Engineers as Problem Solvers: A Deficient Self-Definition for the 21st Century

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Abstract

Problem solving is upheld as a defining feature of engineering identity, and the ability to solve problems is built into engineering curricula as a learning outcome and a graduate attribute. The notion that problem solving is a desirable and defining attribute of engineering education and practice is hardly ever examined critically, let alone called into question.

The goal of the paper is to explore the extent to which our focus on problem solving, and the professional ethos of which it is part, determines our mode of engagement with the world and limits our ability to tackle root causes of social and environmental issues in technologically advanced societies. We argue that a focus on problem solving, at least in its current incarnation, brings with it epistemological and political biases which limit our ability to reflect on our knowledge acquisition and problem definition processes, and therefore to tackle problems effectively. Although a number of authors have suggested ways in which engineers could move beyond problem solving, we contend that the profession's attempts to maintain relevance in the 21st Century will falter unless engineers clearly enunciate the "public good" that they are mandated to build or protect. The nature of this mandate will have far-reaching implications for our institutions, disciplines and educational programs. We illustrate this point by showing how one particular formulation of the public good of engineering can be translated into a new set of disciplinary boundaries.

1 Introduction

Engineers, in academia and practice, often define themselves as problem solvers[1]. We tell our students that their problem solving abilities will distinguish them from other graduates, help them land the job they want and make a valuable contribution to society. Although we never say that we are the *only* technological problem solvers around, there is undoubtedly a hint of exclusivity in the way we talk about ourselves in this respect[2]. Arguably, problem solving is seen by communities of engineers around the world as the single most important skill defining engineering practice—notwithstanding cultural, institutional and disciplinary differences (Downey, 2005). Much anecdotal evidence for this proposition can be gleaned from conversations in the classrooms and hallways of University engineering departments in the English-speaking world. But empirical evidence can also be found in engineering curricula and engineering codes of practice. For example, a middle school learning resource – called "Engineers: Who They Are and What They Do?" – published on the ASME website

[1] In this paper, we make statements which we believe generally reflect aspects of engineering that are practised and taught today, based on published evidence and our own experience; however, we are also aware that the world of engineering is diverse and open to a range of influences across disciplines, nations and cultures, and will of course contain many exceptions to the claims we make here.

[2] Both meanings of "technological problem solving" are intended here: solving problems using technology and solving problems caused by technology and its pervasiveness in the modern world.

(a United States engineering professional development and standards organisation) states that "the engineer is basically a problem solver" (ASME, 2013).

An online survey with 3,600 participants conducted by the US National Academy of Engineering (NAE) studied the public perception of engineering. The first of four key messages expressed by the participants and which the NAE study committee felt should be reinforced was that "engineers are creative problem solvers" (NAE, 2013).

The goal of this paper is to critically examine problem solving as a defining feature of engineering and the extent to which it helps or hinders our ability to tackle social and environmental challenges in the twenty-first century. We begin by reviewing a small body of literature that has questioned the problem solving focus. We then argue that engineers do not necessarily have a concrete sense of the public good they seek to build–a problem rooted in their professional identity–and that a focus on problem solving helps conceal this deficiency. Finally, we attempt to show how articulating the engineer's mandate as a contributor to the public good can lead to a re-conceptualisation of disciplinary boundaries in engineering.

2 A Critique of Problem Solving as Engineering Ethos

The merits and drawbacks of problem solving as a defining feature of engineering have been discussed in the literature[3]. A number of authors claim that education based primarily on problem solving, prevents engineers from thinking outside the technical box and reduces their ability to tackle "ill-structured problems", i.e. those that are characterised by uncertainty, contradictory and incomplete information and multiple stakeholders (e.g., Jonassen et al., 2006). Our approach may also privilege mathematical abstraction and reductionism while overlooking the different ways in which engineering is inscribed into social and political realms, since according to Giddens (2009), "technologies never operate on their own–they are always embedded in wider political, economic and social frameworks, which are likely to govern both how they develop and what their consequences are". A problem solving approach has gained credence in engineering because once a problem has been defined and circumscribed (i.e. the boundaries are identified, distinctions are made between "constants" outside our control and "design variables" we are able to change), a problem solving mind-set allows us to develop powerful analytical tools which elicit the most "rational" solution to the problem. However, it also limits our scope and confines the solution space in which we conduct our search, in at least two ways.

First, problem solving necessarily favours limited-time horizons that are typically determined by the project's own functionalities and the parameters of success and failure pertinent to our client. This is often at odds with the cumulative and long-term effects of our actions, which usually impact the public good and can only be identified by a vision that goes beyond the timeline of the project. For example, designing and building a highway between two major cities is judged by its effective carrying capacity, its cost and its maintenance requirements, rather than the way it fits with national transport policies or the ecological systems it may disrupt. This is precisely what formal environmental impact assessments–a requirement for such infrastructure projects–impel engineers to do: extend their vision beyond individual projects to identify environmental externalities and effects on the global commons. And yet the impact assessment exercise tends to be extrinsic rather than intrinsic to our modes of

[3] For the remainder of the paper, we use the term problem solving in this particular sense of a defining feature of engineering, an analytical process that carries with it, implicitly or explicitly, a particular way of looking at the physical and social worlds.

thinking and action. We tend to do it as an afterthought, sometimes reluctantly. Hence, the environmental dimensions of our engineering projects become marginalised by the very way in which our problems are configured (unless of course the primary purpose of the engineering project is environmental). A redefinition of the problem that would have a better chance of capturing social and environmental dimensions would ask “what is the best way of moving people and freight between the two cities”, rather than, “how best to build a highway between the two cities”? This would open a whole vista of new solutions, including railway and air travel, but would require engineers to be able to understand and work with tools of social policy, economic analysis and environmental science, largely unavailable in our curricula. The “problem”, of course, may sometimes be *given* to engineers, who may not have the political power to reformulate it even if they would like to. However, the question here is whether we have the tools, by virtue of our education and training, necessary to question the problem, reformulate it and assume intellectual leadership in the public debate and policy-making around it.

Second, our problem-solving ethos privileges technical approaches to problems, and abides by a technological rationality that can be biased philosophically and politically. By foregrounding technological constructions of a problem and relegating or overlooking its social and political dimensions, we structure it in such a way that some solutions (predominantly technical in nature) and some interests are favoured at the expense of others. In fact, technical and economic sciences in engineering curricula are *doubly* privileged because they lack the tools to reflectively critique epistemological choices, while marginalising the social and political sciences in which such tools are well developed. A classical example is our preference for supply-side solutions of water and energy problems, when in many cases a reduction in demand is by far the more rational option. Nor is our compliance with the technical paradigm always innocent, since engineering firms are more likely to reap financial benefits from supply-side solutions, which usually require a major investment in infrastructure or technology of some form. This is especially the case when a technological fix suits the political administration, for electoral, ideological or bureaucratic reasons. In the case of energy problems, technical and economic understandings of the dynamics of energy supply and demand will necessarily focus on designing cheaper and more effective materials and processes. However, the energy landscape within which we operate is essentially the outcome of past investment strategies in research and infrastructure, and the political dynamics behind them. Indeed, sound solutions to energy problems must also allow for the fact that energy sectors such as oil and gas only appear more “economical” than renewable forms of energy today because of heavy government subsidies in the past. In other words, in order to cover the full range of available solutions for the future, engineers should be able to evaluate the viability of the oil, gas and coal industries, in a sense engineering themselves, if need be, out of one of the most profitable engineering industries.

Prescriptions typically call for broader paradigms of decision-making and problem definition, as well as problem solving, hence encompassing “non-technical” subject matter in management and social sciences (e.g., Holt et al., 1985; Mitchell et al., 2004; Downey, 2005; El-Zein et al., 2008). Holt et al. (1985) contrast problem solving with what they call “creative design approach”, arguing that the latter, unlike the former, allows engineers to “[combine] analytical thinking with human factors in engineering design to create and take advantage of opportunities to serve society.” Interestingly, the same authors subscribe to the notion, advanced by Small (1983), that the essential task of engineering profession is wealth generation–although for whom and in what form remains unclear. Mitchell et al. (2004) and Pielke (2007) suggest that engineers ought to become “honest brokers” in social conflicts around technology, and act in the interest of the common good rather than corporate or government interests. This necessarily requires engineers (and scientists in this case) to engage with the social and political dimensions of technology, which they rarely have the training to accomplish. Over the last decade, a number of authors have explored in some detail ways in which history, social justice, globalisation, environmental sustainability and politics can be incorporated in engineering thinking and engineering curricula (e.g., Baillie, 2006; El-Zein et al., 2008; Bell, 2011).

Downey (2005) offers a far-reaching analysis of what he sees as a gradual loss of control over technology and technological innovation by engineers, with scientists increasingly able to convert scientific breakthroughs into industrial applications without help from engineers. He argues that engineering education should go beyond problem solving into problem definition and solving (PDS). There is no doubt that encouraging engineering students to engage with the process of problem definition, prior to problem solving, would be highly beneficial and would go some way towards addressing the issues raised above. However, we argue that, without a better articulation of the public good that engineering serves, a shift to PDS is unlikely to reap the benefits it is meant to.

According to Downey (2005), PDS would be characterised by collaborative work amongst the problem's stakeholders, inclusion of non-technical aspects of the problem and the exercise of "leadership through technical mediation". What distinguishes this prescription from business and knowledge management, Downey writes, is that "the scope of [technical mediation by engineers] would *continue to extend* beyond the identity of the firm" [our emphasis] (Downey, 2005). In other words, engineers would have, not just the firm's interests in mind, but some broader public interest. However, Downey does not tell us why this would be expected to occur. Nor is it clear that the scope of engineering vision and action presently enjoys such breadth (as the word *continue* implies). In fact, engineers are likely, as much as technical and business managers, to identify more or less exclusively with the organisation for which they are working, unless they have a clear sense of the public interest of which they are custodians–especially if they are employed in the private sector, as most of us are[4]. A key question, therefore, is what form might such a public good take?

3 What is the Public Good that Engineering Serves?

In a core unit of study taught by the first author to third-year civil engineering students at the University of Sydney, students are asked in the first week of the semester to suggest a word that best describes what engineering is about, who engineers are and/or what their mission is. The words that occur most frequently are "efficiency", "problem solving ability" and "design". What is striking about these descriptions is their moral neutrality as a social good. What they describe are *attributes of modes of interaction with technology*. In other words, they are means to an end, but the end in question remains woefully unarticulated. Efficiency, design and problem solving have the ability to do as much harm as good, depending on whose interests they serve. The planning and implementation of the Holocaust, the conduct of World War II and the incineration of Hiroshima and Nagasaki that concluded that war were all accomplished with considerable efficiency, design skills and problem solving. The September 11 terrorist attack on New York in 2001 and the terrorism of Anders Behring-Breivik in Norway in 2011 must also have necessitated a highly effective engagement with technology and technical problem solving. So what is the morally justifiable end that engineers seek to achieve through technological means?

[4] Engineers, like all other citizens, are moral and social beings, as well as being engineers, and to this extent their identification with their employer is never absolute. However, what we are concerned with here is whether their *professional* identity per se is likely or not to create limits to their identification with the organisation that employs them.

Health practitioners can claim “health of communities and individuals” as the ideal they strive for. The two organising principles for practitioners of the law are “justice” and “respect for the law”. A clear articulation of a public good as a core mission for a profession is of course no guarantee that all members of that profession will act in accordance with that ideal. After all, there are many instances in which doctors are complicit in torture, judges break the law, lawyers take bribes or help the firms they work for bend the law and so on. However, the reason we see these instances as offensive aberrations is precisely because we invest nurses, doctors, judges and lawyers with those ideals and expect them to behave accordingly. Contrast this with the involvement of engineers in the design, deployment and operation of technologies of violence i.e., weapons and ammunition. It goes without saying that, in many instances, this involvement may be entirely justified, depending on the circumstances. Our point here, however, is that engineering contribution to technologies of violence is *not* seen by most engineers as an act in need of justification; it does not seem to offend our professional sensibility and, most of the time, goes unnoticed. This, we believe, is symptomatic of the lack of clear articulation of the public good that engineering is supposed to serve.

An online review of the stated visions or missions of main professional engineering bodies in the UK, USA and Australia reveals a common leitmotif–engineers are concerned with improving or maintaining quality of life. There is far less consensus on what “quality of life” means or how engineers might contribute to it. Some engineering organisations recognise the importance of attempting a definition of quality of life to guide future developments in their profession. The Institution of Chemical Engineers (UK, Australia) demarcates four key challenge areas for the profession: energy, water, food and nutrition, and health (IChemE, 2013) and discusses the technological, environmental, policy, and social dimensions of sustainability in each of these areas. The American Society of Civil Engineers is implementing an educational reform strategy called “Raise the Bar” to help Civil Engineers better deal with modern challenges of globalisation, sustainability and emergent technologies. It defines the purpose of civil engineering accordingly:

“...to utilize, economically, the materials and forces of nature for the progressive well-being of humanity in creating, improving and protecting the environment, in providing facilities for community living, industry and transportation, and in providing structures for the use of humanity” (American Society of Civil Engineers, 2008).

The extent to which these relatively new and progressive articulations of the public good by committees at institutional level have worked their way into our education, mind-set and practice is of course debatable.

Other organisations are less holistic in their definition of the public good. The UK’s Royal Academy of Engineering structures its work programs around four strategic challenges. Three of these challenges are reflexive (improve engineering leadership, education and public recognition of engineers) while the fourth, “Drive faster and more balanced economic growth”, makes reference to public good only through the advancement of corporate interests: “to improve the capacity of UK entrepreneurs and enterprises to create innovative products and services, increase wealth and employment and rebalance the economy in favour of productive industry” (Royal Academy of Engineering, 2012).

Some organisations make no easily accessible and explicit reference to the public good in engineering on their websites. It is common to define the profession by listing its diverse disciplines (e.g., see Engineers Australia, 2013), or by simply referencing the fact that we are responsible for “technological innovation” (IEEE 2013), or the “application of science” (NAE, 2013) for the good of humanity. The absence of a publicly accessible definition of the public good of engineering does not necessarily imply that these organisations have not developed insights into the moral purpose of their profession–Engineers Australia does list some progressive definitions of new engineering disciplines. Yet such definitions restrict the public imagination to engineering as a profession that simply tests, operates and "designs under constraints" (NAE, 2013).

Why do we need to articulate the engineering public good? The most direct answer to this question is that, like medical and legal practitioners, our training and status infers on us power and authority through our connection to technology. How we use this privilege is of great significance to us and to the rest of society, especially in democratic systems of government. An articulation of the engineering public good is, in a sense, our part of the bargain, our way of agreeing to the terms of our contract with society. But another, broader answer to the question is that how we define ourselves and how we see our ultimate aims is bound to have far-reaching implications, not just for our ethical codes, but for almost all aspects of our work: the way environmental sustainability is inscribed in engineering practice, our disciplinary divisions and institutional arrangements, what we teach our students and how we design our curricula and, not least, the terms of our relationship with government and the corporate world. Defining the public good of engineering is of course beyond the scope of this paper. Ultimately, it would have to be the outcome of wide deliberations in the profession and the Academy and may well be context-specific, i.e. it may be different for different communities of engineers. However, in the following section, we will offer one possible formulation of such a public good, but only in order to show how it might lead to a new configuration of engineering disciplines.

4 "Public Good" and Disciplinary Boundaries

Engineering could be defined as a profession which aims to provide access to safe water, air, food, habitat and means of transport, as fundamental human rights; it does so through technological innovation and rational management of resources. Such a formulation is of course a tentative one and open to criticism on a number of fronts. For example, where does information technology, computer engineering and space engineering, all of which are important engineering endeavours, fit into this definition? Shouldn't space exploration be an end in its own right? Can access to clean air be seen as a human right and what are the implications of this? Should the word "equitable" be added before "access" and what would be the implications of this? What does "rational" mean in this formulation? Our aim is not to argue for this definition but to use it for illustration purposes.

Following from this formulation, it is possible to envision a specific set of engineering disciplines, to replace conventional ones:

a. Water engineering
b. Habitat engineering
c. Food engineering
d. Transport and communication engineering

Under this vision, a habitat engineer would need all the knowledge and design and analytical skills that a structural engineer is expected to have today. However, as the custodian of the right to safe shelter, a "habitat engineer" would have the means to understand the causes of urban homelessness, the physical, economic and social dynamics of emergency shelters and refugee camps, housing market economics and politics of urban planning and zoning, to name a few fields of study that are currently considered outside the scope of engineering education. The same argument can be made for a water engineer, who would possess conventional technical skills including wastewater processes, hydrology, water quality and coastal science, augmented by knowledge of the politics and law of competing interests in access to water resources, and the sociology of demand management.

Such a reconfiguration of disciplinary boundaries would be useful in four ways. The first is that, under such a formulation, engineers would still maintain a privileged relationship to technology and would still act primarily, though not exclusively, through technological design and innovation. Second, *which* problems we choose to solve in the first place would be radically altered by this shift: not “structure” but “habitat”, not “chemical” or “civil” but “water”. Technical specialisations would remain important (e.g., chemical processes, structural design, materials science and development) but would no longer have to define our identity. Third, *how* we solve problems would change, with engineering vision becoming broader and engineers more aware of the dangers of technological bias, in both its epistemological and political forms discussed earlier in this paper. Fourth, age-old trade-offs in engineering curricula–between technical and non-technical subject matter, between fundamental and applied science or between analytical and design skills–would be seen in a new light and lead to a rethinking of engineering education in its content, extent and duration.

It is important here to remind the reader of the historical contingency of current disciplinary divisions. After all, the boundaries between mechanical, civil, chemical and electrical engineering, to take four main branches, have always been fluid and have probably emerged for specific historical reasons as shown by Alder (1997) and others. In other words, there is nothing inherently inevitable about conventional disciplinary divisions in engineering. Over recent years, new disciplines have indeed emerged, spanning more than one conventional engineering department and drawing on knowledge from other fields (e.g., *building engineering* with its interest in structural design, energy and water conservation and broader urban planning). The emergence of these new disciplines should serve as a reminder of the increasing mismatch between current disciplinary boundaries and today’s social and technological problems. Nevertheless, and regardless of the degree of truth of this claim, what we hope to have shown here is not so much the superiority of one formulation over another but the extent to which the explicit articulation of a public good or ultimate aim for engineering can have far-reaching consequences for the way we do things.

Conclusions

Problem solving in engineering can be a powerful mind-set, which equips us with the analytical skills needed to negotiate the incredibly complex scientific and technological terrain of the 21st century. However, in its current formulation, it does not allow us to envision the full range of solutions to problems available to society and leaves us with an overly reductionist rationality. As Downey (2005) has argued, it can turn us into mere technical tools in the service of leadership and vision coming from outside engineering.

As a number of authors have shown, it is possible, indeed necessary, for engineering professions to combine a problem-solving ethos with a more reflective worldview that engages with the social and political dimensions of technological challenges. However, we have argued in this paper that, concomitant with this effort, there is a need for us to better define the public good that we are meant to pursue, increase and protect. There is no single answer to this question of course, and different communities of engineers may have different answers. However, if we do not seriously engage in such a debate, as individuals and institutions, in practice and academia, our efforts at tackling the social, economic and environmental challenges of the 21st century would remain limited by inherent, often unconscious biases that limit our understanding of the problems we ask ourselves, or are asked by others, to solve. And if we do not have a thorough understanding of the problem, we cannot expect to be able to solve it.

References

Ken Alder. 1997. *Engineering the Revolution: Arms and Enlightenment in France, 1763-1815* Princeton University Press.

American Society of Civil Engineers. 2008. *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*. ASCE: Reston Virginia, USA. <http://www.asce.org/uploadedFiles/Leadership_Training__New/BOK2E_%28ASCE_2008%29_ebook.pdf>. Date accessed: 17 May 2013.

ASME. 2013. *Engineers Solve Problems*. "Activity 1 – Engineers: Who They Are and What They Do". <http://www.asme.org/groups/educational-resources/engineers-solve-problems/activity-1---engineers--who-they-are-and-what-they> Date accessed: 17 May 2013.

Mitchell CA, Carew A, and Clift R. 2004. The role of the professional engineer and scientist in sustainable development. Chapter 2, in A Azapagic, S Perdan, and R Clift (eds) *Sustainable Development in Practice*. John Wiley & Sons, London.

Caroline Baillie. 2006. *Engineers within a Local and Global Society*. Morgan and Claypool Publishers.

Sarah Bell. 2011. *Engineers, Society and Sustainability*. Synthesis Lectures on Engineers, Technology and Society. Editor: Caroline Baillie. Morgan and Claypool Publishers.

Downey, GL. 2005. Keynote Lecture: Are Engineers Losing Control of Technology? From "Problem Solving" to "Problem Definition and Solution" in Engineering Education. *Chemical Engineering Research and Design* **83**(A8):1-12.

El-Zein A, Airey D, Bowden P, Clarkeburn H. 2008. Sustainability and ethics as decision-making paradigms in engineering curricula. *International Journal for Sustainability in Higher Education,* **9**(2):170-182.

Engineers Australia. 2013. *What is Engineering?* <https://www.engineersaustralia.org.au/professional-development/what-engineering> Date accessed: 17 May 2013.

Giddens, Anthony. 2009. *The Politics of Climate Change*. Polity Press: Cambridge, UK, p.130.

IChemE. 2013. Chemical Engineering Matters: A review of IChemE's technical strategy. <http://www.icheme.org/~/media/Documents/icheme/Media%20centre/Technical%20strategy/c0001_12%20chemical%20engineering%20matters_FSC_web.pdf> Date accessed 17 May 2013.

IEEE. 2013. IEEE Mission and Vision. <http://www.ieee.org/about/vision_mission.html> Date accessed: 17 May 2013

Jonassen D, Strobel J, Lee CB. 2006. Everyday problem solving in engineering: lessons for engineering educators. Journal of Engineering Education, **95**(2), 139-151.

NAE. 2013. *What is engineering and what do engineers do?* <http://www.nae.edu/About/FAQ.aspx> Date accessed: 17 May 2013.

NAE. 2011. *Developing Effective Messages for Improving Public Understanding of Engineering.* http://www.nae.edu/Projects/20760.aspx. Last updated: 15 July 2011. Date accessed: 17 May 2013.

Pielke RA. 2008. *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge University Press, Cambridge, UK.

Royal Academy of Engineering. 2012. *About Us*. <http://www.raeng.org.uk/about/> Last updated: August 2012. Date accessed: 17 May 2013.

Small BW. 1983. Wealth generation–our essential task. *Proc. Inst. Eng.* **197B**:131-141.