AC 2011-928: USING HISTORY OF TECHNOLOGY TO PROMOTE AN UNDERSTANDING OF THE IMPACT OF ENGINEERING SOLUTIONS AMONG ENGINEERING STUDENTS

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A proposal for using history of technology to promote an understanding of the impact of engineering solutions among engineering students

Introduction:

Ten years ago, ABET (Accreditation Board for Engineering and Technology), the primary accreditation organization for post-secondary engineering and technology departments in the United States, revised its requirements for undergraduate programs leading to a bachelor's of science degree in engineering[1]. The new standards, known as EC2000, require for the first time that students receiving the B.S. degree "understand the impact of engineering solutions in a global, economic, environmental, and societal context." Other national bodies have similar standards[2]

The reason behind such criteria is the recognition that, by its definition as the application of scientific knowledge to the solution of real-world human problems, engineering must respond to changing economic, political and social contexts. It immediately follows, therefore, that the codification and transmission of engineering knowledge must adapt in turn. Given, over the past several decades, the ever increasing role of technology in all aspects of society and the increasing globalization of these technology, and the recognition, the new ABET criteria are no surprise. Further given the realization—often through a series of perceived crises such as collapsing infrastructure, global climatic change, or ecological disasters—that the impact of engineers on society is critical, the "social impact" criterion makes perfect sense. Although a social scientist might argue that the engineers setting their own accreditation criteria are not fully aware of the social forces around them, the authors of this paper believe that all members of modern society can agree *a priori* that it is a good thing for science and technology practitioners to be aware of the social context of their work.

However, in the vast majority of U.S. institutions of higher education—and this is true internationally as well—the developers and circulators of engineering knowledge are not the same individuals as the developers and circulators of knowledge about history, society and culture. In fact, they are institutionally isolated from them. Since ABET, which reviews compliance with its guidelines, is comprised of the former, the situation raises the question of how effectively engineering education in the United States (and, by extension, elsewhere) is fulfilling this goal.

The authors of this paper are affiliated with the IEEE History Center. IEEE is the world's largest professional technical association. Since its founding in 1963 by the merger of two century-plus-old societies, the non-profit association has felt the obligation to support a history center to promote the preservation of, research into, and dissemination of the legacy of the fields of interest of its members, namely electrical engineering and computing and related disciplines. The IEEE History Center carries out this mandate through a number of programs. Most notably, it maintains the IEEE Global History Network (GHN), a wiki-based web portal that gives it the capability to deliver educational material to a variety of audiences world-wide, and also gives the users the capability of adapting the material to their own needs.

Since 1990, The IEEE History Center has been located at and formally co-sponsored by Rutgers, the State University of New Jersey. At Rutgers, the IEEE History Center is part of the School of Arts and Sciences and is affiliated with the History Department. Rutgers engineering students are required to take expository writing, four completely open "humanities/social science electives," and a one-credit senior seminar of "professional ethics" (normal courses are 3-credit). At the same time, the authors themselves have taught separately and together with each other and other historians over the past several years a two-course sequence on the history of technology and an introduction to "science, technology and society" with a strong historical component. More specialized history of technology courses have also been given.

One would think that such courses would be ideal for fulfilling the ABET requirement, and that engineering students, if not required to take such courses, would at least be encouraged to do so. Yet very few engineering students enroll in them. Engineering students have a very full curriculum, and take those humanities courses that fit their tight schedules and their own interests. Although it is also important for engineering students—and all university graduates—to be well-rounded citizens exposed to the general principles of literature, history and so forth, ABET suggests a particular responsibility for engineers to study the social context of technology.

Professional ethics are extremely important, but so is the understanding of the relationship of science and technology to culture, to social organization, and so forth. We do not have confidence that our humanities and social science colleagues are integrating science and technology issues into their more general courses. In fact, economics turns out to be the most popular social science for engineers at Rutgers. Economics is important, and it certainly integrates an analysis of technology. However, in the classical way it is taught today in U.S. universities, it is not the ideal discipline for raising sensitivity to cultural issues. The authors believe, in fact, that although all social scientific approaches to technology in society are valid and important, the historical approach would give the students the broadest view, and allow them to transcend the narrow perspective caused by focusing on the cultural milieu familiar to them.

A recent development has given the authors an opportunity to further pursue their ideas. In 2009, IEEE entered into an agreement with the University of California, Merced (UC-Merced) to also become a partner in the IEEE History Center. UC-Merced is the tenth and newest UC campus (it opened in 2005, the first in 40 years; UC Santa Cruz and UC Irvine were added in 1965). As "the first American research university of the twenty-first century" (as it bills itself), UC-Merced is committed to interdisciplinary practice and to performing as a network. At UC-Merced, the IEEE History Center is likewise part of the School of Social Sciences, Humanities & Arts. However, being a new and growing institution with an interdisciplinary mission, the environment UC-Merced is more conducive to working across traditional boundaries than at most long-established universities such as Rutgers. It is this collaborative environment where we have been able to work with both Schools to create two courses that serve both their needs; making social studies and humanities students aware of the role of technology in the story of humanity, and providing engineering students with a course that truly responds to the ABET 2000 requirement of presenting the process of engineering in a cultural context.

The authors of this paper have therefore set themselves four short-term goals:

1. To conduct some sort of broader survey of the current state of affairs to confirm their suspicions that most ABET-accredited institutions are not requiring their students to be exposed to the social context and, specifically, the social history of technology;
2. to consider the practical as well as theoretical considerations for developing a curricular modality that could fulfill the criterion, with particular attention paid to the role of history;
3. to imagine the high-level features and educational outcomes of such a modality;
4. to develop preliminary modular courses on the history of technology that would be approved by both the School of Social Studies, Humanities and Arts and the School of Engineering, and be tested at UC-Merced.

We will take up each of those goals in order:

1) Curricular Survey

In the attempt to bridge the theoretical study of engineering education by social scientists with its praxis, we needed to somehow observe current practice, to see if the Rutgers experience was in any way representative, at least in the United States. In order to get this broader perspective, we turned to *U.S. News and World Reports*, a general interest magazine that annually publishes lists of top higher education institutions and programs in a variety of fields and combinations. Although these rankings are nonscientific and controversial, they are widely consulted and highly influential. By looking at curriculum as described on the websites of the top-ten “Best Undergraduate Engineering Programs (where doctorate is highest degree)” and the top-ten “Best Undergraduate Engineering Programs (where doctorate not offered)”, we have a list of 20 U.S. engineering programs—all high-profile and ABET-accredited—at colleges and universities that are large and small, public and private, technical and liberal arts, military and civilian[3]. The sample is admittedly small, but we suggest that the data are sufficient to go beyond the merely anecdotal. The data are summarized in Appendix I.

In brief, our suspicions were born out. The data show that, indeed, accredited U.S. engineering programs use a very small number of modalities to fulfill the ABET “social impact” criterion: Requiring a specific course, taught by engineers, on engineering ethics; and/or requiring engineers to take some sort of distribution and/or concentration of humanities and social science courses, relying on individual instructors on either the engineering or humanistic side to help the student integrate the two completely ensiled aspects of their education, with no guarantee that this is carried out (and no mandate or support to make it happen).

The common practice of almost all of these departments is to require their students to take some array of humanities and social science courses. This is usually equivalent to, or a watered down version of the general education requirement for all students. Often there is both a breadth and depth requirement (also called distribution and concentration), but no limitation as to the actual disciplines or content—certainly no requirement that engineering or science be addressed directly. Sometimes a writing requirement is rolled into the humanities and social sciences requirement, and sometimes it is separate. Some of the undergraduate colleges require a core curriculum of their engineering as well as non-engineering students, but we found no evidence that core emphasizes or even covers technological issues (the core at each of the three military academies requires a course in military history which presumably has a strong technological component). Where there is a distribution requirement, history of technology and STS courses are often available but, as at Rutgers, we found no evidence that they are favored or promoted, event at technical institutes.

There are a few exceptions. The Rose-Hulman Institute requires all engineering students to take an economic course. We have already expressed our doubt on the efficacy of economics to truly explain the social context of technology. Olin College requires a course on entrepreneurship, which also seems to us limited. Villanova, like Rutgers, requires a course on professional ethics. University of Texas limits the humanities and social science courses that count for engineering distribution, but the remaining list is highly idiosyncratic and not limited to STS-type courses.

Perhaps the “hero” of this group of 20 is Stanford, which has a “Technology in Society” requirement that demands that engineering students take one from among about a dozen specified courses (although one of the options is entrepreneurship). Anecdotally, there are other institutions that have more successfully integrated social impact into the engineering curriculum. Virginia Tech, which boasts of having “the only STS program in the U.S. that is situated within an engineering school at a national, comprehensive university,” provides a four-course sequence that is required of all engineering majors. At Princeton, Dave Billington developed a two-semester history of technology course that—by having engineers take reading and writing sections and non-engineers take an laboratory section—fulfills requirements for each while successfully integrating the two topics. Although not technically required, it draws a huge percentage of the freshman class.

The question is, then, what might be done to enhance and expand such efforts?

2) Curricular Considerations

The authors tried to envision what an ideal teaching modality might be for exposing engineering students to the methods, theories and beliefs of humanities and social science, while also giving them specific understanding of the place of science and technology in human activity. In this way, a limited portion of the curriculum might fulfill both goals of producing engineers who are well-rounded citizens and producing engineers who are specifically aware of the social context of their own chosen profession.

First, there is the question of our framework's theoretical underpinnings. These modules will be firmly rooted in the deep soil of history. Naturally, as historians, our inclination is to look at human actions over time. Beyond our professional bias, we feel that this choice offers important advantages to today's engineering students. The story of technology is inseparable from the greater narrative of humanity. While one can debate the idea of *Homo Faber* as the defining characteristic that sets humans apart from other animals, one cannot deny that technology has been a defining feature of human existence since prehistoric times. One snapshot from the present or from any single time period cannot give the engineering student an appreciation of the myriad ways in which human existence has been both technology contingent and technology forming. Technology is about the many ways in which humans interact with the world through the use of materials, tools, and complex machines. A snapshot makes it difficult to explore important polarities in the creation and use of technology: the universal v. the particular; the intentional v. unplanned; continuity v. change; and necessity v. chance. Many snapshots, spanning a wide range of human conditions, are needed. A broad historical perspective offers this large repository of contexts. History also offers another essential perspective for the student. More than just a rich collection of geographic, economic, political, social, and demographic circumstances, history presents the unique capability of linking contexts over time. Looking at technological change over long spans of time allows to student to differentiate fleeting impacts from the more enduring ones.

Although current technological events are certainly relevant, we feel that a fundamentally historical approach will pull students away their familiar world of the "present" and associated preconceptions, and exposes them to a wider palette of technological outcomes and societal impacts. In the spirit of presenting technology across a broad spectrum of human experiences, in addition to spanning great expanses of time, the modules must also offer engineering students examples from very diverse geographic and cultural settings.

Then there are the practical concerns impacting how such a curriculum might be designed. Note that with all the myriad of academics researching and teaching in humanities and social science, 4S, the international organization trying to "bring together those interested in understanding science, technology, and medicine, including the way they develop and interact with their social contexts" has only 1200 members[4]. Membership in ICOHTEC, SHOT and national societies, such the Japanese Society for Science and Technology Studies, are of the same order and with overlapping membership. Technology societies are immense in contrast; IEEE alone has over 400,000 members, nearly half of whom are academics[5]. Furthermore, as mentioned above, the engineers and social scientists at universities tend to inhabit very distinct silos. The ability of historians and other social scientists to impact engineering and engineering education would seem to be limited. We believe that our approach will help to mitigate these divisions.

3) Curricular Features and Educational Outcomes, Including Examples of Modules that Illustrate the Approach

To deal with these considerations, the authors propose that the best option is to create modules on historical case studies of technology and society that could be integrated into a range of courses. The modules would be designed with the idea not that the audience is primarily non-engineering students with a smattering of engineers, but rather a class of engineering students. The modules taken together would constitute an STS or history of technology course that will fulfill the ABET mandate. However, the modules could also be adapted so that one or more could enhance a broader history course given at a technical institute or an STS course geared toward science and engineering majors. Such modules could even be adapted for pre-university social studies courses. The modules would be built around questions of technology that have been raised by social scientists and might not be intuitive to engineering students. Below are examples of some of these questions and associated issues:

A. How do we account for geographical distribution of technological capabilities, that is, why do some societies exhibit "genius" in one area, when there are so many universal traits that cut across all societies?

> Our first module here will investigate the expansion of iron working in first millennium B.C.E. western Eurasia[6]. Early models of diffusion have given way to an understanding that there were several sites of independent invention. What specific local conditions led to the development in of this technology in some places but not others? What were the geographical, geological and cultural constraints in operation in each locale?

B. Why does it often happen that cultures cannot conceive of certain possible technological trajectories, even though they possess the scientific and technical competence to undertake these trajectories? This includes the concepts of technological lock-in, geographic serendipity, and the occasional advantages of isolation from great centers knowledge. This is in effect a special case of question #1.

- According to Moses Finley[7], the Greeks and Romans were unable, or unwilling, to increase productivity, by multiplying productive capacity per worker, through technical innovation. This contrasts with their medieval descendants, who with initially less scientific understanding were able to multiply their technological effects.

  We propose a module based on another example, the use of very labor intensive technology to construct ships. Boats can be constructed either by shell-first or frame-first methods. In the ancient world shell-first was the exclusive manner for building trading and naval vessels[8]. Shell-first construction is a much more complex and skill intensive method than frame-first. It is also more labor-intensive and more wasteful of wood. Frame-first did not appear until the middle ages. Why? No special tools were needed. It actually required less skill. The needs of the military and empire are usually given prominent roles in technological innovation, and yet when Athens, whose whole empire rested on its command of the sea, was desperately running up against the limits of labor productivity, high costs, and rapidly vanishing timber resources, it could not conceive of any other way to build ships than frame-first.

- Another module related to this one is the evolution (revolution) in the ship's rudder from ancient times to the medieval period[9]. Why were the advanced naval powers of the Mediterranean unable to break away from rudder technology that fundamentally limited the use of larger vessels when at the same time the more backward northern Europeans came up with a revolution in the design of rudders? This example illustrates concepts important to engineers and society. Other potential modules include why the flat-Earth concept of the Earth evolved into a spherical model in Medieval Europe but not in China (which was, if anything, initially more advanced in cartography) and Finley's other well-known example of the inability to Greeks and Romans to conceive of new possibilities for using horses as sources of power. Yokes, which were used for oxen, were completely inappropriate for horses.

C. How does technological diffusion happen and not happen?

- As question #2 suggests, diffusion and invention are both important to the history of technology. Our first example is from the Industrial Revolution and involves the challenges of maintaining technological advantages by trying to keep trade secrets and block the movement of ideas and expertise to competitors. In general, Britain tried to ban out-migration of skilled labor, while the young United States encouraged violation of European patent law. We will look at the example of steel production.

Despite 18th century France's successful efforts in stealing highly skilled metalworkers from Britain, France was unable to replicate British cast-iron know-how[10]. Why? What was the role of geography and geology? This case has the advantage of shouting out to the modern engineering student for a comparison with current U.S. - China industrial and technological relationships.

D. Role of political serendipity in shaping the direction of technological progress.

- Treaty of Tordesillas

By the end of the 15th century, the political acumen of Portugal's Prince Henry and supportive Papal edicts had divided the world into two political, military and trade spheres of influence[11]. Crucial to this division was Portugal's eastern access to the orient. Spain was then confined to a westward exploration of the world. The key point dividing these lines was a meridian drawn rather arbitrarily by the Pope on a flat map with little thought to the fact that the world was a sphere. Everything to the east was Portugal's sphere of influence and to the west Spain's. The line was place somewhere out in the Atlantic. Recalling that meridians are great circles on the globe, it soon becomes very apparent that this line would have repercussions on the other side of the world: within whose side did the spice island fall?

All of a sudden the location of a rather approximate line in the middle of the Atlantic became a great geopolitical concern and raised important scientific and technological issues as to how to measure this line and where to place it. Scientists (cosmographers) who were ordinarily consigned to the margins of decision making were now brought to the forefront of power as both Portugal and Spain negotiated the reality of this line. Technology in the form of measurements, instruments, and cartographic skills followed the science. The negotiations, which ended in the Treaty of Tordesillas, gave a big impetus for the development of specific areas of scientific and technological know-how.

E. Does superior performance always triumph in make technological choices?

- The rise of numerical control (NC)

In his study of the rise of NC technology in the U.S., David Noble[12] offers an excellent example of how non-technical rather than technical considerations favor the success of one technological option over another. The two machine-tool automation technologies available after WW II were record-playback and NC. Record-playback had many advantages. Nobel argues that the military's concern with "social control"

> of the labor process pushed the U.S. towards the pursuit of the more expensive and sophisticated NC technology. In the end, the military's adoption of the NC technology advocated by MIT's Servo lab locked the U.S. on a technological trajectory that opened the door for Japan's eventual supremacy in the machine tool and industrial robotics.

We feel that the proper use of modules offers the best opportunity to get buy-in from engineering departments. Geared to engineers, the modules provide a pedagogically flexible tool for the wider implementation the ABET the technology & society requirements. Although these proposed modules could be strung together into a one-semester course, their real effectiveness will lie in being to integrate them, in an *à-la-carte* manner, into existing courses. The modules will allow more of the existing social science and humanities courses to be more easily retooled in order to accommodate the theme of "engineering in the "societal context".

To engage engineering students, our modules must include more technical details whenever reasonable. When any sort of technical detail, no matter how simple, is introduced into a history of technology course, the eyes of the humanities and social sciences students glaze over. But for an engineering audience, the introduction of more technical details will allow us to explore the interplay between society and design, in ways that are more meaningful to them.

4) Preliminary UC-Merced Courses

The authors have now designed a two-course history of technology sequence, based loosely on the sequence already taught at Rutgers. Thanks to the cooperative environment at UC-Merced, the Curriculum Committees from both the School of Social Sciences, Humanities & Arts and the School of Engineering have actively participated in approving the syllabi of both courses. The courses will be cross-listed. The "Student Outcomes" for these courses also make explicit reference to meeting specific ABET requirements as well as outcomes desired by the school of Social Sciences, Humanities & Arts. The first course will be taught by one of the authors (Vardalas) in fall of 2011.

Conclusions and Future Considerations:

The real measures of the success our effort at UC-Merced will be large enrollment from the Engineering School; and subsequent student evaluations of the courses. In addition to using UC-Merced's evaluation instrument, we intend to design a supplemental questionnaire. Our evaluation questionnaire will have to explicitly explore the views of the engineering enrollees on the perceived relevance to them of each to their education as engineers, and match these back to ABET's goals. We will also attempt to measure student responses to particular modules, to see which resonate more, or at least hold the greatest interest.

The next step will be to take the UC-Merced courses and cross-test them at Rutgers, again using Rutgers student evaluations combined with our own evaluation instrument.

Ultimately, based on this feedback, we hope to disaggregate the modules and make the most promising ones available on the web through the IEEE Global History Network. We envision that the modules will consist of PowerPoint slides, lists of preparatory further reading for both instructors and students, and recommended preparatory and evaluative questions. We will then use the networks that IEEE possesses to promote use of the modules in a variety of academic settings. For example, non-pilot schools seeking to meet the ABET standard in a less invasive way than introducing a new required course might wish to use a few modules in an existing required course, for example a first-year introduction to engineering. Users will also be asked to supply feedback on their experiences. We will modify our original survey and make it available along with the modules; the GHN in fact already has built in discussion capability.

Based on that feedback, we would intend to modify the modules and produce more. We would also promulgate a set of standards/best practices for these modules; the GHN has the functionality to allow others to develop modules based on their own expertise. When a critical mass is reached, we would envision a major campaign to promote the availability of this material.

References:

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11. See, e.g., J. R. Harris, *Industrial Espionage and Technology Transfer: Britain and France in the Eighteenth Century*, Ashgate, Aldershot, 1998.
12. D. Noble, *Forces of Production: A Social History of Industrial Automation*, Knopf, New York, 1984; cf. Chapter 6, "The Sperry Gyroscope Company of Canada and Computer Numerical Control", in John Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, MIT Press, Cambridge, MA, 2001.

Appendix I. A table summarizing the humanities, arts and/or social sciences (HASS: defined slightly differently at different institutions) requirements at the top 20 engineering programs (top 10 in doctoral granting institutions and top 10 in non-doctoral institutions, as ranked by *U.S. News & World Reports* 2010). Data ascertained from the institutional website. Table indicates the number of courses needed to be taken in the different modalities of HASS requirement: "Core" = a sequence of courses in HASS required of all students; "Distribution" = a requirement to take a number of courses in different HASS disciplines; Concentration = a requirement to take two or more courses in a single HASS discipline. It also indicates if any specific HASS course is required from engineers beyond the core curriculum required of all students. Finally it indicates if there are required writing courses. Finally, note that different institutions have different requirements about the mix of humanities, arts and social science courses, and about requirements for the ratio of upper- to lower-level courses in the distribution and/or concentration.

	Core	Distribution	Concentration	Specific	Communication
Massachusetts Institute of Technology	None	4	4	None	2 specially designated HASS courses
Stanford University	3	None	None	STS	3 specially designated courses (1 or 2 in major)
University of California, Berkeley	None	4	2	None	2 specially designated HASS courses
California Institute of Technology	None	12	(Upper-level distribution requirement combined with prerequisites de facto produces concentration)	None	None (assumed to be subsumed by upper-level humanities requirement)
Georgia Institute of Technology	1	4	None	None	None

University of Illinois, Urbana-Champaign	None	6	None	1 HASS course must fulfill “Non-Western/US Minority requirement and 1 must fulfill “Western/Comparative” requirement; there is also a language requirement	1
Carnegie Mellon University	None	4	3	None	1
University of Michigan, Ann Arbor	None	4	(Upper-level distribution requirement combined with prerequisites de facto produces concentration)	None	2
Cornell University	None	6	None	None	3
Purdue University, West Lafayette	None	6	None	None	2
University of Texas, Austin	3	2	None	(Some limitation placed on engineering distribution compared to non-engineering, but not much)	1
Harvey Mudd College	2	None	None	None	None
Rose-Hulman Institute of Technology	None	6	None	Principles of Economics	2
Cooper Union	4	None	None	None	Core assumed to subsume writing

United States Military Academy	15	None	None	None	None
United States Naval Academy	6	4	(Upper-level distribution requirement combined with prerequisites de facto produces concentration)	None	Core assumed to subsume writing
California Polytechnic State University, San Luis Obispo	None	8	None	None	3
United States Air Force Academy	12	None	None	None	Core assumed to subsume writing
Bucknell University	None	4	None	1 HASS course must fulfill Global perspectives requirement	One distribution must be in English; this is assumed to subsume writing
Franklin W. Olin College of Engineering	None	6	None	Foundations of Business & Entrepreneurship	None
Milwaukee School of Engineering	1	6	None	None	1
Villanova University	2	1	None	3 Theology and/or Ethics Courses	1