Archaeology and Engineering:
What can engineers learn from the material cultures of the past?

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Abstract: *The study of material cultures has a long history. Called 'archaeology' in academic contexts, the relationship between objects created by humans and their cultural lives is used by archaeologists to make inferences about how people live and lived, how their technology functions/ed in mechanical as well as in social, political and economic senses, and how innovation supported changes in all these domains. Materials and cultures are thus intertwined. All things created by humans that function in day to day existence have cultural, social, economic and political significances. Since engineers are at the forefront of technological innovation, an understanding of the cultural contexts of material objects is, if not essential, key to comprehending the contexts and impacts that innovations could have. In a sense, Engineering is archaeology of the future. Thus Engineering Educators are not only bound to explore the pedagogical (how we teach) and the curricular (what we teach), they are in a position to explore the contexts of innovation in material cultures. Transformative education moves beyond the reproduction of knowledge and skills, into creative and research based practice. An understanding of these differences can allow Engineers to think beyond the object to the broader context, and beyond the context to the need for more innovation.*

Key Words: engineering education, curriculum, culture, archaeology, innovation

Introduction

This paper explores the impacts of innovations on human history and the importance of understanding the social, economic, political and mechanical contexts of material cultures. It begins by examining the nexus between Archaeology and Engineering, the former being the study of human material cultures of the past, and the latter being defined by Robin King as 'conceptualising, designing, implementing, producing, operating, maintaining, and ultimately disposing of physical and information assets in the form of infrastructure, systems, products and services' (2008: 5). After an exploration of impacts of innovation on human societies, the paper then places Engineering in the context of culture, proposing that, since engineers are at the forefront of technological innovation, an understanding of the cultural contexts of material objects is, if not essential, key to comprehending the contexts and impacts that innovations could have. It continues by suggesting some of the ethical considerations relevant to Engineering and concludes by arguing that, since innovation impacts can be politically, economically and socially significant, an understanding of the cultural contexts of materials and systems, and of the impacts of innovation should be included in Engineering curricula.

Culture and technology

Culture, as it applies to human social relationships and human interactions with the physical world is as complex as are the attempts to define it. While culture can be considered the construction of meaning and the patterns of understanding that are applied to organise our social relationships and the physical world, the authors draw on a more engineering-located definition, based in part on King's description of engineering above. If indeed engineering is 'conceptualising, designing, implementing, producing, operating, maintaining, and ultimately disposing of physical and information assets...' (2008: 5), then all of the verbs King uses happen in historical, political, economic and social contexts. In other words, engineering happens *within* culture: if culture is the way that people live, then engineering is the way that people live with the physical world, some of which they actively construct. Engineering, as culture, is what people live with materially. In thinking about this and the connection with Archaeology which is the construction of hypotheses about how people lived in the past based on their material and physical remains in the present, Engineering is, in a sense, the 'archaeology' of the future.

For example, the invention of the mobile phone has had an enormous impact on peoples' social relationships. It has altered our access to one another, to information, and to our engagement with other technologies, such as the internet. But mobile phones also impact on us politically and economically. We buy the technology, the access to network providers and 'air time', and, as innovations happen, we upgrade, contributing to the push for greater access, better and cheaper technology. While this has benefits to those of us who have access and the economic means to buy into the technology, the downside is that not all people or societies can meet the expense of the phone, the providers' fees or the infrastructure. One of many social and political impacts of engineering is that technological innovation contributes to economic development, yet those who fail to embrace new gadgetry (phones, computers, and so on) are in danger of being left further and further behind.

Archaeology in Engineering, Archaeology and Engineering.

Innovative developments in human technologies have significantly impacted on human lives. Of the thousands of engineering advances, the creation and use of stone tools, the discovery of smelting to allow metallurgy and the adoption of the steam engine in the 17th century rate as especially important. The common theme for all these innovations is that the technology was adopted at times when the society in question had the knowledge and physical resources, but also the political incentive and need for them to flourish.

The use of stone tools, it has been suggested, contributed to the physical evolution of modern *Homo Sapiens* from their primate ancestors (Stanford and Bunn 1999). Stone tools were adopted because a hominid with few physical attributes for predation (that is, no claws and small teeth) came to understand that, with sharp stone edges created by striking one rock with another, it was able to butcher and therefore eat animals possessing thick hide which it could not otherwise consider as food.

Contemporary chimpanzees crack nuts on rocks (Trivedi 2002),[1] and if either the hammer or anvil nutcracker fractures, it would be possible to discover the cutting power of stone. Over time, random striking of rocks evolved into a skill which encompassed all of the design features common to modern engineering: a task is identified (such as the need to create a tool to skin an animal), the resources (stone) need to be collected, weighed against the risks and costs involved (including travel, trade, expediency, spiritual/religious transactions, and so on), the tool has to be manufactured with a maximum of efficacy and a minimum of waste in materials and time. The tool needs to meet the demands of the task, and redundancies and backups need to be considered. The task then shifts after manufacture to the different skill of hunting.

However, without a reason for adopting cutting edges caused by some change in circumstances, it is unlikely that a chimpanzee living in a rainforest would see a need to use stone cutting edges. The climate record of two million years ago indicates that our ancestors faced environmental change, that the forests retreated, and that our hominid ancestors were faced with the option of dying out or adapting to the savannah that was replacing their forest environment (Behrensmeyer 2006). The savannah had fewer trees in which to shelter from predators, but also had many large animals with thick hides which contained a bonanza of food. Pushed by the need for defence and pulled by the allure of a high protein diet, the physically ill-equipped ape had good reason to adopt stone tool

[1] See also Youtube digital recording: http://www.youtube.com/watch?v=NivAusARwd8 Chimpanzee Nut Cracking 3 minutes 46 seconds

technologies. Over a period of two million years, the high fat and protein diet enabled the physical development of a larger brain (Stanford and Bunn 1999): arguably stone cutting edges transformed a relatively defenceless ape into an apex predator.

Metals replaced stonecutting edges because a stone edge, while initially sharper than metal, is brittle, blunts quickly, and never resharpens to an edge as effective as the original. Metal, by contrast, can be resharpened repeatedly. The technological advantage of metal over stone is obvious: while metal requires a more advanced technology to create, the trade off is that it is a more efficient use of resources, and is more effective as a tool.

Smelting requires high temperatures to mobilize the metal out of the ore. While Amerindians used native copper from around the Great Lakes, this could only be accessed after it had oxidised naturally. Supply was thus limited: the production of metal was far outstripped by demand. Consequently, copper, a rare commodity, was used by Amerindians only for ritual and artistic purposes (Wayman 1989: 3-6). However, once the technology of smelting had developed, this enabled supply to increase.

A normal campfire will burn at about 400-600 ^{o} Celsius (Babrauskas 2009), but copper requires about 1100^{o} Celsius to melt (The Engineering Toolbox: Metals –Melting temperatures 2009). Thus, an unusually air drafted campfire (such as a fire in a natural chimney, like a hollow tree, which created a forced draft and therefore a hotter fire), would be needed before smelting could occur. It has been theorised that the smelting of metal could only have been discovered by a potter who, after firing pots in a kiln such as that described above, noticed that some of the stones placed in with the pots had melted. Potters currently use kilns fired up to about 1300 ^{o} Celsius (Goffer 2007: 246), so this seems the most likely route of discovery. Metallurgy enabled stronger, more durable tools: weapons can be used on other groups of humans as well as on food sources. Thus, the development of metals led to the rise of many empires. A correlation between copper technology and the rise of the first empires in Sumeria is unclear in the archaeological record. More certain is the correlation between ironworking, the chariot - another new technology - and the rise of the Hittite Empire (Drews 1988: 92, 105).

The steam engine was invented in Hellenic Egypt by Heron of Alexandria (10-70 AD) (Humphrey 2006: 126-7), but as it consisted of a sphere with two angled outlets to create rotational forces, it was more of a prototype to prove the concept. Heron also invented pumps with pistons (Humphrey 2006: 125), so he had the prerequisites needed and used by later seventeenth century English steam engine makers. But there was no need for steam technologies: the economy of ancient Greece was based upon the labour of slaves. This meant that dirty, tiring and/or dangerous jobs could be done by humans. Neither Greece nor Egypt had usable anthracite coal (black coal) deposits (Thomas 2002: 59; Energy Resources of Egypt 1979) and their dry climates negated the necessity to create efficient pumps. In effect there was no social or economic need for steam energies to be harnessed, while there was a political incentive to keep slaves busy.

The steam engine required three things: a social or economic need, metallurgy of sufficient quality that it could contain the pressures, and a reliable and plentiful fuel source which did not divert resources from other technologies: wood was needed for such things as ship building and housing. Coal is a high energy source relative to its weight compared with wood (Seltzer 1985:3), and the danger of deforesting the countryside with significant impact on those who rely on wood as a source of fuel for such things as cooking had to be avoided. Steam engines were adopted to dewater mines in England because water flooding mines required constant pumping (Garrison 1998: 162ff): men and horses were unable to work continually or effectively. Combined with coal as fuel, steam engines were able to dewater mines perpetually, without relenting and with lower labour costs. Mines thus provided the fuel needed to run the very engines that made mining possible. And with steam power came railways, industrialisation, mass production and urbanisation (Garrison 1998: 169): technological innovation created further problems that could only be solved by further inventions. Technology drove (and drives) the development of technology.

Engineering and Culture in the University: Curriculum

We begin this section with a question: should engineering take its lead from the discipline of archaeology and consider the impacts, political, economic and social, of innovations? In responding to this, the authors gain impetus from the appropriately entitled report *Changing the Culture: Engineering Education into the Future* (Institute of Engineers Australia (IEA) 1996), as well as the more recent *Engineers for the Future* (King 2008). King's report is, in some respects, an evaluation of the IEA report: both were written to reconsider the teaching of Engineering in tertiary institutions.

The 1996 *Changing the Culture* Report recommended 'a culture change' so that 'graduates... [can] lead the profession in its involvement with the great social, economic, environmental and cultural challenges of our time' (IEA Review Report 1996: 6). Graduates of university engineering schools need to

> ...take a more effective societal role... [I]n addition to having the ability to explain technical problems, they must be politically and socially aware so that technical decisions can be made, understood and communicated, with sensitivity, especially across cultural boundaries (IEA Review Report 1996: 7).

While it is likely that the IEA intended the phrase 'cultural boundaries' to mean those borders that separate nation states (for example, different languages or 'races'), this reference can be read more complexly. Cultural boundaries exist *within* societies, from obvious differences in such things as languages and religions, to less overt or visible diversities, such as in levels of education, income, sexual preference, and ethnicity. People do not always 'wear' their cultures in ways that others can 'read'. Likewise, cultures are sometimes shared *across* boundaries: as one example, the Islamic faith is held in common in many nations, and differences in the realisation or interpretation of the faith are subordinate to the fundamental similarities that they share. People are often difficult to pin down culturally because of the complexity and the transitional nature of their identities.[2]

Recommendation Three is identified by King as 'at the core of the *Changing the Culture* review' (2008: 17) and outlines the attributes that engineering graduates should acquire by the end of their degree. Two of the ten listed are the

- ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams... [and]
- understanding of the social, cultural, global and environmental responsibilities of the professional engineer... (IEA Report Summary 1996: 9 – 10).

King reports of this recommendation that:

> Changing curricula to embed the development of all of the required attributes has been easier for some attributes that others, and has been achieved best where curriculum task and assessment have been strongly aligned with the particular attribute (2008: 18).

This strongly suggests that the implementation of 'culture-based' attributes advocated by the 1996 report was piecemeal, a point reinforced by the 2008 report recommendation that the Australian Council of Engineering Deans (ACED)

- implement engineering application activities that address contemporary issues and human dimensions, such as sustainability, environmental impact, risk, and social, business, legal and economic factors [and]
- internationalise engineering curricula and learning experiences (2008: 96).

Given the importance placed on understanding the 'human dimensions' of engineering outlined in this paper, and recommended by both the 1996 and 2008 reports on Engineering curricula, the inclusion of culture-based graduate attributes to engineering programs is becoming an urgent undertaking. If the implementation of graduate attributes relating to 'human dimensions' is not being integrated in curricula by schools of engineering or being done so in an ineffective manner, what is preventing its

[2] One of the ongoing issues in Disciplines of Archaeology is the extent to which an artefact recovered from the past can be regarded as generalisable to the entirety of the human beings or culture which provides its context.

inclusion? Could it be that the paradigmatic shift needed to think beyond the material or system being created to the context and influence of its creation is too great?

Engineers are at the forefront of technological innovation: what they invent has an impact beyond the merely epistemologically transformative – the new contribution to knowledge and to how we think and live as humans in materially cultural contexts. In addition to having social, economic and political impacts, innovations have ethical considerations. Like the invention of the chariot and the non-decorative applications of gunpowder, innovations can lead to the rise and fall of civilisations: the question becomes not so much "how can we create a better 'doo-dad'?" as "should we create a better doo-dad'?" or "if we make a better doo-dad, what will its impacts, both good and bad, be?"

While the destruction of civilisations is an extreme example, archaeology tells us that the impacts of innovation can have global as well as individual consequences. Once a technology has been made available to societies, it is (sometimes fatally) impossible to put the 'genie back into the bottle'. At the same time, it is important to recognise the benefits of innovation and that the boundaries between potentially negative and positive technologies is fluid. The microwave oven, as one example, has its historical genesis in technologies developed for radar in World War Two (Gallawa 2009). Put simply, a knife cuts bread as well as flesh.

Engineering educators are not only bound to explore the pedagogical (how to teach) and the curricular (what to teach), they need also to teach the reproductive knowledge that certifies engineers with skills that, among other things, ensures our safety (why XYZ is important to know). Most importantly, as recommended by King 2008 and the IED 1996 reports, it is essential to explore the contexts and impacts of innovation in material cultures. And this is not a new discourse: archaeology can provide a template by which to consider these aspects.

Conclusion

Engineering education at the tertiary institution has two functions: to reproduce the knowledge of specifications so as to meet professional standards, and to create and transform engineering knowledges, so as to enable innovation. The inclusion of cultural and/or human contexts in engineering curricula, although recommended in two reports which explored the skills needed by engineers in order to face the increasingly global needs of societies, is not given the focus it appropriately deserves.

A solution to this problem could be realised by linking together archaeology and engineering, with the former providing an understanding of the historical contexts and social, political and economic aspects of technological innovation, allowing the latter to be grounded in the long history of creative enterprise that typifies human development. This also links with King's contention that the public profile of engineering as a profession should be raised (2008: iv). Understanding our relationships with material cultures and the way they have changed lives in the past is key in understanding the possible future impacts of technological innovation, and allow a responsible and responsive engagement of graduates from engineering education institutions with human need.

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