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Beyond problem solving: Engineering and the public good in 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. The goal of the paper is to explore the extent to which the focus by engineers on problem solving, and the professional ethos of which it is part, determines their mode of engagement with the world and limits their ability to tackle root causes of social and environmental issues in technologically advanced societies. The paper's contribution to the literature is twofold. First, it argues that a focus on problem solving, brings with it epistemological and political biases which limit the ability of engineers to reflect on their knowledge acquisition and problem definition processes, and therefore to tackle problems effectively. Second, it is proposed here 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, reinforce or protect. The nature of this mandate will have far-reaching implications for engineering institutions, disciplines and educational programs. This point is investigated by translating one particular formulation of the public good of engineering into a new set of disciplinary boundaries and curricular subject matter. A survey of academic and teaching staff at the School of Civil Engineering of the University of Sydney is conducted to assess the extent to which the paper's arguments about the public interest of engineering are likely to be accepted by engineering educators.

1. Introduction

Engineers, in academia and practice, often define themselves as problem solvers. Engineering students are told 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 engineers do not say that they are the *only* technological problem solvers around, there is undoubtedly a hint of exclusivity in this claim. Problem solving is seen by communities of engineers around the world – despite cultural, institutional and disciplinary differences – as the single most important skill defining engineering practice (Downey, 2005). An online survey with 3600 participants conducted by the US National Academy of Engineering (NAE) studied the public perception of engineering. A key message expressed by the participants and which the NAE study committee felt should be reinforced was that "engineers are creative problem solvers" (National Academy of Engineering, 2011).

Furthermore, the focus on problem-solving is institutionalized through its listing as a key competency in engineering University curricula and key formal documents published by national and supra-national engineering institutions, such as the Engineering Criteria of the US Accreditation Board for Engineering and Technology (ABET) (Lattuca et al., 2006) and the EUR-ACE accreditation framework of the European Standing Observatory for the Engineering Profession and Education (ESOEPE) (European Accreditation of Engineering Programmes, 2009). Various approaches to the achievement (e.g., Sudheer Reddy and Srinagesh, 2013) and assessment (e.g., Gibbings and Brodie, 2008) of problem-solving skills and competencies have been proposed in the literature.

Arguably, the most significant change in engineering curricula over the last two decades has been the introduction, in various forms, of various competencies related to environmental and social

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sustainability in engineering degrees (e.g., Lattuca et al., 2006; von Blottnitz et al., 2015). This has generated a rich scholarship on sustainability and engineering, notably in journals such as *Journal of Engineering Education*, *Journal of Cleaner Production* and *International Journal of Sustainability in Higher Education*. The scholarly debate usually revolves around whether sustainability competencies should permeate the whole curriculum (e.g., Price and Robinson, 2015; Christ et al., 2015), how best to develop sustainability learning outcomes and achieve them through problem-based or project-based learning (e.g., Bielefeldt, 2013; Fernandez-Sanchez et al., 2015), how to teach problem-solving of wicked or ill-structured problems associated with sustainability issues (e.g., Downey, 2005; Jonassen et al., 2006) and what kind of barriers within institutions of higher education need to be overcome in order to achieve effective integration of sustainability learning outcomes in the curriculum (e.g., Barth and Rieckmann, 2012; Hoover and Harder, 2014).

Wiek et al. (2011) reviewed the literature on competencies related to sustainability science and offered an analytical framework founded on five types of core competencies: a) complex systems thinking for understanding human-environment interactions, b) anticipatory competencies that help in shaping sustainable futures, c) normative competencies related to values, justice, equity and knowledge, d) strategic competencies geared towards synthesis, green design and community development and e) interpersonal competencies related to inter-disciplinarity, civic engagement and communication skills. Most engineering curricula have incorporated some of these competencies over the last two decades, to varying extents and using different approaches. However, an effective incorporation of normative competencies (point c above) remain largely missing from engineering degrees (e.g., El-Zein et al., 2008; Baillie and Catalano, 2009).

On the other hand, issues pertaining to the mind-sets (e.g., Riley, 2008, p 33), corporatized (e.g., Baillie and Catalano, 2009) and gendered (e.g., Faulkner, 2007; Cech et al., 2011) identities of engineers, as well as their epistemological and commercial biases (e.g., Jamison et al., 2014; Amir and Juraku, 2014) have been discussed in a small but rich body of literature, inevitably raising questions about the nature of the public good that engineers serve and/or ought to serve. However, to the best of our knowledge, there has been no attempt in the literature at critically examining the relationship between a problem-solving ethos and the articulation of the public good of engineering, as well as the extent to which the latter is important or not for incorporating sustainability challenges within engineering education and practice.

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 the ability of engineers to tackle social and environmental challenges in the twenty-first century. The paper investigates three hypotheses. First, the focus on technical problem-solving, while equipping engineers with powerful skills in specific professional contexts, can be detrimental to their ability to tackle key environmental and social challenges. Second, developing a more contextualized engineering education that goes beyond problem-solving requires some articulation of the public good of engineering, which is currently either absent from, or poorly defined in, engineering education and practice. Third, any articulation of the public good of engineering inevitably calls into question historically inherited disciplinary boundaries, as well as the relationship between, on the one hand, the engineering profession and academy and, on the other hand, industry, the private sector and government. The paper investigates these hypotheses through an analytical review of the literature on competencies and mission statements of engineering organizations, as well as a small but rich scholarship that is critical of the technical and problem-solving focus of engineering curricula.

2. Method

The investigation methodology of the paper follows six steps. First, a small body of literature questioning the teaching of problem-solving in engineering is discussed. Ways in which a focus on problem-solving can limit the ability of engineers to engage with the broader context of engineering are suggested and analyzed. Second, a survey of mission statements of engineering organizations in the US, the UK and Australia is conducted and the presence, or lack thereof, of an articulation of the public good that engineering ought to serve is investigated. Third, the rationale for such articulation is presented and discussed. Fourth, the link between disciplinary boundaries, curricular subject matter and the public good of engineering is analyzed. This is done by offering one possible formulation of the public goods of engineering, taking as a starting point fundamental rights to shelter, food, water, energy, connection to social networks and healthy lives and environments. Fifth, a new set of disciplinary boundaries are drawn around these rights and a set of themes that can form the foundation of an engineering education in each of these disciplines, proposed. Hence, the new formulation is used to explore the extent to which an articulation of the public goods of engineering can lead to a significant redrawing of engineering disciplinary boundaries, and may fundamentally change the scope of subject matter covered in engineering curricula. Finally, a survey of academic staff at the School of Civil Engineering of the University of Sydney is conducted, in order to gauge the extent to which they believe that an articulation of the public goods of engineering is important and whether an alignment of engineering disciplines and taught subject matter with specific public goods is likely to produce a better understanding of the public interest of engineering by students.

3. 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. 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 characterized by uncertainty, contradictory and incomplete information and multiple stakeholders (e.g., Jonassen et al., 2006). A problem solving approach tends to privilege mathematical abstraction and reductionism while overlooking social and political complexity, even though “technologies never operate on their own [and] are always embedded in wider political, economic and social frameworks, which are likely to govern both how they develop and what their consequences are” (Giddens, 2013, p. 187). 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 the control of engineers and “design variables” that they are able to change), a problem-solving mind-set allows engineers to develop powerful analytical tools which elicit the most “rational” solution to the problem. However, it also limits their scope and confines the solution space in which they conduct their search, in at least two ways.

First, problem solving necessarily favors limited-time horizons that are typically determined by the project. This is often at odds with the cumulative and long-term effects of a project, 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 (e.g., Peterson, 2010). And yet the impact assessment exercise is often extrinsic rather than intrinsic to engineering modes of thinking and action. It tends to be an afterthought, sometimes a reluctant one. Hence, the environmental dimensions of engineering projects often become marginalized by the very way in which the problems are configured (e.g., Bell, 2011, p. 3). 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 bring up a set of additional solutions, including railway and air travel, and would require engineers to be able to understand and work with tools of social policy, economic analysis and environmental science, largely unavailable in engineering 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. Nevertheless, the question remains as to whether engineering education and training has equipped engineers with the ability to provide intellectual leadership in such a debate.

Second, when considering an engineering problem, the technological aspects are foregrounded and the social and political dimensions are relegated or overlooked, so that some solutions (predominantly technical in nature) and some interests are inevitably favored at the expense of others. A classic example is the preference by engineers for supply-side solutions of water and energy problems, when in many cases a reduction in demand is by far the more rational option (Mitchell and McDonald, 2015).

Nor is 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. For example, past and current government subsidies have entrenched fossil fuels as the most economical mode of energy production (International Energy Agency, 2015). An engineer with a narrow technical and economic understanding of energy supply and demand might limit her design goals to developing cheaper or more effective ways of producing energy from fossil fuels, and overlook more innovative solutions that include renewable forms of energy.

To address these issues, there has been calls in the literature for the adoption of 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., 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."

Pielke (2007, p 77) identifies the reluctance on the part of scientists and engineers to accept the importance of advocacy in science as a significant barrier to the ability of science to influence policy. Over the last decade, a number of authors have addressed the relevance of history, social justice and globalization (Baillie, 2006, p 29), environmental sustainability (El-Zein et al., 2008; Rose et al., 2015) and politics (Bell, 2011, p 43) to engineering practice and education. Carew and Mitchell (2008) and, more explicitly, Halbe et al. (2015) call for engineering students to be taught how best to develop critical awareness of the paradigms underlying engineering approaches to sustainability. This could be usefully extended to paradigms underlying engineering approaches to problem-solving more generally, and help make explicit the biases and limitations in engineering approaches to problem formulation and solution (El-Zein, 2014).

Jamison et al. (2014) offer a historical reading of the tensions underlying the evolution of engineering education (e.g., between scientific knowledge and technical skills; between social and commercial orientations), which have generated three ideal types of engineering education: academic, market-driven and integrative. They discuss the distinction made by Barnett and Coate (2004, p. 65) between the three curricular elements of *knowing, acting* and *being* – the latter related to the formation of transformational self-identity – and argue for an integrative type of education, which they call "hybrid learning", emphasizing citizenship and "broader societal and cultural concerns" to be developed through teamwork on complex social problems (Jamison et al., 2014, p 266). The process of transforming the curriculum, they argue, is also a process of transforming the University's "mission and vision" (Jamison et al., 2014, p 265), although they say much less about the transformation of engineering institutions and disciplinary boundaries.

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, it is argued here that, without a better articulation of the public good that engineering serves, a shift to PDS is unlikely to reap the benefits it should.

According to Downey (2005), PDS would be characterized 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, p 591). In other words, engineers would have, not just the firm's interests in mind, but some broader public interest. However, Downey does not say 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 organization 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 engineers are. Clearly, engineers, like all other citizens, are moral and social agents, as well as being engineers, and to this extent their identification with their employer is never absolute; however, what is of concern here is whether their *professional* identity per se is likely or not to create limits to their identification with the organization that employs them. A key question, therefore, is whether engineers possess a clear sense of the public interest associated with their profession?

4. What is the public good that engineering serves?

In a core unit of study, Sustainable Systems Engineering, 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. “Problem-solving” came top, in 2015 and 2016, followed by the words “design”, “building”, “construction” and “innovation” (in different orders in the two surveys). These terms are morally neutral because they refer to technologies or ways of interacting with technology. They are means to an end but the end in question remains unarticulated.

This is mirrored by a definition of engineering methods offered by Koen (2003, p. 70) as “the use of heuristics to cause the best change in a poorly understood situation within available resources.” What is missing here is any indication of the nature of that change or the criteria by which its desirability can be judged. Efficiency, design and problem solving have the ability to do as much harm as good, depending on whose interests they serve. Indeed, many historical acts of mass murder have been perpetrated with considerable efficiency, design skills and problem solving. So what is the morally justifiable end that engineers seek to achieve through technological means?

Health practitioners can claim “health of communities and individuals” as the ideal they strive for. The two organizing 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 and lawyers 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 these instances are seen as offensive aberrations is precisely because nurses, doctors, judges and lawyers are invested with those ideals and expected to behave accordingly. Engineers, on the other hand, can be instrumental 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 justified, depending on the circumstances. The 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 the professional sensibility of engineers and is seldom examined (e.g., Unger, 1989; Johnson, 1989). This, we believe, is symptomatic of the lack of clear articulation of the public good that engineering is supposed to serve.

Small (1983), and later Holt et al. (1985), suggested that the essential task of the engineering profession is wealth generation – although for whom and in what form remains unclear. Rojter (2011) proposes “commitment to sustainability of the end process of engineering” as the “ideological core of the engineering profession.” However, this definition merely shifts the problem since it raises the question of what exactly is the aim of the end process of engineering. Mitchell et al. (2004) 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 to engage with the social and political dimensions of technology, which they rarely have the training to accomplish.

An online review, conducted by the authors, of the stated visions or missions of main professional engineering bodies in the UK, the 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 organizations recognize the importance of attempting a definition of quality of life to guide future developments in their profession. The Institution of Chemical Engineers (UK, Australia) identifies four key challenge areas for the profession: energy, water, food and nutrition, and health and well-being (Institution of Chemical Engineers, 2016) 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 globalization, 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, p. 21).

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

The UK's Royal Academy of Engineering structures its work programs around four strategic challenges. Three of these challenges are self-referential (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 favor of productive industry” (Royal Academy of Engineering, 2015).

Some organizations 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., Engineers Australia, 2016), or by simply referring to the fact that engineers are responsible for “technological innovation” (Institute of Electrical and Electronics Engineers, 2016), or the “application of science” (National Academy of Engineering, 2016) for the good of humanity. The absence of a publicly accessible definition of the public good of engineering does not necessarily imply that these organizations have not developed insights into the moral purpose of their profession – Engineers Australia does list some progressive definitions of new engineering disciplines. Yet most definitions restrict the public imagination to engineering as a profession that simply tests, operates and “designs under constraints” (National Academy of Engineering, 2016).

The public interest of engineering is clearly affected by how engineers and engineering professional institutions conceive of their relationships with the private, corporate and public sectors, as well as the various communities that are the end users of their products and designs. A view of the engineering profession that closely aligns it with private wealth generation is connected to the rise of free-market ideology in the 20th century. Interestingly, this emerges most evidently in debates on developing national and supra-national engineering competencies. For example, Lucena et al. (2008) argue that increasing international commercial competition and mobility of engineers within multi-national firms have been two important drivers for developing nationally or supra-nationally agreed sets of competencies. They point out that, in the US, the ABET competencies development initiative was launched by a meeting of CEOs of large corporations and Deans of Engineering. A more subtle, but no less important, effect of the private sector and engineering practice on the construction of curriculum is the way particular competencies are valued and others less so, even when they have been canonized through accreditation. For example, a survey of undergraduate engineering alumni of one large public university about the importance of ABET competencies to the engineering workplace, *teamwork, data analysis, problem-solving* and *communication* (in this order) came top, achieving a qualitative score that places them between “extremely important" and "quite important" (Passow, 2012). *Contemporary issues, experiments* and *social and environmental impacts of engineering* were found to be least important, with *social and environmental impacts* ranked last, based on an average score placing it between "somewhat important" and "quite important", though closer to the former than the latter. Another example comes from a survey of the construction industry whereby *Environmental Awareness* was ranked as least important, while *ethical issues* and *problem-solving* were ranked highest (Ahn et al., 2012).

Moreover, while the US and Europe have succeeded in producing agreed-upon competencies documents (ABET, 2006; appendix D; European Accreditation of Engineering Programmes, 2009), the effort appears to have made less progress in Latin America as a result of, according to Lucena et al. (2008), a strong tradition of the engineer as a public servant, concerned with the building of national infrastructure and, therefore, resistance to a redefinition of engineering as a tool of private industry – hence, revealing what is in essence a debate about the public good of engineering.

5. Rationale for defining the public good that engineering serves

Why is there a need to articulate the engineering public good more explicitly than has been provided in the examples reviewed above? The most direct answer to this question is that, like medical and legal practitioners, engineering training and status confer on engineers power and authority through their connection to technology. How engineers use this privilege is of great significance to themselves and to the rest of society. An articulation of the engineering public good is, in a sense, the engineer's part of the bargain, his or her way of agreeing to the terms of a contract with society. But another, broader answer to the question is that how engineers define themselves and how they see their ultimate aims is bound to affect their ethical codes, including sustainability principles, disciplinary divisions and engineering curricula. Above all, self-definition of engineering will affect their relationships with each other, and with private and governmental institutions, in which they work or with whom they interact.

Ultimately, an explicit expression of the public good of engineering would have to be the outcome of wide deliberations in the profession and the Academy and may well be different for different communities of engineers. For example, it is reasonable to expect that communities of engineers and/or stakeholders of technology and technological change may view their roles, aims and aspirations very differently depending on whether they operate in high- or low-income settings, or whether they belong to egalitarian societies or ones in which vast inequalities are present, or countries emerging from military conflict or civil unrest as opposed to nations benefiting from peaceful existence and political stability.

In the following section, one possible formulation of the public goods of engineering is offered. However, this is not to suggest that this is a preferred formulation in any particular setting. Instead, this view of the public good is articulated hypothetically, only in order to show how it might lead to a new configuration of engineering disciplines.

6. "Public good" and disciplinary boundaries

One possible definition of the goal of engineering reads as follows:

Engineering aims to help provide access to safe water, air, food, habitat, means of transport and communication, and healthy lives, 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 space engineering, an important engineering endeavor, fit into this definition? Can access to clean air be seen as a human right and what are the implications of this? How do cross-cutting issues, such as energy and materials, fit into this picture? The aim here 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 (see Table 1):

a. Habitat engineering
b. Water and food engineering
c. Transport engineering
d. Communication engineering
e. Biomedical engineering
f. Ecological engineering

In order to assess the effect of such disciplinary rearrangement on the engineering curricular, Table 1 also suggests a list of subject matters that would be covered in engineering study degrees under each discipline. However, given the exploratory nature of the exercise, no attempt is made here to define competencies and learning outcomes which would also need to be articulated and incorporated in any curriculum.

Under this vision, the curricula of all disciplines will have a common base shown in the table, probably covered in the 1st and/or 2nd year of studies (see Table 1, third column). 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 shelter for residential, education, leisure and economic purposes, 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 and food engineer", who would possess conventional technical skills including wastewater processes, hydrology, water quality and soil science, augmented by knowledge of the politics of competing interests in access to water resources, economics of food, nutritional health, legal and political dimensions of international water conflicts, as well as dynamics leading to famine and food and water shortages.

"Transport engineers" would be concerned with road design, thermodynamics and energy, urban planning and social equity in the transportation sector. "Communication engineers" would need knowledge of electronics, computer science, management and information systems, privacy laws, cyberbullying and online fraud, and the politics and ethics of surveillance. Finally, "ecological engineers" would be concerned with designing schemes for modifying or conserving ecosystems, and protecting them from human activities. Their educational background would consist of elements of ecology, environmental transport processes, waste and resources, environmental politics and environmental justice and conflict resolution (see for example, Mitsch and Jørgensen, 2003).

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 engineers 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 specializations would remain important (e.g., chemical processes, structural design, materials science and development, energy processes) but would no

Table 1
Hypothetical Disciplinary Reconfiguration of Engineering and its Effects on Subject Matter Covered in Engineering Curricula (list of key subject matter is indicative not exhaustive).

Public good as a right to	Disciplines	Subject matter common to all disciplines	Subject matter specific to discipline
Housing in peace, security and dignity	Habitat Engineering	Computational engineering; materials science; energy and thermodynamics; complex systems; ethics; economics; equity and social justice; political science and conflict resolution; international development	Statics and dynamics; structural, geotechnical and mechanical design; construction management; urban history and urban planning; sociology of space, homes and homelessness; politics of housing and development; disaster science and logistics.
Clean water and healthy nutrition	Water and Food Engineering		Fluid mechanics and dynamics; soil science; ecology; geotechnical and geo-environmental design; water and waste-water treatment; food economics; international development; nutritional health; environmental law and conflict resolution; international development.
Effective and safe transport	Transport Engineering		Mechanical design; urban history and urban planning; transport systems and urban forms; construction management; system dynamics and automation; environmental impact analysis; economics of work and travel.
Effective and safe means of communication and connection to global networks	Communication Engineering		Electrical energy; control systems; circuits and electronics; informatics analogue, digital and power electronics; communication and networks; privacy, security and encryption; sociology of new media.
Healthy lives	Biomedical Engineering		Biology, anatomy and physiology; sociology of health and illness; nanotechnology; biomedical imaging and instrumentation; cellular and biomolecular science; biomedical computation; public health and health care systems.
Healthy environment	Ecological Engineering		Ecology; soil science; environmental transport theory; air pollution; water and marine pollution; soil and groundwater pollution; conservation; water treatment and waste management; environmental law; environmental risk management; environmental politics.

longer have to define the identity of most engineers. Third, *how* problems are solved 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 (e.g., Jamison et al., 2014) – 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 Layton (1986) 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; *biomedical engineering* combining medical and engineering sciences). Even where no new disciplines have emerged, paradigms cutting across disciplines have been suggested as a means of teaching engineers environmental sustainability (e.g., Halbe et al., 2015).

The emergence of these new disciplines and engineering paradigms should serve as a reminder of the increasing mismatch between current disciplinary boundaries and today's social and technological problems. In proposing the hypothetical disciplines described above, the paper makes no claim to some universally-applicable and unchanging, ideal disciplines. What has been hopefully 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 engineers do things.

7. Survey of academics on the public interest and engineering disciplines

An online survey was conducted amongst academic members of staff (including teaching staff) of the School of Civil Engineering of the University of Sydney where the first author is based. The aim of the survey was to evaluate the extent to which engineering educators and scholars perceive a connection between, on the one hand, disciplinary boundaries and, on the other hand, the extent to which engineering students and educators have a conception of the public good of engineering. The survey was made of 6 multiple-choice questions. In addition, respondents were provided with the possibility of commenting on the questions or elaborating on their answers in an open-ended question format. The survey was created using Google Forms, piloted and sent out using standard categorized emailing lists at the school. Table 2 show the six questions and the results of the survey, including, for each question, three one-sided *t*-tests of significance of proportions, for the following alternative hypotheses: “a majority of respondents agree or strongly agree with the statement”, “a majority of respondents have mixed feelings or are neutral” and “a majority of respondents disagree or strongly disagree with the statement”. *t*-test results for these three hypotheses are shown in Table 2, under columns titled

Table 2
Results of Survey (percent of respondents shown in brackets; 23 respondents out of 53 survey recipients, i.e., a response rate of 47%; test of significance: one-sided *t*-test of proportions).

	Strongly agree (SA)	Agree (A)	Mixed feelings/neutral (MFN)	Disagree (D)	Strongly disagree (SD)	t value (*: 95% significance interval ***: 99% significance interval)		
						SA + A	MFN	D + SD
1. "It is important that graduate engineers have a satisfactory understanding of the public interest which their profession is meant to serve"	14 (61%)	7 (30%)	2 (9%)	0 (0%)	0 (0%)	3.85^{***}	−3.85	−4.69
2. "Graduate engineers do have a satisfactory understanding of the public interest which their profession is meant to serve"	0 (0%)	2 (9%)	18 (78%)	3 (13%)	0 (0%)	−3.85	2.63^{***}	−3.47
3. "It is important that engineering educators have a satisfactory understanding of the public interest which their profession is meant to serve"	16 (70%)	6 (26%)	0 (0%)	1 (4%)	0 (0%)	4.32^{***}	−4.69	−4.32
4. "Engineering educators do have a satisfactory conception and understanding of the public interest which the engineering profession is meant to serve"	3 (13%)	10 (43%)	8 (35%)	2 (9%)	0 (0%)	0.56	−1.41	−3.85
5. "The configuration shown in the table is better than conventional disciplinary boundaries (e.g., civil, mechanical, electrical) at eliciting the public interest that engineering is meant to serve"	1 (4%)	7 (30%)	9 (39%)	5 (22%)	1 (4%)	−1.5	−1.03	−2.25
6. "All other things being equal, the configuration shown in the table is more likely than conventional disciplinary boundaries (e.g., civil, mechanical, electrical) to produce engineers that have a stronger understanding of the public interest that engineering is meant to serve"	1 (4%)	10 (43%)	7 (30%)	5 (22%)	0 (0%)	−0.28	−1.88	−2.63

"SA + A", "MFN" and "D + SD", respectively.

The survey is clearly limited because the sample size is small ($n = 23$) and represents a group of educators in a single department. However, it is clear that the vast majority of respondents agree or strongly agree that it is important that engineering educators (96%) and engineering graduates (91%) have a good understanding of the public interest that engineering is meant to serve. That this is the majority of opinion is significant at the 99% confidence interval (CI) using a one-sided *t*-test for sample proportions.

It is also clear that there is uncertainty among the staff about whether students meet this standard. The majority of respondents reported that they had mixed feelings or were neutral about whether students possessed a satisfactory understanding of the public good (78%; majority at 99% CI). Although only a minority of respondents outright disagree that the suggested framework would be better than conventional disciplines (26%, minority at 95% CI) or would provide an increased understanding of the public good (22%, minority at 99% CI), the response to the framework is clearly lukewarm. There seems to be resistance to a reorganisation of traditional boundaries, and even to developing the idea of the public good in engineering curriculum, as answers in the optional comments section indicate. One respondent believes that a need for understanding of the public good could be couched in terms of a general "ethics" course, while another argues that the problem lies in lack of fundamental science knowledge, which prohibits working effectively in multidisciplinary teams. Another respondent rejects the idea of the public good altogether and believes engineers should just "do [their] job properly. Social justice, political science, conflict resolution: these have no place in an engineering degree." On the other hand, one respondent wrote: "[the configuration in Table 1] motivates students more effectively to know that they are solving real world problems [and not] just focusing on a discipline – [it] provides them with a more problem-solving approach."

Overall, despite a recognition in the department that engineers should understand the public good, there is some uncertainty about whether this goal is being achieved, and significant uncertainty about, or resistance to, a reconfiguration of engineering disciplines.

8. Conclusions and further research

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. This paper has contributed to this debate by highlighting ways in which the focus on problem solving in engineering, while equipping engineers with a powerful mind-set and analytical skills, leaves them with an overly reductionist rationality and limits their capacity to engage with the social, environmental and political contexts of technology. In addition, the paper has shown that the public good that engineering serves remains poorly defined and is rarely discussed. This forms an obstacle to the profession's engagement with the wider world. It has also shown how disciplinary boundaries and normative competencies have the power to exclude particular views of the public good while reinforcing others. An alternative, hypothetical formulation of the public good could shape different disciplinary boundaries that are better aligned with self-defined engineering goals (e.g., equitable access to food, water, transport and shelter). A survey conducted at an engineering school of the University of Sydney has revealed that educators believe in the importance of developing an understanding of the public good amongst students but are uncertain as to whether this is being achieved or whether a reconfiguration of engineering disciplines would be beneficial.

At least two lines of enquiry may be pursued as extensions of this work. First, the survey conducted here can be extended to target a broader audience of graduate and undergraduate students and educators, across a number of institutions, in Australia and overseas, as well as practicing engineers in small and large organizations. The survey could be supplemented with, or preceded by, qualitative research to develop a better empirical understanding of the way engineering practitioners, educators and students conceive, and articulate, the public interest of their profession. Second, the discussion presented in this paper could be expanded into a dialogue between engineering educators and industry, as well as professional organizations by conducting workshops to develop alternative formulations of the public interest, disciplinary boundaries and curricular structures. Such discussion would necessarily debate the extent to which a future vision for engineering should aim for a formal re-arrangement of disciplinary boundaries, with all the institutional change that this might entail, or whether the drawbacks of such a change might outweigh the advantages.

It is critical for the engineering profession that such a dialogue takes place. This is because, without such an engagement with the issues raised here, the unconscious biases inherent to traditional engineering education will limit the profession's efforts to understand and therefore tackle the complex social, economic and environmental challenges of the 21st century.

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