. Few will have the dual citizenship to vote in more than one domain, to keep the gates secure between science/engineering and social values, or to allow the gates to be partially opened.

Membership in a discipline implies the qualification of a researcher to speak from the body of knowledge and to be familiar with the antecedents of new scientific claims, tying a proposed finding to a bibliography of previous work and to a platform of accepted methodology. A prominent engineering professor leaves professional credentials behind when venturing into cultural studies or the sociology of indigenous people, and vice versa. In interdisciplinary work it is sufficient to be familiar with the previous statements in relevant disciplines, but not necessarily to be qualified to independently judge their validity. If an outsider can scrutinize the bibliography of another body of knowledge and learn the conclusions, but not necessarily be able to confirm or refute them, then is that person qualified to *use* statements from that other body of knowledge and apply them in the field in which he or she is professionally qualified or licensed? Such excursions must be subject to validation by those in the visited discipline, but there must be some generosity in inter-field borrowing for sustainability education to succeed. "If education must not only provide for the reproduction of skills, but also for their progress, then it follows that the transmission of knowledge should not be limited to the transmission of information, but should also include training in all of the procedures that can increase one's ability to connect fields jealously guarded from one another by traditional structures of knowledge" (Lyotard, 1984: 51-52).

Alumni The unusual strength of university alumni in the US derives from funding mechanisms that financial endowments given by faithful alumni, the loyalty deriving from collegiate athletics, and the absence of competition from other mechanisms of community identification. Alumni sometimes tie their financial contributions to policies that preserve the college atmosphere that they remember fondly if not always accurately. They serve on university advisory boards not only because they might be substantial donors but also because they connect the campus to its external constituencies, especially in industry. Any significant change in curricula or degree doctrines is likely to face opposition from some of these powerful alumni. Furthermore, engineering accreditation is performed by committees that often include such alumni; recognizing the inertial tendencies of these external constituencies, Norman Augustine recommended "including representatives of the liberal arts on accrediting teams, to reflect the importance of a broader education" (Augustine, 1996). Without much evidence to the contrary, Lyotard's cynicism seems reasonable: "any experimentation in discourse, institutions, and values (with the inevitable "disorders" it brings in the curriculum ...) is regarded as having little or no operational value ... it is safe to assume that responsibility for it will devolve upon extrauniversity networks" (Lyotard, 1984: 48-50).

Faculty Humboldt declared that science obeys its own rules. The university, however, has an obligation to allocate its research efforts in science to "the spiritual and moral training of the nation." The resulting tension between these mandates generally has been healthy. Two hundred years ago Immanuel Kant described universities as being pulled toward both functions, with a resulting "conflict of the faculties." The "higher faculty" were the three established faculties of theology, law, and medicine, which to Kant had a strong tendency toward superstition because they depend upon tradition and authority. Rather than truly educating the people, the higher faculties offer magical solutions (how to save those who have sinned, how to win cases without being honest, how to cure bodies that have been treated with negligence). The "lower faculty," in contrast, were rooted in reason, asking basic questions about all matters --including those of the higher faculty-- and using reason rather than tradition or authority as the criterion. This inevitable conflict, then, pits tradition against skeptical rational inquiry.

Derrida (1992) pointed out that as the necessary autonomy of the philosophers (including natural philosophers, or scientists) became institutionalized, perhaps inevitably, they separated themselves from their role vis-a-vis the higher faculty. At the same time philosophy became more internally autonomous, promising that its self-criticism would provide all of the controlling authority it needed. The conflict of the faculties, then, became increasingly first an isolation of the faculties, and then the mutual intellectual irrelevance and institutional competition of the faculties. If engineering had developed as a profession a century earlier, where would Kant have put them in his university structure -- as a higher faculty, and if so, in what way is philosophy (and the moral reasoning derived from sociological and political studies) allowed to keep them honest? At the same time, the social critics and community visionaries need reality checks: what is physically possible, and what cost? It is not clear in the academic evolution of sustainability which is the lower faculty.

University faculty are not known for the rapid evolution of their lectures and syllabi. Curricular changes usually are slowed, often fatally, by professors desperately clinging to "their" courses, deducing that a generation of satisfied (or at least unrebellious) students prove that nothing needs to change. They are captives of their training, their professional exposure to those whom they resemble the most, and a tenure and promotion system that gives small rewards for curricular redesign, especially in research universities. Even when faculty believe that courses should be organized to pursue critical thinking rather than defined bodies of knowledge, they actually organize it around field-related content (Stark, 1990). In an age of just-in-time or just-for-you manufacturing, university courses tend to be just-as-they-always-were. Sustainability studies, regardless of how enthusiastically they are promoted by progressive educators or university administrators, will not overcome the inertial culture of higher education.

The necessary cultural change is not for all faculty to embrace sustainability, but to move away from each professor having insisting that one limb of the body of knowledge continue to be represented in the curriculum in the same way that he or she learned it. "Past discussions of engineering education have largely focused on how to squeeze an adequate amount of [math, sciences, humanities, and social sciences] into the four-year framework of the conventional bachelor's degree program. And the goal of the discussion is usually to negotiate an acceptable compromise among the champions of the various elements. We must understand that we limit our horizons by hoping the university will pay attention to our particular professional problems and by arguing about shifting a few credit hours here or there" (Clough, 2000: 38).

<u>Curricular Models</u> The 1994 "Green Report," ("Engineering Education for a Changing World"), issued by the Engineering Deans Council and the Corporate Roundtable of the ASEE, concluded that although the post-World War II research-intensive university model has been the standard of excellence, "the world now demands new models." Not all engineering programs should provide the same service. Some should combine traditional engineering education with broader skills such as communications, decision making, and policy setting. Others should become more like law or medical schools, providing professional education and practical on-the-job experience to engineering students. And some would continue to focus on doctoral programs and heavy research emphases. Whatever the model, the Green Report recommended that contextual knowledge, ethics, communications, and other topics not be delivered through separate courses but "by incorporating them into existing curricula and through non-classroom activities." In other words, not just the curricula should change, but the content of each engineering professor's course should evolve.

In its 1995 report on reforming engineering education, the National Research Council proposed "a period of experimentation and self-assessment," and suggested changes such as modularizing the curriculum, exploring educational innovations and practices in other countries, and requiring "the study of science, technology, and society (or equivalent) for undergraduates." It also recommended re-examining the four-year undergraduate engineering degree; in the words of Norman Augustine, former president of the National Academy of Engineering, "It is time for the four-year engineering degree to join the slide rule, log tables, the French curve, and ammonia-reeking blueprints as artifacts of the past." (National Research Council, 1995; Augustine, 1994).

Curricula are human institutions, derived not from a divine organization of knowledge but from a variety of disciplinary and social phenomena. They have been described as "the battleground on which society debates education" (Clark Kerr in Rudolph, 1993). The debates usually involve a variety of considerations, including purpose (e.g., general or vocational/specialized), diversity of learners (elites or masses, post-secondary or mid-career), content (prescription vs. student choice), instructional process (lectures vs. experiential), and assessment (Stark and Latucca, 1996: 44-45). Curricula assume consensus in which the relevant faculty agree that a particular set of courses and material comprise the appropriate body of knowledge. A curriculum depends on its implied determinism: students who take the prescribed courses in Discipline A will be able to solve A-type problems, and when they complete the curriculum they will be qualified as members of A. With insulated feedback from the multidisciplinary nature of the real world, the graduate in most fields is likely to be shocked to find that (his) college education has made him a specialist who is "not learned, for he is formally ignorant of all that does not enter into his speciality; but neither is he ignorant, because he. . . 'knows' very well his own tiny portion of the universe" (Ortega, 1932: 112).

Engineering And The Liberal Arts

Universities of the Middle Ages established seven branches of liberal learning: grammar, logic, and rhetoric (literature and philosophy -- the trivium), and arithmetic, geometry, astronomy, and music (the quadrivium -- science and the fine arts). As educational institutions evolved, “liberal arts” came to be distinguished from the “useful arts.” Particularly over the past 150 years, the distinction developed into institutions and cultures that competed for status and resources. “Unless the liberal arts can be approached *through engineering* they will seem lifeless and frivolous to those of us who are professional engineers (Florman, 1968: 17; emphasis added).

Today the technical arts and liberal arts coexist, but often strongly separated except for occasional courses on “engineering for poets” or science fiction for engineers. New joint degrees in engineering and the liberal arts are emerging at many universities, such as Penn State, Purdue, and Michigan, and other colleges are developing team-taught courses that blend engineering with history, economics, and ethics. The Engineering Projects in Community Service (EPICS) program at Purdue has demonstrated how innovative course structures can bring engineering and liberal arts majors together in long-term applied learning projects. In general, however, these programs remain outside the mainstream of engineering education. Vanderburg has investigated the degree to which engineering education teaches students about the impact of technology on human life, society, and nature, and the extent to which students learn to use this knowledge “in a negative feedback mode to adjust engineering methods and approaches to achieve a greater compatibility between technology and its context.” What he found confirmed “how undergraduate engineering education has separated the economy from the ecology of technology”: very few courses attempted to include lecture, textbook, or laboratory materials about the human, social, and natural context of engineering, or about how engineering practices should be adjusted as a result of these contexts (Vanderburg, 1999). The social science and humanities departments at many universities are equally insular; courses on “technology and society” or “ethics and engineering” are usually taught by faculty who make no effort to talk with engineers or gain first-hand knowledge of technological development.

The concept of instruction (“objectivism”) that assumed that students were empty vessels, waiting to be filled with the knowledge that was stored in professors and disciplines, was first put forward in the mid-1600's by Johann Comenius. But Lyotard, even before the World Wide Web, foresaw a change: “As long as the game is not a game of perfect information, the advantage will be with the player who has knowledge and can obtain information. By definition, this is the case with a student in a learning situation. But in games of perfect information,” which the new forms of information technology make available to any student with a connection and a search engine, the advantage “comes rather from arranging the data in a new way.... This capacity to articulate what used to be separate can be called imagination.... which allows one either to make a new move or change the rules of the game.... then it follows that the transmission of knowledge should not be limited to the transmission of information, but should include training in all of the procedures that can increase one’s ability to connect the fields jealously guarded from one another by the traditional organization of knowledge” (Lyotard, 1984: 51-2).

Prospects For Change

The objective of sustainability in an engineering curriculum is lead students to realize the scientific and technical, ethical, and political logic of sustainability in such a way that they would not be able to imagine doing engineering without it. This extends beyond a professional code of ethics: Florman dismissed these as having "traditionally stressed gentlemanly conduct rather than concern for the public welfare" (Florman, 1981: 168-9). The engineering code of ethics tended to treat the practicing engineer as an individual unit, working alone in a laboratory and facing temptations when it was occasionally necessary to interact with other people. But for sustainability the key normative question is social ethics, not individual ethics: "instead of viewing ethics as a tension between the morality of the individual and the practices of society, ... the focus should be shifted to the tension between the ideal and the actual norms and structures that characterize group processes and social institutions.... this shift for engineering ethics... moves the focus from relatively powerless individuals to the actual processes of decision making in technology" (Devon, 1999: 87; Davis, 1998).

The task is not to make engineering students feel responsibility for the existence of technological risks in the current or future world, especially in the absence of reliable predictors of what those risks will be and how society will weigh them against the benefits of technology. For example, would a "responsible" engineering student of 1910 refused to have devoted a career to automotive engineering even if some omniscient prophet of that time could have predicted with certainty the phenomena of air pollution, drunk drivers, urban sprawl, etc.? Should society have discouraged or prohibited the development of air conditioning in the 1940's without complete knowledge of the environmental effect of coolants such as CFCs? The challenge is whether to produce "minimally programmed units" whose education consists of efficiently-administered lists of facts and theories, or citizens capable of discussing a "national subject" (in this case, actually, a global subject: sustainability), which must derive both its questions and its answers from a sociocultural awareness (Readings, 1996: 87).

In their summary of the history of the American Society of Engineering Education, Reynolds and Seely (1993) demonstrated that not very much is new. In the 1880's engineering educators were already becoming concerned about the constraints imposed by a four-year curriculum. In 1918 a report by C. R. Mann to the Society for the Promotion of Engineering Education reported on a survey of practicing engineers that revealed that "initiative, tact, honesty, accuracy, industry, personality, and other qualities of this kind" were the traits most highly valued by employers, and recommended a engineering curriculum that paid more attention to values and culture. In the 1930's the Wickenden report described engineering education as a compromise between academic and professional study and called for a more general undergraduate curriculum with more attention to liberal studies. A report in 1940 from the National Society of Professional Engineers recommended making two years of pre-professional training in a liberal arts program a requirement for an engineering license. The Hammond report, also in 1940, called for two parallel and integrated "stems" in the undergraduate curriculum, one scientific and technical, the other in humanities and social sciences, with specialized engineering courses moving to the graduate curriculum. The 1955 Grinter report was explicit in its recommendations:

[The student should] be given an understanding of the nature and function of some of the principal [humanities and social science] disciplines, together with an introduction to the methods of thinking likely to be most conducive to further growth in these fields within the life experience of the student. The courses should be designed to liberate him from provincialism, whether geographical, historical, or occupational, and to give him a sense of the satisfactions that he can gain later in life by adventuring more deeply into the areas of critical and creative thought represented in the humanities and social sciences" (ASEE, January 1994: 82-83).

The 1965 Goals of Engineering Education (Walker) report "argued that rapid technological change, the need for more science, and the equally pressing need for a grounding in the humanities and social sciences demanded that engineering follow every other profession and move specialized, professional studies to the master's level." (Reynolds and Seely, 1993: 143) This report received a particularly hostile reaction, especially from industry and engineering professional societies. "The president of one of the large Midwestern universities (said) that the leaders of American industry and government do not want -- indeed, will not tolerate -- a large number of engineers who receive a rich, truly professional education" (Florman, 1981: 151).

The very gradual response to these reports is largely the result of a collective action problem: which university will go first, which student will volunteer for a general engineering degree or non-exit 4+-year program, and which employer will take the first chance on such graduates? The NSF Engineering Education Coalitions program, created in 1990 to encourage colleges and universities to form coalitions in curricular reform, recognized the advantages of collective action by engineering programs. However, "the traditional engineering education culture is often distinctly 'non-communal,; i.e., highly competitive and individualistic" (Cordes et al., 1999). As in the marketplace, innovation is risky. "Engineering education tends to be conservative in both its pedagogical methods (including curriculum) and its institutionalized attitudes. This conservatism produces a degree of stability (perhaps inflexibility is a more apt term) that results in a relatively slow response to external stimuli" (National Research Council, 1995: 32). Past curricular transformations in engineering programs occurred in response to external demands and pressures. Many research universities with engineering programs dropped their "shop" courses in the 1950's, largely because science courses seemed more fundamental and relevant to engineering research, but the current context offers incentives for change that are far more poorly defined (deriving from the ambiguous nondiscipline of sustainability), and bridge the most different intellectual traditions in academia (professional engineering programs and the humanistic disciplines).

Conclusion

Curricular changes related to sustainability are being proposed at a time when the range and intensity of challenges to traditional educational programs are increasingly rapidly. Universities are confronting an environment in which their their return on taxpayers' investment, their research ties with industry, their traditional methods of instruction, and their responsiveness to demographic and workforce changes are combining to put substantial stress on higher education. These more immediate pressures may increase the university's willingness to innovate and allow sustainability to creep into the curriculum more easily than in a status quo environment. On the other hand, they might focus too much of the university's attention and energy on short-term needs, such as the changing market demand for new types of education or the concerns of lawmakers about the relevance of educational programs for next year's occupational needs.

With the aging of the American undergraduate population, the experience with which students will enter their curricular programs will be broader, and they may be less satisfied with narrowly-prescribed and inflexible courses of study which exclude subjects that they have already learned are relevant in their careers. Readings (1966: 174) foresaw "the development of an increasingly interdisciplinary general humanities department amid a cluster of vocational schools, which will themselves include devolved areas of expertise traditionally centered in the humanities, such as media and communications. . . This is a historical irony, since such a prospect has striking similarities to the original plan of many land-grant universities, before most of them bought into the research University model as the way to acquire increased prestige and concomitant funding."

Conflict among disciplines can take various forms, many of them not productive. Yet perhaps there is some value to conflict between engineering and other disciplines: in 1751 Diderot and d'Alembert voiced the creed of the Encyclopaedists that the tension and incommensurability between disciplines actually benefits the growth of knowledge by encouraging disciplines to treat the questions and methods of other disciplines as problems, thereby offering criticisms which would raise the quality of work within them all (Darnton, 1984). The roots of the modern university are in the Enlightenment, which was supported by the exposure of Western societies to other cultures. Sustainability offers the possibility of exposing modern institutions to more diverse aspects of their own cultures -- in a sense, a miniature counter-Enlightenment, encouraging a critical examination of established divisions between bodies of knowledge and curricular territories. Engineering will still be engineering even if it absorbs core questions and methods that are not themselves engineering questions. The gene pool would be strengthened, not by the creation of "a generalized interdisciplinary space but [by] a certain rhythm of disciplinary attachment and detachment, which is designed so as not to let the question of disciplinarity disappear . . . [Instead,] disciplinary structures would be forced to answer to the name of Thought, to imagine what kinds of thinking they make possible, and what kinds of thinking they exclude" (Readings, 1996: 176).

History provides many lessons that paradigm shifts in ideas and education require ripeness, as concepts and worldviews outside the mainstream await the social and intellectual maturation that forces change:

> "Why is it that the discovery that Copernicus made could not directly and of itself change the world of his time? On the other hand, why did it, five generations later, become the great idea on which a radical mutation in the human horizon was based? Very simple: during the Middle Ages the individual sciences, therefore science as such, represented a kind of secondary knowledge; they were, we might say, a spiritual activity of the second class. . . . in order that

a single scientific discovery like the Copernican idea should produce an actual world change, it was necessary for men first to decide to acknowledge the fact that, generally speaking, scientific truth is truth of the first class, a creative truth. Only within that general change in the evaluation of the sciences could the Copernican theory radiate all the formidable and vital consequences which were pregnant within it" (Ortega, 1958: 82-83).

As long as the culture of engineering remains willfully separated from the social sciences and humanities, the uncomfortable questions raised by sustainability will continue to be viewed as second class questions, unable to change the world. Incremental adjustments assume the ability of the environment to be patient.

If universities cannot demonstrate flexibility and adaptability to their students, what lessons will the students infer about the need for flexibility in the organizations for which they will work? Future engineers will do what needs to be done, outside of the T section of the library. In the Library of Congress classification system, which was developed mostly between 1898 and the 1920s, the letters D, E, and F designated books on history, H was the social sciences (but J was political science), all of the sciences had only one letter (Q), and technology had only the T. To many students and scholars, this was the given codification of the organization of knowledge. Information was found in a *place*. It had a location in a journal or a book, and if that publication was in a library it had a prescribed physical location. Students knew whether they were receiving information from the realm of social sciences (library call letter "H," fourth floor) or from the realm of technology (call letter "T," sixth floor). On the Web, there is no location, no realm. A search engine has no concern about disciplinary boundaries of traditions. Regardless of the shortcomings of web-based research and publication, it threatens the traditional organization of knowledge in a way that may make the fixed curriculum as archaic to students as the card catalog.

Engineering is not a timeless dialogue between humans and nature; the processes of technological development have been shaped by social, cultural, and political forces. The practice of engineering must become more consciously contextualized if sustainability is to be realized. Universities must be leaders in developing innovative responses to the challenges of sustainable development, but this will require a sincere and enthusiastic recognition that "sustainable technology" is only a partial piece of the answer.

The key challenge for engineering curricula, then, is not to transform engineering or its techniques, but to imbue the education of engineering students with the contingent nature of engineering solutions. The inherent complexity of sustainability will make its pursuit more a matter of asking many questions than the discovery or application of well-defined engineering design principles. For the university, evolving social needs, new environmental problems, flexible career options, rapidly changing markets, and new information technologies will make the maintenance in higher education of our "jealously guarded" fields an outmoded luxury. No institution, no college or university or academic department, will find or create the perfect symbiosis between technological and humanistic perspectives on sustainability, but they should aspire to provide opportunities and settings for each institution to increase its responsiveness as new scientific and technological knowledge develop and as social priorities change.

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