WHY CHANGE ENGINEERING EDUCATION?: PRAGMATIC PERSPECTIVES FROM THE HUMANITIES AND SOCIAL SCIENCES

T. Staley
Virginia Polytechnic Institute and State University
Blacksburg, United States
https://orcid.org/0000-0002-2785-7958

D. Bairaktarova[1]
Virginia Polytechnic Institute and State University
Blacksburg, United States
https://orcid.org/0000-0002-7895-8652

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ABSTRACT

Engineering education in the early 21st century is being transformed in many ways to meet the technological challenges of the future. In particular, the role of the humanities and social science in engineering coursework is under new scrutiny, as educators attempt to strengthen students' proficiencies in aspects of the profession including interpersonal and intercultural skills, assessment of broader impacts of technical work, and especially ethics. These developments are often framed as responses to the demands of employers and institutions, who view these 'soft' skills as increasingly relevant to the work life of technical professionals. In this concept paper, we wish to pursue a somewhat different line of thought: We will examine arguments from the philosophy of science and technology, and from the social sciences, about the value of teaching engineers (as well as other technical professionals) to think through humanistic, social, and cultural lenses. We will review a range of perspectives supporting educational reform along these lines, with a particular focus on work in the recent pragmatic tradition (including Sellars, Mitcham, and others). Having established a range of theoretical defenses for educational reform along these lines in engineering fields, we will then consider the distinctions among them and how these insights might be applied most effectively in engineering curricula. We will conclude by reviewing available evidence for the practical utility of such interventions. We hope, by situating current reforms more firmly within a principled framework of ideas, to provide deeper support for positive change in the education of future engineers.

[1] *Corresponding Author*

D. Bairaktarova

dibairak@vt.edu

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1 INTRODUCTION

Why change engineering education? Our title question is meant to be somewhat provocative for a number of reasons. Foremost, we observe that engineering education might be expected to change continuously in response to new developments in technical knowledge and associated technological systems. Furthermore, continuous improvement is part of the accepted ideology of both engineering fields and contemporary institutions of higher education, making change an expected default condition for curricula in general. In these senses, the answer is obvious. However, here we are concerned not with this kind of process of spontaneous pedagogical adaptation, but rather with an intentional guided shift that has been conspicuous in engineering curricula for more than 30 years – particularly in the United States – toward greater inclusion of humanistic, social, and cultural subject matter in undergraduate engineering courses, or in elective coursework associated with engineering degree programs.

In that context, our question remains challenging to longstanding assumptions about the specialized nature of engineering knowledge, as a fundamental technical skill set. In addition, it calls for consideration of what the fundamental objectives of engineering education, and higher education more broadly, are and ought to be in the 21st century. It might also provoke responses from some quarters about how to assess the merits of engineering curricula (or, again, university curricula in general) and the outcomes that they produce. As such, an examination of recent trends toward broadening engineering curricula opens up a potentially productive discussion about both educational practices and the principles they represent.

Our primary interest here is in the relationship between engineering education on the one hand, as a specific form of institutionalized technical preparation, and general education on the other, as a process of providing individuals leverage to participate fully in a contemporary society permeated by technologies and engineered systems. Recent shifts – either proposed or actually adopted – in engineering education have conspicuously focused on strengthening the capacity of students in technical programs of study to include a greater depth of humanistic and social skills. These include developing capacities in such areas as communication, team dynamics, human-centered design, ethical reasoning, cross-cultural understanding, and analysis of social impacts. All of these can be (and are usually) justified by the demands of engineers' professional role in a highly technological society: The technical preparation of 21st century engineers is understood to entail working within distinctive social and institutional contexts that require skills that are oriented more toward interaction with other people than with the technological objects that engineers devise, produce, and maintain.

2 DISCUSSION

2.1 Demands for Design Knowledge

We begin this discussion by noting that curriculum changes such as those just described have been institutionally mandated by professional accreditation boards on the basis of feedback from professional societies and consulting bodies, industrial employers, and other stakeholders. In this sense, broadening the engineering skill set is straightforwardly a matter of demand, which has been solidified by evidence for the efficacy of such changes. To remain an accredited engineering program, ABET requires specific student outcomes related to social responsibility, including "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability", pg.1 [1].

While there is an obvious logic to this line of thought, we want also to examine some more foundational arguments for strengthening the intersection between engineering education and general education. To begin, we note some observations about the limitations of putting social awareness into practice in an engineering context. Students may absorb and retain a consciousness of such considerations while still failing to develop effective ways of incorporating them into engineering work. Within design tasks, for example, students have difficulty in connecting social consciousness with user needs. Often, when students are responsible for identifying customer needs, their efforts are limited to the results of surveys and focus groups, in which relevant data is collected early in the design process often without subsequent iterations. Students typically treat the customer as a list of requirements that serve as an input to the design process. Within this context, interventions are needed to help students better think through details beyond survey results while striving towards socially conscious levels of understanding. Designers need both domain-specific knowledge and situation-relevant strategies to design effectively [2].

It is apparent that students need to know how customer or client information influences the design of products and systems even when the human-centered details are not explicit. This thinking can be enabled through an increased level of social consciousness, or an awareness of the impact that design decisions could have on the cultural, social, and emotional aspects of the end-users. In situations where the designers lack exposure to end-users, the mapping between user needs and product attributes is non-trivial and challenging for students. Thus, while adopting this approach may provide an added level of understanding about constitutive human factors, obstacles still emerge from the diversity of users and contexts that may be relevant from one situation to the next.

2.2 Fostering the Individual Engineer

Another perspective on broadening engineering design education, less focused on the needs and wants of users, might emphasize instead the personal development of the individual engineer themselves as the primary benefit. Societies more than ever are more knowledge-based with a drive for development of new competencies effective for rapidly changing global world. In a such global society, where everyone deserves the opportunity to be educated, the philosophers Rousseau and Dewey's educational models both emphase the learner's own motivation. As discussed by Noddings, Rousseau's open education model recommends building education on the interests of students, enriched with hands on experience, and learning by doing, feeling, observing and deemphasized formal lessons [3]. Dewey is also known for his work on the role of experience and its function in education. "Experience" in the context of education, for Dewey, is personal meaning and social interaction. Dewey wanted students to experience a personally unified curriculum – one that makes sense to them in terms of human experience and particularly, in terms of their own experience [3]. This train of thought recommends a broad and flexible curriculum primarily by virtue of the beneficial outcomes expected to accrue to the engineering student. In effect, both Rousseau and Dewey are arguing for engineering education to be construed as a process of *Bildung*, in which both technical and social skills are fundamental to the engineer's personal development.

However, this perspective still leaves a significant role for social interactions and experiences in driving the process. Design is an extremely social form of inquiry. Design is defined as a reflective practice as described by Donald A. Schon [4]. Major concepts of this model are surprise and reflection. A designer or student has a canonical way of doing and something unusual happens when these practices confront a new social situation that causes the student to reflect on the situation. Surprises come from the unpredictability of design situations and a designer engages in a reflective conversation with the context and materials, a process that may aid in developing a deeper understanding of the design problem [5]. The early stage in design and the iterirative nature of design in general, resembles educational model explained by Dewey and his emphasis on immersion and experience in education. It is also highly congruent with the spiral curriculum approaches often taken by educators to guide students through a developmental process within general education. Viewed from this perspective, engaged personal development is facilitated by repeated exposure to new contexts and interactions. Engagement and development over time mitigates some of the concerns noted earlier about engineering students' initially "transactional" approach to user-centered design.

Whether motivated primarily by questions of social consciousness or personal development, advocacy for broadening engineering education ultimately entails a renewed emphasis on the professional and ethical responsibility associated with the engineering profession. In an educational environment that strongly distinguishes technical knowledge from social or human knowledge, attending to both can easily appear to be a challenging task, especially if construed as the sole responsibility of the educated professional engineer. Consider: In learning the engineering profession today, students are encouraged and expected to consider the effects of their actions (and non-actions) including the economic, environmental, political, societal, health and safety consequences of their work, while also keeping in mind the manufacturability and sustainability of their structures and products. As Robin Tatu notes in discussing the book of Douglas, Papadopoulos, and Boutelle "Citizen Engineer": "A successful 21st century engineer must become "part environmentalist, part intellectual property attorney, part MBA, and part diplomat – not to mention an expert in an engineering discipline, a great teammate, and a skilled communicator" [6] (Prism, pg.52). Similarly, the National Academy of Engineering suggested in *Educating the Engineer of 2020* [7] that:

> Within the context of the changing national and global landscape, The USA National Academy of Engineers enunciated a set of aspirations for engineers in 2020. The future engineers have to be technically proficient engineers who are broadly educated, see themselves as global citizens, can be leaders in business and public service, and who are *ethically grounded*. The committee set targeting attributes needed for the graduates of 2020. These include such traits as strong analytical skills, creativity, ingenuity, professionalism, and leadership.

Presented with calls such as these for engineering education to instill such comprehensive and multivalent competence, both educators and students have struggled to fulfill the brief. This has led to extended controversies over specifics of curriculum design (spiral or across-curriculum models, standalone courses, discipline-specific requirements or interdisciplinary elective structures, etc.) each of which offers its own benefits and limitations for content, learning, and engagement. From the perspective of student engagement in particular, it is difficult to motivate students to take ethics education seriously as ethics is usually included in the engineering curriculum as an elective.

Further, the cases use as models in teaching engineering ethics are intended to reflect ethical problems that arise frequently in engineering under rather ordinary circumstances, but undergraduate students found these dilemmas too complext. However, real-life is complex, dynamic and embigous and it is important that students understand the differences between models and real life, and the importance of selecting the model which is appropriate for the situation. One way to overcome this tension is if case studies are limited and the main focus is on cases inspired by real interviews and guest speakers from professional engineers. This partial circumscription of the framework for ethical education facilitates disciplinary engagement (per the previous paragraph) but also provides an opportunity to rehearse different perspectives as models for real human-social situations.

2.3 Building Scientific Culture

In addition, the notion of engaging with complexity through models leads back to a perspective articulated by the pragmatic philosopher Wilfrid Sellars in his 1962 “Philosophy and the Scientific Image of Man” [8]. In that essay, Sellars addresses a fundamental issue regarding the epistemological divide between scientific knowledge (collectively designated the “scientific image”) and human-social knowledge (which he refers to as the “manifest image”) – interpreting each as models of the real world to be reconciled with one another in human experience. While Sellars was concerned primarily about how philosophy might function to mediate between the (apparently distinct) scientific and manifest images of the world, his analysis also offers a new perspective on how technical knowledge and humanistic knowledge might best be synthesized – an obvious concern in contemporary debates about broadening the engineering mindset in practice.

In brief, Sellars argues that the elements of the manifest image, which include such things as intentions and communality and which represent the intrinsically social-human side of reality, must be considered as subjects for inquiry through both scientific and humanistic lenses. The central position of ethics (principles of proper action) to these concerns should be obvious. Thus, the simple moral of Sellars' argument is that principles of good judgment and knowledge of how to act are at stake in our development of knowledge about persons. The shared concerns of humanity – both in our contemporary situation and perennially – encompass multiple sociotechnical dimensions. Sellars pushes us to recognize that addressing these considerations effectively must be a holistic enterprise. On his view, it is the purpose of philosophy, as a human endeavor to produce a synoptic view of these various dimensions of reality as a precondition for fundamental understanding of the world. Philosophy not to be thought of as an intellectual activity in isolation, but rather philosophical perspective serves as a mark of both personal education and cultural development. The emphasis is less on individual *Bildung* than on social progress through collectively shared knowledge. This is not an argument against disciplines *per se*, but a recognition of the value in bringing disciplinary perspectives into conversation with one another more effectively. This requires some level of shared education at the individual level, as well as coordination of communities of knowledge.

Bringing this train of thought back into contact with our concerns about engineering education, Sellars' viewpoint attempts to break down the division between technical and non-technical knowledge that looms so large in debates about how to broaden the engineering mindset to include human and social factors. In his own words,

> [T]he conceptual framework of persons is not something that needs to be *reconciled with* the scientific image, but rather something to *be joined* to it. Thus, to complete the scientific image we need to enrich it *not* with more ways of saying what is the case, but **with the language of community and individual intentions**, so that by construing the actions we intend to do and the circumstances in which we intend to do them in scientific terms, **we *directly* relate the world as conceived by scientific theory to our purposes, and make it *our* world** and no longer an alien appendage to the world in which we do our living [8].

Thus, in our context, the fundamental pragmatic argument that Sellars is making can be summed up as follows:

1) The historical development of science and technology has led to an apparent – but ultimately false - dichotomy between two worldviews: One founded in reason ('scientific image') and the other in human intentions ('manifest image').
2) Among the consequences of this false dichotomy is an externalization of ethics from technical work. This is a problem for engineering education.
3) Human-centered development of science and technology requires greater attention to the individual and collective phenomena of human experience.
4) New knowledge from the social sciences can serve as the fulcrum point for this reconciliation.

Ultimately, then, Sellars' perspective suggests that the key to developing the kinds of engineers being sought by advocates of change today is to embrace an interdisciplinary vision of knowledge that focuses in particular on sciences of humanity in all their apparent complexity. From a practical viewpoint, this would entail a greater pedagogical emphasis on boundary crossing and developing capacities to take multiple perspectives on real world issues, especially beyond a narrow conception of scientific knowledge, as well as a shift in priorities for associated research programs across the modern university. In other words, Sellars encourages us to think about issues in 21st century engineering education from the standpoint of comprehensive institutional change, not merely curriculum change.

This vision is strongly echoed in a variety of recent sources in the social sciences and humanities. For example, one recent review of the social sciences in the United States notes a number of characteristic conceptual foci guiding contemporary work, including 'comparative historical sociology', 'social causal mechanisms', 'new institutionalism' and the 'cultural turn'. Taken together, these emphases reflect several foundational principles: that social – and by extension sociotechnical – outcomes are best viewed as deeply and causally contingent on circumstances requiring case-by-case study within a context of social entities and institutions by means of a heterogeneous interdisciplinary array of methods. One of the key challenges involved in sustaining such inquiry is to coordinate and communicate among the various contributing fields. Another key point of reference is the National Science Foundation's recent survey, Rebuilding the Mosaic [9]. This synthetic treatment of prospects for productive investment in the social, behavioral, and economic [SBE] sciences notes an emerging focus on work with systematic, synthetic, problem-oriented, and data-intensive dimensions. It documents interdisciplinary transformations encompassing not only greater collaboration within and among SBE fields, but also stronger bonds with STEM and humanities fields as well. The four central thematic areas identified in the Mosaic study highlight issues of population, resource access, communication, and technology, and emphasize the challenges of tracking the social environmental mechanisms involved in the disparate paths of different cultures to material and intellectual stimuli; fostering interaction among technical communities and interested publics; and negotiating global versus local interests, values, and cultures. This cross-section of global ethics concerns represents an important connecting thread between inquiry in a wide variety of critical and interpretive disciplines. The same concerns are also articulated in Frodeman and Mitcham's recent call for a 'broad, deep and critical' interdisciplinarity spanning – and transcending – academic boundaries as a means of integrating contemporary knowledge for the formulation of better STEM policy [10].

3 SUMMARY

While this brief survey can only indicate some of the factors that motivate contemporary change in engineering education, we hope that we have at least indicated a few significant distinctions apparent in calls to broaden technical curricula to incorporate specific humanistic and social skills that are more traditionally associated with general education. These different – and potentially mutually reinforcing – motivations reflect an intersection of priorities from professional, pedagogical, and philosophical perspectives. At one level, attention to human-centered design practices has stimulated greater recognition of the value of social knowledge within the engineering workplace. At another, studies of educational engagement suggest that broadening curricula will foster a more satisfied individual engineer, thus making the profession more attractive to a greater spectrum of students. Further, philosophers of science have observed that the demands of modern technological society require new kinds of practical knowledge that are based in human and social factors. While oriented toward different positive outcomes, all of these stimuli point toward a congruent strategy for improvement in the education of engineers, with the common thread being that an ability to contend comprehensively with issues of values – at the level of the individual, the profession, and society at large – is increasingly required in today's world.

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