The Untapped Value of Engineering Education

Using engineering's insights to tackle our most important problems

Engineering provides an approach to problem-solving which is practical yet rigorous. In its commitment to rigor, pure mathematics strays into the abstract and impractical. Fields like number theory and topology develop elaborate mathematical machinery but rarely make contact with the world of experience. Conversely, the technicians responsible for building and maintaining engineered systems have deep practical understanding, but rarely engage with the underlying physical theories to which these systems are indebted. Engineering balances the often conflicting pulls of practicality and theoretical rigor—mathematical abstraction is entertained only to the extent that it has bearing on technology, on the physical world. Engineering rigor entails respecting the constraints of mathematics and natural law, while practicality means building and using models whose primary purpose is to enable the development of technology.

Good engineers know that the models they use to describe, predict, and control the behavior of physical systems—from electrical circuits to load-bearing structures—are not true in any strong sense of the word. The long list of assumptions which precedes any derivation in engineering dispels such illusions, suggesting that models are but approximations to some inscrutable underlying thing. But as our technological world makes clear, engineering models are powerful in spite of their simplifications. Though simplifications can be made for the sake of expediency, engineers learn that they do not have carte blanche. Nature, via physics, imposes clear constraints which must be respected. A model of a mass bobbing on a spring may depart from the real world by excluding air resistance, but it must conserve energy to make any physical sense. Engineering does a nice job of simultaneously instilling in students a humility about models, and a deep respect for fundamental constraints. The dynamics of the mass can be simplified by treating it as a rigid body—as a point, by neglecting friction—but energy conservation can never be ignored. So there are models, which are bespoke simplifications of the world, and there are constraints which any model must respect. Negotiating between customizable models and the constraints of fundamental laws teaches engineers to be both practical and rigorous. My sense is that this approach to problem-solving—the culmination of a successful engineering education—is useful well beyond traditional engineering disciplines. To fully realize the benefits of this approach, engineers should learn to see that their skills are useful for engaging with social problems as well as the physical world.

One such problem is thinking through technology's multivalent influence on society. As I will argue, the engineering approach of building models and identifying constraints can provide useful insight into social, ethical, and political problems of this sort. But for most students and professionals, it is typical to balk at questioning the problems that engineers are tasked with solving. There is an implicit idea of the division of labor here: society makes demands for products and services, and engineers respond to such demands with solutions of ever-increasing sophistication. For the most part, the problem statements coming from society are not viewed as the engineer's business. As an example, very few aerospace engineers are concerned with the ethics, philosophy, or politics of flight, as it seems obvious that society's appetite for this technology certifies its value. Perhaps engineers become more philosophical when considering work in the defense industry, but the manufacture of private sector goods is usually viewed as a topic for which critical reflection is unnecessary. But life is increasingly technological, which means that technologies control the ways in which we interact with friends (social media), employment (remote work), politics (online news), and how we spend our time (entertainment). Technology profoundly influences our experience of the world. Could something so ubiquitous honestly be viewed as neutral, as not in need of critical reflection? Engineers are comfortable thinking about the *how?* of technology production, but not the equally important questions of *why?* or *for whom?* What might it look like to focus the logic of engineering on these questions as well? After all, such questions about the *purpose* of engineering are just a small step away from more familiar questions about the *practice* of engineering. Seeing the wide-reaching influence of technology raises doubts about the division of labor story—shouldn't engineers have some responsibility for the things they create? With this in mind, it is clear that engineers should be comfortable with both sets of questions.

Engineers must be willing and able to think more philosophically about how technologies shape the world—and why this matters—if they are to utilize their problem-solving skills on the big questions of ethics and human flourishing. The advent of large language models is an unequivocal example of how private sector companies can radically reorient the public's understanding of topics as diverse as education and consciousness. In spite of this tremendous power, the technologists behind companies like OpenAI are not subject to any democratic electoral process. One might rely on the conviction that all technological development is good, or that market pressures will select for technologies that contribute positively to humanity, but, from the atomic bomb to social media's attention economy, there are many examples showing these hopes to be ill-founded. An alternative is to encourage engineers—as holders of the power to shape the world through technology, and as members of society's de facto intellectual elite—to apply a fertile blend of rigor and practicality not just to their work, but to reflections on the social consequences of their work.

Of course, I am not the first to argue that technologists should draw from the humanities in order to engage with social, ethical, and philosophical questions. Zakaria (2015) calls for a broader definition of innovation, which includes "how technologies interact with human beings," as opposed to focusing only on technical dimensions. Nussbaum (2010) challenges the increasing emphasis on STEM education, arguing that humanistic learning is essential for healthy democracy. In a follow-up book, she encourages policy makers and analysts to see how quantitative measures of a country's development can mislead by prioritizing narrow economic markers over genuine human flourishing (Nussbaum, 2013). Flyvbjerg shows with a case study that analytical and technical ways of encountering the world must be complemented by more holistic and intuitive approaches—which he calls *phronesis,* using the ancient Greek term for practical wisdom—in order to achieve just outcomes for a Danish town (Flyvbjerg, 2001, pp.

144-165). Winner convincingly demonstrates the insufficiency of standard "personal responsibility" approaches to engineering ethics, advocating for a "political" approach to engineering which emphasizes seeing responsibilities and impacts at the level of the community (1990). As a team of philosophers and physicists, Frank, Gleiser, and Thompson problematize the common assumption that science provides an objective view of reality, claiming that this distracts from other "experiential" ways of knowing which are essential for understanding the world (2024). Lastly, Leydens and Lucena from the Colorado School of MINES propose an "engineering for social justice" curriculum which aims to reduce the harms of engineered systems through six criteria for justice (2018, p. 21). All of these approaches rightfully acknowledge that engineers are not taught to think as humanists, and that this can lead to poor outcomes for those who are downstream of engineered systems. Each proposal strives to incorporate into engineering a way of thinking which is external to engineering in order to realize more just technologies. Naturally, engineers must be educated to understand the intricacies of the social and political systems which their technologies impact.

What these approaches miss, however, is that there is a wealth of knowledge from *within* engineering that might supplement these insights from the humanities. The potential to make use of these hard-earned problem-solving skills on ethical, social and political questions is the untapped value of engineering education. The practicality and rigor of the engineering mindset need not be at odds with the holistic, normative approaches of the humanities. Here, one of my goals is to sketch how techniques from engineering can be mapped onto these social problems from which they have historically been isolated.

In order to think about the social consequences of a technology from an engineering perspective, we need to know what "variables" to pay attention to—an integral first step in the model-building process. Though any model of the good life—perhaps consisting of things like health, community, connection to place, enjoyment of beauty, agency—is necessarily an oversimplification, it is an important step in thinking normatively about technology. Of course, the quality of a human life cannot be scored against a short checklist, but a model of flourishing which is thoughtful, holistic, yet clear, offers many benefits. Here, as in the case of engineering, a good model will define and focus on the salient variables, discarding extraneous details in the process. This simplifies the problem, provides a common language, and clarifies what is important to pay attention to. But if one's goal is to steward technological development to promote such a vision of the good life, it is also necessary to responsibly reckon with social, political, and economic constraints. Capitalism is probably not going anywhere soon. The status quo has inertia, and companies are motivated by the bottom line. Hopefully, the practicality of the engineering mindset disavows utopianism which can only imagine flourishing in a radically different world. With a model in hand and an understanding of constraint, engineers are uniquely adept at analyzing and controlling systems. Given the power that technologists wield in today's world, it is increasingly important that they think as both scientists and humanists, simultaneously asking *what is possible?* and *what is good?* An engineering education is primarily seen as a reliable route to financial security, to intellectually stimulating work, or if you are an employer, to hiring an employee who is comfortable with challenges. But alongside these virtues, through pushing engineering thought into the territory of the humanities, we can view an engineering education as a useful tool for thinking about and acting on important social problems, although they resist distillation into simple mathematical formulae.

Finding a way to steward technology for the good of society, as opposed to the good of a few corporation's shareholders, is one such social problem. But there are obviously many others. I imagine a new kind of engineer, intellectually outfitted for the wickedly interdisciplinary problems of the 21st century. First and foremost, such an individual's loyalties need to be with the wellbeing of people, whether that is the local community, nation, or the world. Through its passion for justice, the humanities succeeds in fostering this loyalty, and science tends to fail. In order to understand people and their needs, it is necessary to engage with stories and narrative, not just abstract and impersonal theories. It is also necessary to ask ethical, political, and philosophical questions which engineers are often uncomfortable with: What process or group determines the problems that engineers work on? Who gains and who loses from a product? What are the goals of technological innovation? What role does engineering play in actualizing human flourishing? What role should it play? Though some prominent 20th century scientists like Robert Oppenheimer and Bertrand Russell were engaged in such questioning, the academy's current emphasis on specialization and research output makes this quite rare. For most of us, answers to these questions paint the picture of an often imperfect world. The injustice and irrationality such humanistic questions expose is the interdisciplinarily-engaged engineer's call to action. How can engineering's insights best be applied to these problems?

In order for students to appreciate the flexibility inherent to the engineering thought process, it is necessary for their education to go beyond memorization and passive absorption of concepts. Engineers need to be educated as participants in the fundamentally creative process that builds up each discipline. The study of fluid mechanics revolves around an imaginative application of Newton's Second Law (F=ma) to each and every particle in a flow. It is amazing that the same principle which describes collisions of billiard balls can be used to model turbulent vortices in the flow around an airplane wing. When students can clearly distinguish between empirical physical laws, creative modeling choices, and self-evidently true consequences of mathematics, they have acquired a birds-eye view of the subject matter. This perspective helps recognize that science relies on human ingenuity and imagination as much as it does on the empirical study of nature. It becomes clear that we can't help but think through models, that models attend only to what is relevant, and that relevance is defined in reference to human goals. From this vantage, we observe the fundamental movements of mind which transform confusion and complexity into clarity and predictability. With this flexible and philosophical view of the scientific process, students will see that the techniques they are learning could be used to grapple with any problem.

If engineers can be convinced through deeper study of the humanities to devote their efforts to the wellbeing of people and communities, and if they learn to see engineering fields as particularly clear-cut examples of a universal modeling process, we may start to harness some of engineering's power to make progress on social problems, even when solutions are not technological. This is because the utility of thinking which is both practical and rigorous need not be limited to the development of technology. In fact, if we accept that basic, universal virtues like health, community, place, beauty, and agency are what really matter, we—as students, professionals, and citizens—should be stricter in demanding a clear account of how traditional technological innovation fosters these things. Of course, in a diverse, liberal society there is no reason to expect consensus around core values, and my list may be contested. But spirited, thoughtful, and self-conscious debate about values—and especially technology's role in realizing them—is a far-cry from the widespread political and philosophical illiteracy characteristic of a traditional engineering education. Whether they know it or not, engineers accrue power as technology continues to infiltrate more areas of life. Perhaps the future may bring a more radical reimagining of technology's place in society, but the first step toward more humane technology is educating engineers to see their power and to use it responsibly.

What exactly does it mean to use this power responsibly? This is an abstract and open-ended question with answers seriously constrained by the realities of the current world. But engineers have extensively trained in balancing the rigors of abstract thought with practical constraints. I trust that we can find an answer to this question if we go looking for it. But such pursuits may involve deviating from the beaten path of comfortable careers in industry and academia, and thinking about problems that lack the infrastructure of recognition and prestige that narrow technical questions enjoy. One can only hope that committing to goals beyond personal comfort, innovation for its own sake, or corporate profit is reward in itself.

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