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Abstract

The importance of science in development has been increasingly recognised in development discourses and policy since 2000. The triggers influencing policy debates include the Millennium Development Goal debates, the then UK Chief Scientist's work to get science onto international agendas, the UK government's own efforts on global development, and more recently the Sustainable Development Goal debates. Other triggers include increased public engagement with the issues of science and development, for example via the influential Sci-Dev Net web site. The increased interest in science for development has been mirrored by an important focus on innovation and development, which emphasises the importance of creating knowledge to create value.

This extremely positive transformation in development thinking has been less mirrored for the role of engineering in development. Engineering has been less emphasised in these debates, which is surprising given its importance to development policy and practice. Engineering and engineers are important for the building and maintenance of transport, water, energy, informatics, urban systems, as well as systems for health and medicine, and infrastructure of various kinds. The UK engineering academy writes 'engineers make things, they make things work and they make things work better'. Engineers do invent and innovate, but not always, or even often, in the ways meant by those who emphasise the applied science nature of engineering.

This article aims to investigate why engineering has not received more emphasis, including why development engineering has not been better institutionalised in the way that tropical medicine, and perhaps even science and innovation for development, have. This may be even more pressing at a time of heightened global environmental and social inequality challenges. It explores the nature of engineering in development, highlights recent efforts to headline engineering for development and, using this evidence, including analysis of what engineers know and do inside international development, to suggest ways in which its profile and effectiveness can be enhanced. It amounts to a call for a new area of engineering – development engineering.

Keywords: development, engineering, policy

1 Introduction

One important result from the rise in support for international development associated with the Millennium Development Goals (MDGs) has been the growth in support for the idea that increasing development capacities crucially involves increasing support for science in development. Over the last decade or two, science has become more central to development agendas. Outside the UK, many northern governments and academies have increased funding support to developing country science, and a new set of practices and collaborators have emerged. For example, many developing country governments have prioritised science and named ministers of science. Some major prizes have been established to forefront the excellence of southern scientists, and some northern scientific academies have worked hard to support their counterparts in the south. In the UK a major partnership has come into being that better integrates major research funders and government departments into the UK Collaborative on Development Science (UKCDS), based at the Wellcome Trust.

The notion that science is important for national development has also been clearly mooted, with support for the application of science into technology and innovation a part of many policy orientations. This paper begins from the observation that, although the increasing support for science is a positive aspect of the new development agendas, there needs to be a greater investigation of why engineering has not received the same emphasis, whether that lack of emphasis is important, and if so how to improve the profile and effectiveness of engineering.

Our main argument, which we will evidence, is that to better understand and improve our knowledge of how engineering is important for development, we need to understand the nature of engineering itself. Put simply, what is going on in the name of engineering? For example, engineering is not just application of science. In many cases science follows the engineering break-through. Neither by any means is engineering or innovation always led by research, or R&D. But such thinking is ubiquitous in science technology policy arenas, and widely elsewhere. Technology is often seen solely with science as the application of science 'For many decades now the term "technology" has been closely linked with invention (the creation of a new idea) and innovation (the first use of a new idea)' (Edgerton, 2008, ix)

Nor is 'engineering for development' an effective approach to development policy because the complexity of different varieties of engineering knowledge and practice makes it impossible for there to be a simple concept of 'engineering for development'. The notion that there are straightforward approaches to the provision of appropriate engineering for developing countries (development engineering as the search for appropriateness to poorer societies) won't work in and of itself. At the other end of the spectrum, neither will the idea work by itself that best quality engineering can be simply transferred from advanced contexts to developing ones (best with best).

Given the importance and complexity of engineering in development contexts, re-conceptualisation is required that goes beyond applying better science in engineering and innovation. Pressure to increase the resources for better local engineering in the South needs to go hand in hand with work to improve the conceptualisation of what is high quality engineering and good engineering for economic and social development.

In much debate on engineering and development a dichotomy is presented between 'best with best' and 'appropriate and humanitarian'. 'Best with best', international partnerships between top research universities, is for example the strategy of the UK Engineering and Physical Sciences Research Council (EPSRC) 'EPSRC has a "best with best" strategy on international collaborations with targets being BRIC countries, USA, Japan and European Union' (EPSRC, 2014). On the other hand, there is a long and continuous history of focus on appropriate and intermediate technologies. But 'other engineerings' are also relevant, including: the Japanese manufacturing-innovations that have been used to excellent effect for industrial catch-up (see

Forbes and Wield, 2002; Kaplinsky and Posthuma, 1994); and the massive increase in Chinese infrastructure projects in many developing countries. Together with other changes, the environment for engineering in developing countries has changed dramatically, but with extremely uneven local engineering capabilities.

In this article, we aim to go beyond the dichotomy between 'best with best' versus 'appropriate and humanitarian' engineering. The kind of engineering that works – that gradually gets integrated into working routines and practices – is much harder to categorise than that. We will argue rather that there are different types of engineering, just as there are different types of engineer. By different types of engineering, we do not mean the normal categorisations of civil, electrical, mechanical, aeronautical, chemical and so on, but different styles of engineering practice, process and policy. We will also suggest that development engineers might be stronger in some aspects of engineering practice, process and policy and weaker in others.

The paper comes from one year of research, made up of desk research, content analysis and preliminary interviews. The desk research focused on analysis of academic and policy publications and documents. Content analysis focused on detailed investigation of socio-economic impact case studies of engineering research submitted to the UK research excellence exercise of 2014 – REF 2014. Interviews and meetings have been held with the UK Royal Academy of Engineering and Department for International Development, and with engineers researching low energy for sustainable development.

We begin by summarising key definitional and conceptual issues. What is meant by science and development science? What is meant by engineering and development engineering? Then, we focus on the nature of engineering, particularly on the differences between the nature of engineering knowledge and scientific knowledge. We then turn to the question of what kinds of engineering make up development engineering? And, who is engaged in development engineering? Finally, we suggest various ways in which the profile and effectiveness of engineering can be enhanced.

2 Definitional and conceptual issues – Development Science and Development Engineering

2.1 Development Science

Science and development has received much more attention than engineering over the last decades. 'Internationalist' scientists such as JD Bernal and Joseph Needham spent time extolling the historical leadership of less developed nations in the early development of science (Bernal, 1969, Needham, 1954-2008). In the sixties and seventies, scientists around Nobel prize winning physicist Abdul Salam established various institutions to build developing country scientific capabilities, including the International Centre for Theoretical Physics in Trieste and linked Third World Academy of Sciences, and so on (Nganga, 2012). From then, there have been various periods of pressure that science mattered for development: that international development depended to a significant extent on scientific knowledge and scientific discoveries. The phrases 'science and development' and ' science for development' have been used since then to capture the sense that 'catch-up' and 'modernisation' is dependent on the reach of science into developing countries.

Institutionally, two national development agencies were established specifically to build scientific capacity in developing countries. The International Development Research Centre (IDRC) was set up by the Canadian Government in 1970 and the Swedish Agency for Research

Cooperation with Developing Countries (SAREC) in 1975 by the Swedish government. Both agencies have worked hard to emphasise the importance of science (joined increasingly by technology) in development (see Garrett and Granqvist, 1998; Bhagavan, 1992). The German agency GTZ, later GIZ, was set up with a strong remit to support technology and innovation. Other agencies have also supported innovation as part of general donor policies, policies which do however, change quite regularly.

More recently, the phrase Development Science was chosen as the focus of the UK's initiative to group together the most important UK research donors to development - the UK Collaborative for Development Science (UKCDS). This emerged as a way of increasing the international and development orientation of UK research. It covers a broader range of activities relating to the organisation of development aid and assistance targeted at research, communications and impact. It operates in four key areas: global health, sustainable development, making science work for development and natural disasters. UKCDS calls development science 'the application of science to humanitarian and development planning, decision-making and practice'. More narrowly, UKCDS also calls it the 'best science for international development' (UKCDS, 2016).

The idea that science would lead to development was a wholly positive concept in the 1950s and 1960s, in the early days of the UN agency for education science and culture (UNESCO), for example. But the idea that science would lead to development came under sustained attack from the late 1960s. The critiques were of various types. Firstly, that first world science was no panacea for developing countries – and that some other type of science, more focused on the specific issues of third world development (food, poverty, water, energy, rural development, on the need for more labour intensive technologies if employment was to be created, etc) might be proper foci for support. In short, that science for development had to be more 'appropriate'. Second, that science was not a panacea for development anywhere. That technology and innovation – development of new products and processes were what promoted development and that these did not always, or even often, come from science (de Solla Price, 1963, Vincenti, 1991).

Little by little the balance moved from science (S) towards technology (S&T) and then innovation (STI). For example, the Millennium Development Goal Initiatives brought renewed interest in STI and a UN Millennium Project Taskforce that produced a major influential report on STI entitled 'Innovation: applying knowledge in development' (eds Juma and Yee-Cheong, 2005) which acted as a driver for a wide range of actions, for example in energy, life sciences, water and sanitation . Whilst that report focused on innovation and presented knowledge as a means to improve innovation, the implementation has gradually shifted back towards science. Clark and Frost (2016) have recently argued that these initiatives never quite shrugged off the science-led approach to STI, in an article aptly called 'it's ITS, not STI'. In particular, the positive push to reinvest in research and universities in Africa after the neo-liberal onslaught that brought crisis and collapse in the 1980s and 1990s, has overshadowed the push towards innovation and technology. But, in almost all of these discussions engineering has been invisible. Somehow it has been lost in the search for the relationship between science technology and innovation.

2.2 Development Engineering

This paper, though, is aimed not at the general problem of lack of emphasis on technology and innovation. It aims to explore why engineering has fallen from the development agenda, with some notable exceptions (eg Juma, 2006, 2016). It is strange that it has so fallen. First, engineering matters in general, perhaps especially so at this moment in history. There have been calls for engineers to work more closely with scientists to address grand challenges including climate change (Petroski, 2011). Engineering has not fallen from its key place in university education, though Vincenti (1991) suggests that engineering receives less attention than science and is often seen as 'just' applied science. Second, engineering matters for development, which is one reason why there are so many engineers in developing countries.

So, what is development engineering? The term 'Development Engineering' is perhaps even more invisible than development science, maybe due to the increased attention given to technology and innovation as vehicles for development. These are seen to encompass not only material objects/gadgets but also the institutions, business and systems needed together for technologies to have an impact on less developed countries. There is a small but growing community that answers to the name development engineer. The new Elsevier journal *Development Engineering*, edited from UC Berkeley defines its journals take on development engineering as 'applying engineering and economic research to the problems of poverty'. UC Berkeley has set up, with USAID support, a Development Impact Lab (DIL), MIT has the MIT D-lab and GRIT, Stanford and Duke universities have initiatives and the University of California has set up Blum Centers at each of its ten campuses. There is evidence, albeit somewhat circumstantial, that some at least of these initiatives are in answer to the younger generation who are more in tune with engineering to address the world's problems Organisations like the US Engineers without Borders, with strong student support, have been important. Many have postgraduate teaching in the subject as well as research. In the UK, UC London has recently launched a Masters in Engineering for International Development to join Cambridge which has had for some years a Masters in Sustainable Development, with strong engineering focus. The Open University has funded a research initiative in inclusive innovation and international development. In 2014, at a round table organised by the UK Centres for Development Science (UKCDS) and the Royal Academy of Engineering (RAE) one of the speakers observed that mainstream engineers didn't want to be seen as 'development engineers', and new funding mechanisms pushing resources towards engineering and development could help to redress the perceived lack of status of this career path. And the RAE has championed engineering and development over the last decade (Juma, 2006, Guthrie et al., 2008).

To an extent, there seems to be a bottom up push from students, and from some practitioners, as well as a more top down push that is being attempted via National Science Foundation sandpits in the USA, and the UKCDS/RAE roundtable examples. There is also an increased move towards interdisciplinarity, Mode 2 knowledge systems, and so on, which may also be a lever. For example, practitioner water engineers who work in villages in developing countries have long argued there is a need to incorporate a systemic understanding of what they might call 'contextual factors or software' in development engineering, which include an appreciation of local gender and power relations, provision of health and hygiene education, and finance systems for maintenance and operation of the 'hardware' - pipes, boreholes, water pumps and latrines - in order to have a sustainable water and sanitation system that delivers good health to a village population for at least 20 years following installation (Robbins, 2007).

Humanitarian engineering is an associated and recent emergent grouping. There are a group of mostly US oriented institutions, including universities with interests and courses (Ohio State, Arizona State, Colorado School of Mines, Penn State, Dartmouth College). In the UK, Coventry University has a master's degree in Humanitarian Engineering and describes humanitarian engineering as 'using engineering in a sensitive and sustainable way to address issues that limit opportunities and development in communities'. Thus, it can be applied on a local, national or international level and is not necessarily restricted to a disaster or crisis situation. There is also a Journal of Humanitarian Engineering, produced by the Australian Engineers without Borders, with 3 issues so far.

There are other variants of this development engineering 'turn'. One is inclusive innovation (Chataway et al. 2014, Heeks et al. 2014) meaning innovation that directly serves lower income and excluded groups. Examples often cited are the M-PESA mobile finance initiative in Kenya, and The Honey Bee Network, which supports grassroots inventors. Various university labs are also often cited, like MIT's D-Lab and Duke's Developing World Healthcare Technologies Lab, which conducts research on novel biomedical technologies for use in low-resource settings, provides training in biomedical technology design and repair, and a maintains library of technical resources for health care in the South.

Finally, the terms frugal or Jugaad innovation are now also used (Leadbetter, etc) to signify innovation that begins in a pro-poor context that can be translated into cheaper or easier innovation in a developed country context (Radjou et al., 2012; Leadbeater, 2014). In engineering terms, frugal implies preserving the most critical functions only so that a product or process can do its principle function much more cheaply than the 'normal' design. The $80 i-Pad developed for India is an example of this type of engineering. But 'frugal' brings to the conceptualisation of development engineering the notion that developed as well as developing countries can benefit, and that private corporations might be important as well as those other public and not-for-profit organisations involved in development projects.

The 'best with best' approach is sometimes seen as a counter idea to those introduced above. 'Best with best' rests on the assumption that 'best' practice can be encouraged through international collaboration between the world's best institutions from the developed together with the developing world's top institutes. This 'best with best' will bring major advances in science and engineering. The UK's Newton Scheme is an example of this type of thinking, and now includes bilateral collaborations with sixteen emerging nations, that include the BRICS as well as Chile, Indonesia, Malaysia, Mexico and Kenya.

These examples: of emerging development engineering as engineering applied to the problem of poverty; of humanitarian engineering as engineering applied to risk and disaster; of inclusive and frugal innovation; and of best practice international collaboration; begin to give a sense of what is said to be going on in the name of engineering. These are signs of emergent ideas and practices that constitute development engineering. In addition, of course, are the massive ongoing activities of everyday engineering in the developing world. We think that there is more than fashion to these changes of terminology from appropriate/intermediate to frugal, best with best, inclusive, and so on. It feels like the changes bring more actors onto the development engineering stage – a change from developing country focus to society in general, that includes more developed country agencies and large and small private companies.

These are significant development initiatives, but not nearly as important as the initiatives in medicine and health. Medicine includes within it a formalised legitimate space for the health and medical priorities of international development, with its tropical medicine sub-field (and institutions), and strongly development-oriented sub-fields like public and community health, nutrition, and health systems. Recently, a group of global health institutions have emerged around the world as awareness and funds have grown for HIV/AIDS, major world diseases like malaria, neglected diseases and non- communicative diseases, including an increasing awareness that chronic diseases may have specific needs in different countries.

The sub-fields of engineering have no formal ‘development’ or ‘tropical’ sub-field to build institutional support for engineers that work on development activities and engineering practices relevant for development. There are a set of emerging interest groups, such as those in: humanitarian engineering, disaster engineering, sustainable development, and now development engineering to go with the set of existing engineering sub-fields that have strong development links, like: water and sanitation, infrastructure, food systems, energy and information technology.

Overall though, at present Engineering does not as yet have such well established sub-fields of legitimate scholarship and practice that could be brought in development engineering and it is hard to find agreed conceptualisations and definitions.

Where would one begin to build a baseline theory of development engineering? What follows are some ideas.

3 The nature of Engineering

From the vast lexicon of descriptions of engineering it is possible that it might be perceived as ‘all things to all people’ and therefore not easy to make coherent. The UK Royal Academy of Engineering definition emphasises the breadth and complexity, but also begins to give insights to help show the coherence:

‘The first thing to say about engineering is that it covers so many different types of activity that it’s very hard to define.

Engineers make things, they make things work, and they make things work better. Engineers use their creativity to design solutions to the world’s problems. Engineers help build the future. Engineers work on a vast range of different areas that affect people. These include things such as advances in biomedical engineering like new materials for hip replacements or advanced prosthetics.

Engineers build the word around us including buildings, roads, bridges, schools and hospitals. Engineers also manage our water, gas and electricity supplies and they also develop new ways to generate electricity such as wind and solar power.

Engineers make the food we eat and the medicines we take. They also develop new materials like high performance sports fabrics or new electronic displays.’ (RAE, What is Engineering? accessed RAE web site 10 March 2016).

This short description gives a set of important conceptual clues about the nature of engineering: that engineers innovate new products and processes, but engineers also keep things working, which is not innovation. Edgerton quotes a survey of Swedish engineers in 1980 that noted that 72% of them worked on maintenance – supervision of existing things (Lundqvist, reported in Edgerton, 2008, p100). They make things work better, which suggests incremental, gradual, rather than radical and disruptive, innovation. Engineers work in a wide range of sectors like construction, transport, energy, information, health, food and agriculture, mining and many kinds of manufacturing. Edgerton reports that some developing countries now specialise in the very labour intensive practices of breaking down sophisticated products. He uses the example of Alang beach in Gujarat, India, which was the ‘single largest centre of the shipbreaking industry’ (Edgerton, 2008, p 208). Each sector has a different context – resulting in engineering being very context-driven. So perhaps engineering is the practice of bringing together scientific and experiential knowledge for the purpose of developing and putting technologies to productive/problem solving use.

Marsden and Smith (2005) describe engineering in a visionary way, strongly related to visions of development:

‘Engineers are empire-builders: active agents of political and economic empire, they have worked to build and expand personal and business empires of material technology founded on and sustained by durable networks of trust and expertise’.

The UK education Quality Assurance Agency (QAA) Subject Benchmark Statement emphasises commercial and social value:

Engineering drives technological, economic and social progress. It deals with the delivery of practical solutions to problems, which includes some of the greatest challenges and opportunities of our rapidly evolving world. Engineers apply their understanding, knowledge, experience, skills and know-how to create social and economic value…Engineering relies on three core elements, namely scientific principles, mathematics and realization … .Realization encapsulates the whole range of creative abilities which distinguish the engineer from the scientist; to conceive, make and actually bring to fruition something which has never existed before – and to create Intellectual Property, associating invention with commercial or social value. This creativity and innovation to develop economically viable and ethically sound sustainable solutions is an essential and distinguishing characteristic of engineering, shared across the many diverse, established and emerging subjects within the discipline.’ (QAA, 2015: 6)

We summarise below examples of some elements of engineering that are important for the conceptualisation of development engineering.

3.1 Engineering is complex and messy

First, engineering covers a very wide range of activities; a huge breadth of sectors. One way to categorise engineering is through the various sub-areas of engineering, for example the classic areas of civil, mechanical, and electrical. There are also relatively ‘new’ (twentieth century) areas like aero, chemical, nuclear, bio-, industrial, systems, design, not to mention new areas like informatics. Broad and highly professionalised areas like civil engineering can be broken down into more specific sub-areas like environmental, geotechnical, structural, transport, water resources, and so on, each with their own associations. There are well over thirty broad sub-categories of this type evidencing the breadth of the concept engineering. Thus context is a key part of engineering since there is no one solution or approach. (Bucciarelli, 1994)

Such a categorisation allows some categorisation, and thus clarification, of types of engineering and types of engineer, but it allows much more than that because each of these categories contains a history of institutions, status, forms of professionalisation and types of practice. For example, most of these sub-areas of engineering have a set of practices, rules, routines and also a formal educational system with professional qualifications and gradings. Historically engineering was about ‘pupillage’ and the introduction of university-level engineering courses had a ‘complex’ reception. Many technological universities were once technical colleges. A few centres in the UK were upgraded early in the 1960s (UMIST, Strathclyde) and others became Colleges of Advanced Technology (including Surrey, Salford, Loughborough, Bath, Heriot-Watt, Loughborough).

Interestingly, this university-based history does not make visible the complex role of empire and commonwealth, and of military engineering, both of which are important parts of the history of development engineering. Historians of empire suggest a close connection between engineering, industry and the military. For example, the Royal Engineers were central in establishing the infrastructure that allowed for military campaigns into the Punjab. These bridges and roads eventually became the central components of civil infrastructure, trade and economic expansion. At the same time empire-building was 'messy' and 'unfinished' As Darwin points out 'empire on closer inspection betrayed its improvised and provisional character' (2012, pxii-xiii).

The complexity, messiness and context-driven nature of engineering goes beyond its multi-sectoral nature as we illustrate below.

3.2 Engineering comes from doing things/practice

Much can be learned from the practice of engineering – the kind of activity (work) that is done. Engineering practices bring coherence between the different sub-areas of engineering and build new experiential knowledge. The work of engineering is at least as important as the place of education/teaching. Thus, the university and research institute is important but is more secondary than it is for 'science', for example, or even medicine? What is the work of engineering then?

As Vincenti puts it: 'For engineers, in contrast to scientists, knowledge is not an end in itself, or the central objective of their profession' (1991, p6) Rather it is 'a means to a utilitarian end – actually several ends' (p6). Vincenti uses a quote from the British engineer Rogers to illustrate his point at engineering is about more than knowledge creation: 'Engineering refers to the practice of organizing the design and construction [and operation adds Vincenti] of any artifice which transforms the physical world around us to meet some recognised need' (Rogers, 1983, quoted in Vincenti, op cit, p6). Design has to do with the plans from which the artifice is built, construction is the process by which these plans are translated into the artifice and operation deals with the employment of the artifice in meeting the recognised need. So to engineer, according to Vincenti is about doing things (design, construction, operation) to 'bring into being' and use new artifices. For Vincenti, engineering is a separate sphere of knowledge.

To labour a little these definitional issues engineering involves things (materiality), practices, processes and policies. The processes include modelling (building a model of how something may work, or how a future product or process may work). And it involves debugging, evaluating and improving. It can involve pulling something apart and then rebuilding it (re-engineering). All of these activities are key for the ways we think about engineering being an intrinsic part of development.

Of particular definitional importance for our 'best with best' and appropriate dichotomy is the contrast between 'Normal' vs 'radical' design and technology, and by extension engineering. Constant defined 'normal technology' as what 'technological communities normally do' as what Vincenti describes as 'the improvement of the accepted tradition or its application under new or more stringent conditions' (Vincenti, p7). For example, normal design, says Vincenti, is 'the design involved in such normal technology. The engineer engaged in such design knows at the outset how the device in question works, what are its customary features, and that, if properly designed along such lines, it has a good likelihood of accomplishing the desired task' (p7). By contrast, as in 'best with best' engineering for radical design the 'designer has never seen such a device before and has no presumption of success … . Though less conspicuous than radical design, normal design makes up by far the bulk of day-to-day engineering enterprise' (p8).

As with design, normal engineering makes up by far the bulk of engineering work. That is not to say that routines are completely devoid of creativity. Engineering involves trial and error, and serendipity. The application of new science is not at the centre of most day to day engineering but that does not imply that engineering requires no creativity or ingenuity.

Often engineering practices change routines and so shape a new way of doing things. New practices can become more and more ’normal’ and familiar and transcend the previous way of doing things, often without any scientific and published article or formal R&D. It is possible to study the driving forces that bring about change but this often requires detailed study on work processes and practices rather than reading about them. (see Mackenzie and Wadjman, 1985, Bijker et al., 1987).

3.3 Engineering is not primarily about radical or disruptive innovation

The term innovation and the term engineering are not synonymous. Engineering can involve a disruptive innovation. Recent examples in informatics include the PC, iPad, and the web. It can also involve major transformations in economy and society, as with the development of wind and solar energy in the last decades. These developments have involved very large numbers of small and medium innovations that add up to a big change. Engineering can also be about process: small changes in the workplace, flexible changes to make things work; small fixes to keep things working. Examples include when new quality standards require changes in engineering processes as with the chemical processing of drug tablets and capsules. It can also involve the day to day slog of keeping a process going, a production line continuing to improve productivity, and so on (continuous improvement). The rise of Japanisation of manufacturing is perhaps the most important example, with just-in-time, Kaizen and so on. Such changes started by Japanese firms have spread around the world (see Forbes and Wield, 2002 and Kaplinsky, 1994).

Engineering a big project with many hundreds of engineers of different types certainly constitutes in and of itself a particular sphere of knowledge even though it may not involve any links with science institutions or any primary research. Edgerton sees most engineering as ‘technology in use’ (engineers as maintainers vs innovation-centrism). He does see innovation as a powerful discourse in North and South and suggests that Intermediate technology never took off because it was seen as ‘second best’.

3.4 Engineering is reflective as much as it is rational

Much of the professional ideology of engineers is rooted ‘in feelings of self-importance and a belief in an ability to lead, based on qualities of technical expertise and rational decision-making not held by the public at large’ (Robbins, 2007, p99). Robbins calls this ‘traditional’ engineering and contrasts it with ‘reflexive’ engineering as produced by the water and sanitation engineers he studied who worked in the global south. Robbins argued that although some types of engineering may be more consistent with taking a reflective approach than others, ‘many of the challenges faced in the South are as much social as they are technological, and therefore reflectivity is an important way in which engineers can engage with real problems in developing countries’ (p100).

Robbins uses the work of Layton (1971) who categorised the self-perceptions of engineers as: agents of technological development, impartial and logical, and responsible for ensuring positive technological change. Robbins found from his interviews of water and sanitation engineers working in the South, that they saw themselves rather differently. Many of them had been drawn to the appropriate technology movement (Dunn 1978; Schumacher 1973). Some spoke of ‘their distress at some traditional engineers they knew who often thought of crises, such as the Asian tsunami and Hurricane Katrina, simply as business opportunities' (Robbins, p 105). Robbins used the example of Engineers without borders (EWB) US to build his notion of reflexive engineering (see table 1 below). The EWB-USA vision has six elements: change, culture and people in host communities, partnership, sustainable projects, education and understanding.

Table 1 Traditional and reflexive engineers compared

	Traditional engineers	Reflexive engineers
Technology/society relationship	Technological shaping of society	Socio-technical dynamics
Perception of lay technical competence	Public dearth of understanding	Public is a knowledge resource
Means of making decisions about technology	Experts 'engage' and educate the public	Public/expert dialogue and agreement
View of development	Technologically driven	Livelihoods based
Technological uptake	Experts communicating to the public brings acceptance of technology	Social, economic and environmental factors explain why technologies are adopted or rejected
Politics of knowledge	Engineers know best	Engineer/stakeholder partnership
Epistemological approach to problems and solutions	Technical specialisation	Complex systems
View of expertise	Narrow, discipline based	Broad and holistic, interdisciplinary
Conceptual starting point	Designs	Socio-technical systems

Source: Robbins, 2007

3.5 Summary

In summarising the nature of engineering we have focused on four elements: complexity and breadth; the practice base of much engineering; that engineering is not all about new things, innovations, but also involves keeping things going; and that engineering is not just about rational thinking but can involve reflective thought. All of these elements, and others, have given a sense of the engineering spheres of knowledge.

What constrains perception and reality of engineering and its usefulness for international development and poverty alleviation? What might change that situation? From our short sketch of the nature of engineering, we can imagine a different perception of engineering as able to deal with messiness and complexity, as more focused on doing things than science, and able to reflect carefully and provide solutions with international development.

Engineering exists as a set of formal disciplines (mechanical, electrical, civil, informatics, bio, chemical, and so on). It does get taught in universities and colleges around the world. It encompasses a 'de facto' set of powerful professional institutions. Engineering is about a wide ranging but definable set of activities that are not easily written down and passed on. Practices matter as much as theory. Practices include strong relationships between complex organisations and institutions.

Engineering matters therefore. But sometimes it does itself a huge mis-service by defining itself as narrowly technical and quantitative. Engineering is often perceived as too narrow. It is often perceived as male gendered, quants-oriented, and inhabited with 'nerd-like' characteristics. Within the culture of engineering there are some who embrace and humorously send up the 'nerd' image – MIT sells pocket protectors with the tagline 'nerd pride' and one article author saw a T-shirt in Berkeley with 'women are nerds too'. Indeed, terms like technology and innovation might be more positively seen as more of a broadly based combination of technical, institutional, social and business concepts and practices. If that is so, then that would be a crashing critique of engineering perceived as too narrow and technical to be of much use to development processes. It might be that the general critique of engineering as having a narrowly technocratic culture might also generate the sense that it is not core to the development process.

We are interested in how these 'types' of engineering, and in particular on the idea that best practice engineering and appropriate engineering can co-exist and be brought together in productive ways.

4 The nature of Development

Development has a history which originated in rather technocratic 'models' and planning before a period that emphasised 'practices' and then more recently an increasing focus on reflection and critique (Mosse, 2003; Mohan and Wilson, 2005). We illustrate the contribution of development to our focus on development engineering with three short 'takes' on development (rational versus reflective or improvisational; interdisciplinary; and development as bricolage.

4.1 Development as rational vs development as reflective

Mosse (2005) argues that development studies originated in the instrumental doing of development, the planning of development; more recently moving to a more reflective, critical position. He suggests (p1) that development studies began as 'future positive', and emphasised models over practices and events. Development was instrumental rather than critical, emphasising the rational over the reflective nature of development. From the 1960s however, important critical voices appeared with alternative analyses of development (eg Hirschmann 1970, Amin 1976 and Rodney 1972).

What are the key focus areas of development? Generally, discourses include those on: poverty, inequality, agrarian change, urbanisation, industrialisation, labour, migration, gender, state and non-state institutions and governance, development policy and practice, environment, climate change and energy systems. This subject matter suggests that development is to a large extent still grounded in the 'doing' and the 'planning' of development.

But increasingly, the study of development has become more reflective and critical. In each of the key area there is excellent critical scholarship with significantly increased funding in many countries. The report of the HEFCE on the UK research assessment exercise in Development Studies in 2008 emphasised that the 'mix of disciplinary and inter-disciplinarity, of creative encounters between the frontiers of disciplines, the capacity to examine the relationships between the local and the specific on the one hand the general and universal on the other, and the combination of primary data gathering and use of secondary sources constitute the distinctive contribution of Development Studies' (HEFCE, 2009, p8-9). In the exercise in 2014 the report emphasised the strength of research in poverty and deprivation, environment and development, migration, agriculture, science technology and innovation in development, with 'strong examples of inter-disciplinary and multi-disciplinary research that addresses grand challenges in a way that transcended disciplinary boundaries (HEFCE 2015, p98).

4.2 Interdisciplinary or disciplinary

Development is an intensely interdisciplinary area. Not only does it include a huge range of social science disciplines (like economics, anthropology, sociology, politics) but also a wide group of natural, engineering and medical disciplines. But perhaps its defining characteristic is its problem oriented and thus interdisciplinary approach. The UK research evaluation exercise (2008) Development Studies subject overview report gives a flavour of this approach: 'In the 21st century assessment period, development studies flourished not only inside dedicated departments, in cognate disciplines and thematic departments in the social sciences and humanities, but also in branches of development science such as agriculture, engineering, medicine/public health and climate change. In no mean part this is due to the impact of globalisation on research and teaching in cognate disciplines. The report mentions important sub-fields that include: environment and development (climate change, water, energy, land use, natural resource management, conservation); and, science technology and innovation (biotechnology, ICT and infrastructure, urban development).

Mohan and Wilson (2005) also contrast the 21st century style of development studies with the critique of development studies of the late 1990s. In 2001, the research assessed from the last years was penalised for not being 'ground-breaking 'and lacking in 'theoretical innovation' because it was largely applied and funded on the basis of government policy and not academic autonomy.

Mohan and Wilson try to get beyond what they call the unhelpful duality between 'academic interdisciplinary research' and 'problem-focused interdisciplinary research'. They suggest that there are two stylised descriptors for interdisciplinary scholarship. One descriptor is interdisciplinary as beyond theory and application; the other as interdisciplinary as requiring rigour. .Whilst insisting on rigour as necessary to insight in development studies, they see three fundamental reasons why interdisciplinarity is necessary to development studies. First, that development is about problem solving: 'The "correct" definition of interdisciplinarity matters far less than the correct appreciation of the true problem to be solved' (Hansson 1999, 342). Srinivas (2016), provides a detailed analysis of how problem-solving heuristics are a key element of state capacity. Second, that 'political, economic, social and ecological problems are complex and do not obey the boundaries of knowledge established by disciplines' (Mohan and Wilson, p 273) and third that interdisciplinary 'can identify new or unforeseen issues. It is based on the argument that creativity usually occurs through the juxtaposition of different or disparate entities' (op cit, 173).

In summary, development studies has moved from being interdisciplinary solely in its problem-orientation, to aspiring to the production of useful interdisciplinary knowledge through its integration of study of 'real world problems' and intellectual rigour that 'transforms the intellectual landscape' (273).

4.3 *Development as messy and improvisational*

The third element we introduce is that development is 'messy' in the sense of complex. Much early research on development studies sought or provided models, though there were classic exceptions, such as Hirschman who recognised the complexity and non-linearity of development processes (1967, 1990). The emphasis on models and planning has morphed into on increased acceptance of reflectiveness, messiness and improvisation. A recent book by Frank Barrett, *Yes to the mess*, (2012) suggests that an improvisational mind-set and skills are essential to deal with complexity and change. Using the heuristic of jazz, he describes how key jazz skills are the simultaneous art of unlearning, performance and experiment. Writing in the management genre, he argues that leaders must be expert improvisers.

Frances Cleaver (2012) disputes the model of what she calls development by design and argues that institutions are formed through the uneven patching together of old practices and accepted norms with new arrangements. To develop her concept of development as bricolage she draws on a range of contemporary strands of development thinking about 'collective action, participatory governance, natural resource management, political ecology and well-being to develop understanding of how resources are managed' (p i). Similarly, Duncan Green, Senior Strategic Advisor at Oxfam GB, argues against the linear Fordist approach common to many nongovernmental development interventions saying that in other domains, such as the private sector this has been 'long since abandoned … in favour of systems thinking, disruption and innovation' (2015, p 2). He terms his approach strategy as 'whitewater rafting' (complex, messy) rather than strategy as 'supertanker' (rational, fordist). Key aspects of development contexts as complex systems are:

- They are quite literally out of control (systems evolve in unforeseen ways)
- Every context is specific and different (local contexts are shaped by local actors)
- Critical junctures and shocks (systems have moments of unexpected change)
- Resilience (related to capacity and well-being; the ability to thrive despite challenge) (2015, p.7)

In an interview with one of the authors Green observed that an improvisational and iterative way to respond to these systems as a development professional 'is that you have to think and act at the same time in a kind of dance between the two…the essence is to learn to dance with the system. And I think if you're going to work in these kinds of environments you have to become more interested in dancing and less in controlling.'

4.4 *Summary*

This brief sketch emphasises the changes in development thinking from instrumental 'doing development' towards more reflective, interdisciplinary problem oriented and improvisational approaches. To what extent have such changes in development impacted on the engineering done in the name of development.

5 The nature of Development Engineering

We shall attempt to characterise development engineering though we cannot as yet be very precise. We do not think that anyone has yet found a 'good enough' characterisation, though neither do we think we have an answer. Rather we hope to provide an approach for others to critique and change by producing a ‘good enough’ characterisation that can be built on. Key elements of such characterisation include:

1 ‘Best with best’: is a laudable aim but may risk a narrow notion of ‘best’ as: science and theory based and less related to best practice, which of necessity can change with context and thus not be absolutely original; as discipline oriented and thus not made relevant to complex development problems that require multidisciplinary and interdisciplinary solutions; and, best as meaning technically quantum-leap rather than gradual, incremental improvements, or even new ways of keeping things going. Thus best with best is important but not enough as a conceptualisation of development engineering.

2 Away from best with best there has been a long history of attempts to champion different alternatives. These alternative engineerings can be bunched into two grand periods. First the 1960/70s enthusiasm and energy around appropriate/ intermediate/alternative technology. These alternatives built a huge head of steam with major changes and new institutions, such as Practical Action/Intermediate Technology Development Group. Second, the period 2000s/10s. Here concepts like frugal innovation, inclusive innovation, bottom of the pyramid, engineering for sustainability, green engineering, humanitarian engineering have all gained some traction. Perhaps the major negative element with this latest rush on energy and enthusiasm is the danger of too big a spread of concepts and thus dilution of efforts. However, we think that there is some evidence that alternatives have. To an extent and unevenly, infiltrated into the mainstream.

3 There are many engineering activities, and many engineers, that bridge dichotomies. For example, the United Kingdom municipal engineers interviewed by Johnson and Wilson (2007) were in many ways ‘traditional’ and but they had reflected and learned from work with Ugandan municipal authorities that context matters, that other stakeholders matter, and had learned that listening to users and other stakeholders was important for improved practice. They loved going back to first principles to help engineer some kind of social good.

4 Important elements of development engineering such as ‘best with best’ and ‘appropriate’ miss out other crucial elements, two of which are related. Historically, development engineering might begin with colonial, imperial and military engineering. Some institutions were built on the need to build colonial revenues. Examples are the Royal School of Mines at Imperial College, and the closely located Imperial Institute, a location (South Kensington) established after the Great Exhibition of 1851. The latter became the Tropical Products Institute, DFID’s only public sector laboratory. It was privatised during the Thatcher public sector cuts, becoming the Natural Resources Institute, based at the University of Greenwich.

5 Finally, there are a set of activities which partially bridge the gap between best with best and appropriate- post colonial engineering. Institutions such as Cranfield University in agro and water engineering, Loughborough in Water, are world-leading examples based in the UK.

One constraint on building a good working characterisation of development engineering might be that there is no one (or few) leading institution, no School of Development Engineering to compare with the London and Liverpool Schools of Tropical Medicine. We believe that this is a good moment to try once more to bring together these key elements of development engineering. Table 2 is an attempt to pull together some of the practices that might fit under the rubric of development engineering. Along one axis it maps the ‘traditional’ sectors that are all important elements of engineering key for development (like health and disability, water and sanitation, transport and construction). Along the other axis is a more complex typology of possible ways to rethink development engineering. These include the ‘best with best’ and ‘appropriate’ descriptors of development engineering.

Another set of concepts cluster together as: first, things/materiality: the making, putting together and deployment of objects – like bridges, factories, schools, metro systems, and so on; second, practices, the activities that make up development engineering; third, processes, that involve approaches like re-engineering, systems, dynamics, design, forecasting, etc. digital technologies play a major role here; and fourth we have added policy, because development engineering is also crucially about building alliances and networks to make things happen to alleviate poverty.

Emphasising scale allows the introduction of small scale initiatives that have often been overlooked in engineering syllabuses. Standards setting is also crucial since the setting of global standards often freezes out local engineering solution to development problems. These two categories could be seen as part of taking a more reflective approach. Much development engineering will remain disciplinary, and it is hard to believe that engineering education will suddenly change its traditional divides, but we also need to find ways of categorising interdisciplinary thinking, practices and policies.

Table 2 Key elements of development engineering (with examples of projects in progress)

Sectors>>>>>>>> Types of engineering practice v v v	Agro-food	Health and disability	Water and sanitation	Energy	Infrastructure (transport, construction)	Digital engineering
'Traditional' engineering	Chemical, bio, process	Mechanical, electrical, chemical	Civil, mechanical	Civil, mechanical, electrical,	Civil,	Electronic, ICT
Kinds of engineering: best with best, high tech, universal knowledge	New rice varieties (Aberystwyth and India/Nepal	Diagnosing malaria using magneto-optic sensors (Exeter and Kenya	Cost effective safe wastewater use (Leeds and WHO)		Assurance of durable concrete structures using novel testing technologies (Queens Belfast and China)	International disaster monitoring satellite constellation (Surrey and UN)
Appropriate, low tech, more local knowledge?	Post-harvest loss education (Writtle and Mauritius)	MIT Freedom Wheelchair		Improving the effectiveness of alternative energy systems (Edinburgh and East Africa)		
Mixed		Shoe design to combat tropical diseases	Removing arsenic from groundwater (Queens Belfast and India)	Off-grid energy generation (Soton and Kenya)	Animal buildings with lower temperatures	
Artefacts/ practices/ processes/policy	Clean energy and agro-industry in SSA (Surrey)			Understanding the barriers to uptake of clean cookstoves (Nottingham and South Africa)		
Scale (large/small)				Energy from rice straw (Manchester) (Large scale) The next generation of low cost energy-efficient products (OU)		

				(Small scale)		
Standards (Rigid/flexible)	Modification of hydro-colloids to provide novel food products, with new industrial standards Sudan and Kenya)	Simplification of the R&D process, purification and manufacturing of new drugs				
Rational/reflective	Measuring chili heat with electro-chemistry					
Disciplinary/ ID and problem oriented		Materials, ultrasound and biology towards enhanced walking cane for visually impaired (Leeds)				
Regional networks (N-N, N-S, S-N, S-S)			Networks of users and researchers to deliver improved water services in Uganda			
Institutional networks/Networks of innovation (unis, res insts, NGOs, professions, donors, businesses)		Public private partnerships to stamp out sleeping sickness	Cost effective waste water treatment (Universities, World Bank, WHO, companies)			
Impacts/ Benefits/ engagement	Agrobiodiversity conversation for food security					
Development dimensions	Climate resistant crops for global food security	Low energy design strategies for healthcare buildings	Water quality improvement through integrated environmental health	Community based mini off grid electricity generation	Needs based approaches to urban land management (Heriot Watt/Edinburgh)	

A serious analysis of what constitutes development engineering will also include analysing the networks that will make things happen, both regional networks that may consolidate local initiatives, and institutional networks more generally. Some of these are already well established and there is growing support for more. The national academies of engineering are increasingly working together to strengthen north-south cooperation.

We have started to populate the table and below we give a few examples of some key activities. But so far our examples come from quite a narrow base, mostly UK REF impact case studies. We invite others to add detail and to reshape the categories so we get an improved notion of what is development engineering[1].

We are in process of researching more examples of development engineering. These include examples from the UK Research Excellence Framework 2014 which for the first time included examples of impact from research. A significant proportion of case studies prepared had international development impact. Robbins et al (2016) has further details. These examples, in the main, emphasise 'best with best' and science-led approaches to engineering, or at least, for obvious reasons, engineering that is seen as excellent from a university-based perspective. We are also in process of researching the DFID-EPSRC Energy and Development programme which is intended to increase clean energy access, resilience and wealth creation in developing countries. The research is focused on five themes: energy systems and decentralised use; solar; bioenergy; urban and transport; and energy efficiency.

At least since 2000, DFID have been focussed on getting more of the knowledge development they have funded into use in developing country contexts. An example is the DFID Research into Use programme (Clark et al, 2013). Other hot spots of development engineering in the UK include the Newton Fund for bilateral collaboration with 15 emerging nations, and most recently the Global Challenges initiative.

6 Conclusions

The paper set out to investigate why engineering has not received more attention in recent times, in contrast to the emphasis on science and innovation. We showed that a series of initiatives has allowed engineers and others to increase research and practice in what we call development engineering. However, efforts are quite fragmented and development engineering has not been well conceptualised or institutionalised. The paper has shown that present conditions exist to rethink the nature of the relationship engineering and development, and we propose that the new area of development engineering is conceptualised so that it includes a wider range of types of engineering and not just 'best with best'. A focus solely on 'best with best' has the danger that engineering will not relate to economic production and social need. At present, there is no School of Development Engineering, but a lot of development engineering cells and individuals. At the very least there is a need to begin joining them up. Whilst such changes begin we suggest that our research be extended to investigate the methods of development engineering, and investigate what engineers do (what they do, in what circumstances, in what teams and institutions) in the areas of development engineering. We need to know how they see themselves? how others see them? how they attribute value to what they do? We need to unpick the social networks that evolve and grow, and look for the emergent systems of people and things.

We have seen that dichotomies such as; 'best with best'; vs 'appropriate; large and small scale; and rational vs reflective; can get us some distance in characterising development engineering,

[1] Please send your comments to the correspondence contact author

that there are often more similarities than differences in the approaches of engineers to development problems. But the kind of engineering that works – gets integrated into working practices – is harder to characterise than that.

Around the world we see a new generation of social scientists, scientists and engineers responding to the twin grand challenges of environmental unsustainability and social inequity in holistic, joined-up ways. These seem to have the potential to create engineering practices that combine the best-with-best and appropriate approaches. In April 2016 UCL engineering held an ‘inclusive engineering education symposium’ guided by the question ‘how can we ensure that engineers have the skills and experiences to address global problems?’ aiming to help produce engineers that are ‘creative and inclusive in their approach and delivery of engineering solutions. The nascent field of sustainability, sometimes called ‘green’, engineering is focused around developing ways to use energy and resources without comprising the environment or people’s abilities to meet their needs. Key organisations include the World Engineering Partnership for Sustainable Development (WEPSD), which seeks to ‘redesign engineering responsibilities and ethics to sustainable development, analyse and develop long term plans, find solutions by exchanging information with partners and using new technologies and solving the critical global environmental problems, such as fresh water and climate change.’

Better understanding of what engineering is helps improve our knowledge of how engineering is important for development. Engineering is not just application of science. There are different styles of engineering practice, process and policy. Much creative engineering involves the day to day slog of keeping things going and slowly improving how things are made and distributed. Reflexive engineering is strongly socio-technical, livelihood based and highly contextual, with complex and interdisciplinary problem solving. That makes urgent the need to better resource development engineering.

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