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How to cite:

Robbins, Peter; Watkins, Andrew; Wield, David and Wilson, Gordon (2017). Development Engineering Meets Development Studies. *Third World Quarterly*, 38(10) pp. 2187–2207.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.1080/01436597.2017.1323551>

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Development Engineering Meets Development Studies

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Acknowledgements: This research was supported by the Open University Innovation Knowledge and Development research fund and the Inclusive Innovation and International Development strategic research initiative.

Development Engineering meets Development Studies

Abstract

The importance of science in development has been increasingly recognised in development discourses and policy since 2000. Engineering is less visible though engineering and engineers are important for the building and maintenance of transport, water, energy, industrial, informatics, urban and health systems. This article aims to investigate why engineering has not received more emphasis, including why development engineering has not been institutionalised like tropical medicine. It explores the nature of engineering in development, highlights recent efforts to headline engineering for development and, using analyses of what engineers know and do inside international development, suggests that its profile and effectiveness is emerging.

Keywords: development, engineering, inclusive innovation, knowledge, policy

1 Introduction

The support for international development associated with the Millennium Development and Sustainable Development Goals has included increasing support for science. Governments and academies have bolstered developing country science, and a new set of practices and collaborators have emerged. Many developing country governments have prioritised science and named ministers of science. Major prizes have been established to forefront southern scientists, and some northern scientific academies have assisted counterparts in the south. This paper begins from the observation that, although the growing prominence of science is a positive aspect of new development agendas, there needs to be better investigation of why engineering has not received the same emphasis, whether more emphasis is important, and if so how to improve the profile and effectiveness of engineering.

Our main argument is that to 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. Neither is engineering always led by research, or R&D. Nor is straightforward '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 one simple concept of 'engineering for development'. The notion that there are easy approaches to the provision of appropriate engineering for developing countries will not work in and of itself. At the other end of the spectrum, neither will the idea work that best quality engineering can be simply transferred from advanced contexts to developing ones.

Given the importance and complexity of engineering in development contexts, re-conceptualisation needs to go beyond applying science in engineering and innovation. Pressure to increase support for local engineering in the South requires improvement of conceptualisation of what is high quality 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).ⁱ There is a long history of focus on appropriate and intermediate technologies. But ‘other engineerings’ are also relevant for development, including the Japanese manufacturing-innovations that have been used to excellent effect for industrial catch-upⁱⁱ and Chinese infrastructure projects in many developing countries.

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. We will argue rather that there are different types of engineering, just as there are different types of engineer. We do not mean just the normal categorisations of civil, electrical, mechanical, aeronautical, and chemical, but different styles of engineering practice, process and policy. Development engineering might be stronger in some aspects of engineering and weaker in others. We show that development engineering is less a marginal activity than an emerging one, where new knowledge, practices and communities are bringing human social activity more centrally into engineering, which is normally seen as predominantly technical. These emergent practices amount potentially to a significant shift in engineering political economy.

The paper comes from research using secondary source data, content analysis and interviews. The desk research focused on content analysis of academic and policy publications and documents. Content analysis included detailed investigation of socio-economic impact case studies of engineering research submitted to the UK research excellence exercise 2014 (REF 2014). We analysed all the REF 2014 impact case studies with a broadly engineering and international development orientation from any disciplinary area, not only narrowly engineering disciplines (121 cases in all).ⁱⁱⁱ We also include analysis of data we have gathered on the DFID-EPSRC energy and development research programme (USES) which focuses on the themes energy systems; bioenergy; urban and transport; and energy efficiency. The data analysed is summarised in Tables 2 and 3. Interviews and meetings have been held with the UK Royal Academy of Engineering and Department for International Development, and with engineers researching energy for sustainable development.

We begin with key definitional and conceptual issues. Then, we focus on the nature of engineering, particularly on the differences between the nature of engineering knowledge and scientific knowledge before turning to the question of what kinds of engineering make up 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*

Normally, science has been analysed as a set of theoretical and experimental practices and processes to produce new knowledge about natural phenomena. Increasingly, such knowledge has ‘determined technical processes, economic systems and social structures’^{iv} with application into new products, processes and services (innovation), often involving technological changes that require engineering knowledge.

Science and development has received more attention than engineering and development. In the sixties and seventies, scientists surrounding Nobel prize winning physicist Abdul Salam established institutions to build developing country scientific capabilities, including the International Centre for Theoretical Physics in Trieste and linked Third World Academy of Sciences.^v 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.

The idea that science would lead to development was a positive concept in the 1950s and 1960s but came under sustained attack from the late 1960s. The critiques were of various types. That first world science was no panacea for developing countries – and that other types of science, more focused on the specific issues of third world development might be more ‘appropriate’. That science as an internal activity without the contextualisation and socialisation of knowledge was no panacea for development anywhere. Thus, technology and innovation were key and that these did not always, or even often, come from science.^{vi}

Gradually, 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^{vii} 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, Clark and Frost have recently argued that these initiatives never quite shrugged off the science-led approach to STI.^{viii} In almost all of these discussions engineering has been invisible.

2.2 *Development Engineering*

This paper aims to explore why engineering has fallen from the development agenda, with some notable exceptions.^{ix} It is strange that it has disappeared. First, engineering matters in general. There have been calls for engineers to work more closely with scientists to address grand challenges including climate change.^x Second, engineering matters for development.

Before examining engineering more generally, we will consider the development context. What is development engineering? An initial consideration suggests that it is about making things and building systems that provide solutions to global problems. It emphasises working across disciplinary and geographic domains, and inclusivity with a focus on those ‘left out’. It includes engineering applied to problems of poverty, risk and disaster but much more – urban, rural and infrastructural. The term ‘Development Engineering’ is used unevenly but there is a small but growing community that answers to the name development engineer. The new journal *Development Engineering*, edited from UC Berkeley defines its journal’s take on development engineering as ‘applying engineering and economic research to the problems of poverty’. University of California at Berkeley has set up, with USAID support, a Development Impact Lab (DIL), MIT has the MIT D-lab. The University of California has set up Blum Centers at each of its ten campuses. There is evidence that some at least of these initiatives are in answer to a younger generation’s call for engineering to address global problems. Organisations like Engineers without Borders, with strong student support, have been important. University College 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 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 said that pushing resources towards engineering and development could help to redress the perceived lack of status of this career path. The RAE has championed engineering and development with various initiatives over the last decade.^{xi}

There is also an increased move towards interdisciplinarity. 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.^{xii}

Humanitarian engineering is an associated and recent emergent grouping. There are a group of mostly US oriented institutions, including universities with courses (Ohio State, Arizona State, Colorado School of Mines, Penn State, Dartmouth College). 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 new *Journal of Humanitarian Engineering*, produced by the Australian Engineers without Borders.

Another variant of development engineering is inclusive innovation meaning innovation that directly serves lower income and excluded groups.^{xiii} Examples often cited are the M-PESA mobile finance initiative in Kenya, and The Honey Bee Network, which supports grassroots inventors. 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.

The terms frugal or Jugaad innovation are used to signify innovations from a pro-poor context that can be translated into a developed country context.^{xiv} In engineering terms, frugal implies preserving only the most critical functions so that a product or process operates its principle function much more cheaply than 'normal' designs. The \$80 i-Pad developed for India is an example of this type of engineering. 'Frugal' brings to development engineering the notion that developed as well as developing countries can benefit, and that private corporations might be important in development projects.

'Best with best' is sometimes contrasted with the ideas 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 and developing world to bring major advances in science and engineering. The UK's Newton Scheme is an example of this approach, 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 engineering applied to the problem of poverty, give a sense that the emergent ideas and practices constitute 'new' development engineering. In addition, of course, are the

ongoing activities of everyday engineering in the developing world. We suggest there is more than fashion to these changes of terminology from appropriate/intermediate to frugal, best with best, and inclusive. 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. There are three drivers for the changes we observe. First, there is a social movement element based on engineers, development NGOs and others responding to challenges. Examples of organised initiatives include Engineers without Borders and Practical Action. Second, there is a ‘beyond the fragments’ coming together of alliances of developments groups and institutions with technical/engineering institutions, including in universities. And thirdly, there is increased funding: from endowments, donors and within educational institutions.

In medicine, late nineteenth century concerns about public health led to new sub-fields (public health and tropical medicine). Bazalgette designed the London Sewer in response to the Great Stink of 1858. It was completed in 1875. The London School of Hygiene and Tropical Medicine was founded in 1899.^{xv} But engineering has no formal ‘development’ or ‘tropical’ sub-field to build institutional support for engineers that work on development activities and engineering practices relevant for development. Engineering does not have well established sub-fields of legitimate scholarship and practice 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 to situate a new sub-field?

3 The nature of Engineering

From the vast lexicon of descriptions of engineering it might be perceived as incoherent. The UK Royal Academy of Engineering definition emphasises the breadth and complexity, but also helps 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 world 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.’^{xvi}

This short description gives a set of important conceptual clues about the nature of engineering as a human activity: engineers innovate new products and processes, but also keep things working, which is not innovation. Edgerton quotes a survey of Swedish engineers in 1980 that noted that 72% worked on existing things.^{xvii} They make things work better, which suggests incremental, gradual, rather than radical and disruptive, innovation. Engineers work in a wide range of sectors. Edgerton reports that some developing countries 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’.^{xviii} Engineering is the practice of bringing together

scientific and experiential knowledge for the purpose of developing and putting technologies to productive/problem solving use.

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... . This creativity and innovation to develop economically viable and ethically sound sustainable solutions is an essential and distinguishing characteristic of engineering.’^{xix}

The characteristics of engineering strongly reflect recent conceptualisation of the growing contextualising and socialisation of knowledge, as argued by, for example Gibbons et al and Nowotny et al.^{xx} Important for the conceptualisation of development engineering is the following:

3.1 *Engineering is complex and messy*

The complexity and messiness of engineering is manifested in the variety of sub-activities; the complexity of order and disorder in the systems that engineers must take into account; and the distributed knowledge systems within engineering knowledge.

One way to categorise engineering is through its classic sub-fields, for example civil, mechanical, and electrical. There are also ‘newer’ (twentieth century) sub-fields like aero, chemical, nuclear and ‘new’ fields like informatics. Highly professionalised areas like civil engineering can be broken down into more specific sub-fields like environmental, geotechnical, and structural, each with their own associations. There are well over fifty broad sub-categories evidencing the breadth of the concept engineering.^{xxi}

Such a categorisation allows clarification of types of engineering and types of engineer, and each category contains a history of institutions, status, forms of professionalisation and types of practice. Most 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, with contestation between theory and practice. Many UK technological universities were once technical colleges.

Science and industry are best analysed as two distinct social systems, entered by different routes. Bridging the gap historically involved increasing the numbers of technical workers, some professionalised, some not.^{xxii} Engineering in the UK has historically been weakly professionalised and seen as defining work of rather low status, so that the term engineer is used loosely to cover all types of technical worker, much denigrated as ‘dirty’ and thus very different to scientific work done in labs. In the USA also there is ‘a wide range of different kinds of engineers with very different statuses. As a result the professionalism which is so influential in other “middle-class” occupations in the United States has remained illusive’.^{xxiii} This in stark contrast to the highly professional systems of continental Europe. Engineers have also tended to have employed status rather than self-employed.

^{xxiv} The British colonial systems tended to reflect this lack of status for those who kept things going rather than those responsible for administering the empire. The experience of engineers working in development is thus very different from those working primarily in the north, where engineers have been closely connected with the development and management of capitalism and major corporations in countries like the USA.^{xxv}

University-based histories do not make visible the complex role of UK empire and commonwealth, and of military engineering. Historians of empire suggest a close connection between engineering and the military. For example, the Royal Engineers were central in establishing the infrastructure that allowed 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’. Darwin suggests that empire ‘betrayed its improvised and provisional character’.^{xxvi}

Trevelyan evidences that the foundation of engineering practice is distributed expertise ‘enacted through social interactions between people: engineering relies on harnessing the knowledge, expertise and skills carried by many people, much of it implicit and unwritten knowledge’.^{xxvii}

Thus, 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 engineering practice – the kind of activity (work) that is done. Engineering practices bring coherence between different sub-areas of engineering and build new experiential knowledge. The work of engineering is at least as important as education. The university and research institute is important but less so than for science or medicine. As Vincenti puts it: ‘For engineers, in contrast to scientists, knowledge is not an end in itself, or the central objective of their profession’.^{xxviii} Rather it is ‘a means to a utilitarian end – actually several ends’. Vincenti uses a quote from engineer Rogers to illustrate his point: ‘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’.^{xxix} 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. Engineering is a separate sphere of knowledge.

Engineering involves things (materiality), practices, processes and policies. The processes include modelling (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 such activities are key for engineering as intrinsic to development.

Routine engineering makes up by far the bulk of engineering work, though routines are by no means devoid of creativity. Engineering involves trial and error, and serendipity. Often engineering practices change routines and so shape a new way of doing things – engineering processes are often ongoing processes of translation to get things to work better. 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.^{xxx}

3.3 *Engineering is not primarily about radical or disruptive innovation*

The terms innovation and engineering are not synonymous, though recent examples in informatics (the PC, iPad, and the web) illustrate that engineering can involve disruptive innovation. It can also involve major transformations in economy and society, as with the development of wind and solar energy in the last decades where large numbers of small and medium innovations add up to a big change. Engineering is also 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 involve the day to day slog of keeping a process going, a production line continuing to improve productivity as with just-in-time and Kaizen. Such changes started by Japanese firms have spread around the world.^{xxxi}

Engineers 'performing a large number of diverse tasks' were termed 'bricoleurs' by Levi-Strauss.^{xxxii} Levi-Strauss used the concept of bricolage to describe that people creatively draw on a combination of practices, memories of activities and thoughts in society where levels of technology and divisions of labour act as constraints on what is possible, to 'make do with whatever is at hand' (p11) but with the result 'to renew or enrich the stock or to maintain it with the remains of previous constructions or destructions'.^{xxxiii}

3.4 *Engineering is reflective as much as it is rational*

Much of the professional ideology of engineers is rooted in 'belief in an ability to lead, based on qualities of technical expertise and rational decision-making not held by the public at large'.^{xxxiv} 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'.^{xxxv}

Table 1

Robbins used the work of Layton^{xxxvi} 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.^{xxxvii} 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'.^{xxxviii} Robbins used the example of Engineers without Borders (EWB) US to build his

notion of reflexive engineering (table 1). The EWB-USA vision has six elements: change, culture and people in host communities, partnership, sustainable projects, education and understanding.

3.5 Summary

To conceptualise engineering and its relevance to development, we have focused on four elements: breath and complexity; the practice base of engineering; that engineering is not primarily about disruptive innovation; that engineering involves reflexive thought. These elements give a sense of engineering spheres of knowledge. Engineering is about a wide ranging but definable set of activities that are not easily written down and bequeathed. Engineering involves communities of practice – networks that bring together distributed expertise – social and technical. Engineering matters. But sometimes it does itself a huge mis-service by situating itself as narrowly technical. It is often perceived as male gendered, quants-oriented, and inhabited with ‘nerd-like’ characteristics.^{xxxix} 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’. It might be that the perception of engineering as having a narrowly technocratic culture generates the sense that it is not core to development processes. To the contrary, we show that engineering is closely embedded in development policy and practice.

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 as development engineering meets development studies.

4 The nature of Development

Understanding development engineering requires framing of key relevant elements of development. We illustrate the potential contribution of development to development engineering with three short ‘takes’ on development. We do not pretend that these are the only relevant framings of development but those that follow are selected to help us understand the nature of development engineering as described in section 5.

4.1 *Development as rational vs development as reflective*

Mosse argued that development studies originated in the instrumental doing and planning of development; moving to a more reflective, critical position.^{xl} He suggested (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.^{xli}

Development discourses suggest that development is to an extent still grounded in the ‘doing’ of development, but with strong critical analysis of social and economic inequality. The report on the UK research assessment exercise in Development Studies 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’.^{xlii} 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'.^{xliii}

4.2 *Development as Interdisciplinary*

Development is an intensely interdisciplinary area. Not only does it include a huge range of social science disciplines but also a wide group of natural, engineering and medical disciplines. The UK research assessment exercise (2008) Development Studies subject overview report gives a flavour: '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.'^{xliv} The report mentions important sub-fields that include: environment and development and, science technology and innovation (biotechnology, ICT and infrastructure, urban development).

Mohan and Wilson try to get beyond what they call the unhelpful duality between 'academic interdisciplinary research' and 'problem-focused interdisciplinary research'.^{xlv} They suggest that there are two stylised descriptors for interdisciplinary scholarship. One descriptor is interdisciplinary as beyond theory and application; the other interdisciplinary as requiring rigour. Whilst insisting on rigour as necessary to insight, 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'.^{xlvi} Second, that 'political, economic, social and ecological problems are complex and do not obey the boundaries of knowledge established by disciplines'.^{xlvii} 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'.^{xlviii}

In summary, studies of development have moved from being interdisciplinary solely in its problem-orientation, to the production of useful interdisciplinary knowledge through integration of study of 'real world problems' and intellectual rigour that 'transforms the intellectual landscape'.^{xlix}

4.3 *Development as messy and improvisational*

Development is 'messy' in the sense of complex.ⁱ The emphasis on models and planning has turned into an increased emphasis on reflectiveness, messiness and improvisation.

Frances Cleaver 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'.ⁱⁱ Similarly, Duncan Green, Senior Strategic Advisor at Oxfam GB, argues against the 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’. ^{lii} He terms his approach strategy as ‘whitewater rafting’ (complex, messy) rather than strategy as ‘supertanker’ (rational, Fordist). 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

These three takes on development thinking illustrate a move towards more reflective, interdisciplinary problem oriented and improvisational approaches, in synch with our conceptualisation of engineering. To what extent have such changes in development studies impacted on the engineering done in the name of development?

5 The nature of Development Engineering

In this section, we characterise development engineering. We do not think that anyone has yet found a ‘good enough’ characterisation, for example some present characterisations are quite narrow. The *Development Engineering* journal defines development engineering as ‘applying engineering and economic research to the problems of poverty’. We suggest that social and international development expertise and research is also required and provide an approach for others to critique and change by producing a ‘good enough’ characterisation on which to build.

Table 2 pulls together key practices that fit under the rubric of development engineering. Along one axis it maps those ‘traditional’ engineering sub-fields perceived as important for development. Along the other axis is a typology of one way to rethink development engineering, dividing ‘best with best’ from ‘appropriate’ descriptors of development engineering. We have populated the table with examples from our fieldwork. ^{liii} ‘Best with best’ is a phrase used to denote an ideal where the best researchers in the north link with the best from the south to produce new top class engineering knowledge. ‘Appropriate’ and ‘humanitarian’ rather describe engineering deemed relevant to poor developing country contexts – see section 2.2. Table 2 gives examples of ‘best with best’ development engineering – one example for each of the sub-fields of engineering. Each is a collaboration between top research institutions and each is a good example of engineering with strong social and economic relevance (such as new rice varieties, malaria diagnostics and safe waste water).

‘Best with best’ is an important element of development engineering but risks a narrow notion of ‘best’ as:

- science and theory based and less related to best practice, which of necessity can change with development context;
- as discipline oriented and thus not relevant to complex development problems that require multidisciplinary and interdisciplinary solutions;
- and, as technically quantum-leap rather than gradual, incremental improvements, or new ways of keeping things going.

Thus best is important but not sufficient to conceptualise development engineering. That said, table 2 has evidence of important and useful ‘best’ development engineering.

Table 2

5.1 Alternatives to ‘Best with best’

There have been attempts to champion alternatives. First, the 1960/70s enthusiasm around appropriate technology produced a head of steam and new institutions, such as Intermediate Technology Development Group, now called Practical Action. Second, in the period 2000s/10s concepts like frugal innovation, inclusive innovation, bottom of the pyramid, engineering for sustainability, green, and humanitarian engineering all gained traction. Perhaps one negative element is the danger of too big a spread of concepts and dilution of efforts. Nevertheless, there is evidence that alternatives are infiltrating into the mainstream.

Table 2 has one row of examples of highly effective development engineering which cannot be so easily characterised as ‘best with best’ or ‘appropriate’. But, it is not easy to differentiate any of the 18 examples in table 2 on a spectrum between ‘best with best’ and ‘appropriate’.

Some engineering activities bridge best with best and appropriate. Institutions such as Cranfield University in agro and water engineering, Loughborough in water, are world-leading examples in the UK, and table 2 has examples from other institutions. We propose that this ‘simple’ typology of development engineering needs to be enhanced with another group of categories (Table 3). Table 3 is our approach to enhance the typology of development engineering, using categories taken largely from innovation and development theory and summarised earlier in this article.^{liv}

5.2 Enhancing the engineering development typology

One new category presents engineering as differentiated between objects, practices, processes or policies: things/materiality, the making, putting together and deployment of objects – like bridges, factories, schools, and metro systems; practices, the activities that make up development engineering; processes, that involve approaches like re-engineering, systems, dynamics and forecasting, digital technologies play a major role here; and policy, because development engineering is also crucially about building alliances and networks to make things happen to alleviate poverty.

Emphasising scale allows for making visible the small scale initiatives that are often overlooked. The category ‘standards’ is also crucial since the setting of global standards often freezes out local engineering solution to development problems – success in much development engineering depends on different standards. We also emphasise the importance of reflexive engineering to go with rational approaches to engineering (Table 1).

Development engineering depends on the traditional disciplinary boundaries of engineering whether old and or new disciplines, not least because of the professional support that can be given to engineers around the world. But many successful initiatives in development engineering depend on interdisciplinary thinking, practices and policies.

Our final categories arise from the observation that development engineering importantly requires networks to build the expertise and environment to make things happen: regional networks that can consolidate local initiatives, and institutional networks. Some 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. These categories together make up Table 3 which was built from our research of a wide range of cases from the UK Research Excellence Framework 2014 and the DFID-EPSRC Energy and Development programme.^{lv}

Table 3

We suggest that an approach based on the categories in our typology will improve conceptualisation of development engineering. For example, it gets away from prioritising products over processes and policies; it highlights scale; regulatory context; levels of reflection; interdisciplinarity, involvement of geographically dispersed networks with public-private collaboration.

We believe that this is a good moment to bring together these key elements of development engineering.

6 Conclusions

The paper set out to investigate why, given its socioeconomic importance, engineering seems to be largely invisible in international development. The reason may be because it is largely taken for granted as a day to day, routine set of activities. But that cannot be right. For example, there have been responses to calls to improve global vaccination research. But hospital and health centre building, equipment and maintenance is forgotten. There are calls to improve maths and physics education, but water and sewage systems are still underinvested.

Engineering is not invisible to the engineers who make it happen nor to intended beneficiaries. Its invisibility is at a different level – at the level of policy making, academic inquiry, and for those who ask what is going on. Nobody would suggest, for example, that development economics should not be subject to critical inquiry. The same argument applies to engineering – it is too important in the practice of development not to be scrutinised. By forcing ‘development engineering’ blinking into the limelight, we have the potential to improve our understanding of both international development and engineering in the world. It is admittedly early days, but we suggest in this article that there are clear signs that development engineering is evolving and maturing as an important field of development knowledge.

The paper has examined the nature of engineering in development by studying what activities are going on in the name of engineering that aspire towards development. We have examined what engineers do, in what circumstances, in what teams and institutions. We showed that a wide-ranging 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 a focus solely or simplistically on ‘best’ or ‘excellent’ engineering for development has the danger that engineering will not relate to economic production and social need. We have seen that dichotomies such as ‘best with best’ vs ‘appropriate’, are useful but do not

get to the heart of what constitutes engineering in a development context. The kind of engineering that works – gets integrated into working practices – is harder to characterise. In building a relevant concept of engineering we focused on its breath and complexity, its practice base, that engineering is not primarily about disruptive innovation and that it requires reflexive thought. Similarly, our take on development emphasised its reflective, interdisciplinary and improvisational nature. That allowed us to build a provisional typology to categorise development engineering.

At present, there are a large number of development engineering cells and individuals. Making them more visible requires synthesis. Around the world we see a new generation of engineers, social scientists and scientists 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 ‘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, like the World Engineering Partnership for Sustainable Development seek 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 to improve our knowledge of how engineering is important for development. Much creative engineering involves the day to day slog of keeping things going and slowly improving how things are made and distributed. Engineering is strongly socio-technical, livelihood based and highly contextual, with complex and interdisciplinary problem solving. That makes urgent the need to better support and make visible development engineering, which is now an emerging sub-field of engineering.

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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

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

Sectors Types of engineering practice	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 to improve livelihoods in India and Nepal (Aberystwyth U. and various Indian/Nepali institutions)	Diagnosing malaria using magneto-optic sensors (Exeter U and Kenyan partners)	Cost effective safe wastewater use (Leeds U and WHO)	Energy from rice straw (Manchester U and International Rice Research Institute)	Assurance of durable concrete structures using novel testing technologies (Queens Belfast and various Chinese universities)	International disaster monitoring satellite constellation (Surrey U. and United Nations)
Appropriate, low tech, more local knowledge?	Post-harvest loss eradication (Writtle College and Mauritius)	MIT Freedom Wheelchair (MIT)	Networks of users and researchers to deliver improved water services in Uganda (Loughborough U)	Improving the effectiveness of alternative energy systems (Edinburgh U and East Africa, Indian institutions)	Needs based approaches to urban land management (Heriot Watt/Edinburgh U)	Cardio-Pad tablet device (Catholic University of Central Africa)
Mixed	Energy efficient rural food processing (Newcastle U, KNUST Ghana, JKU, Nairobi, Njala Uni Sierra Leone)	Shoe design to combat tropical diseases (Sussex U Addis Ababa U)	Removing arsenic from groundwater (Queens Belfast, Tata Steel, Bengal Engineering U etc)	Off-grid energy generation (Soton U and Kenya)	Animal buildings with lower temperatures	Ultra-cane ultrasonic aids for visually impaired (Leeds U)

Table 3 Enhancing the typology of Development Engineering

Types of engineering practice	Explanation	Examples
Artefacts/ practices/ processes/ policy	Products are often the focus of engineering, but activities associated with development engineering may emphasise practices processes and policies	Examples where processes and practices are emphasised over artefacts/objects: Clean energy and agro-industry in Sub-Saharan Africa (Surrey U); Understanding the barriers to uptake of clean cookstoves (Nottingham U and South African partners)
Scale (large/small)	Often large scale and sophisticated is emphasised over small and simple	Example of large scale: Energy from rice straw (Manchester U) Example of small scale: The next generation of low cost energy-efficient products (OU)
Standards (Rigid/flexible)	Rigid standards can freeze out new entrants and constrain new ways of doing things and thus slow innovation	Example where new engineering requires more flexible standards: Simplification of the R&D process, purification and manufacturing of new drugs Example where new engineering requires new standards: Modification of hydro-colloids to provide novel food products, with new industrial standards (Sudan and Kenya)
Rational/reflective	See Table 1	
Disciplinary/ Interdisciplinary	Interdisciplinary skills are needed in development engineering both because of: the complex problem oriented nature of the engineering; and the rigour needed to identify unforeseen issues in multiple contexts	Example of an intensely interdisciplinary engineering solution: Materials, ultrasound and biology towards enhanced walking cane for visually impaired (Leeds U)
Regional networks (N-N, N-S, S-N, S-S)	Success often depends on local knowledge and context from multiple situations, and on different types of expertise which might be concentrated regionally	Networks of users and researchers to deliver improved water services in Uganda
Institutional networks/Networks of innovation (universities, research institutes, NGOs,	Engineering activity and Implementation depends crucially on engagement of all relevant actors, users and	Public private partnerships to stamp out sleeping sickness; Cost effective waste water treatment (Universities,

professions, donors, businesses)	producers	World Bank, WHO, companies)
Impacts/ Benefits/ engagement	Measuring the impact of a development change is complex and is an integral part of development engineering	Agro-biodiversity conservation for food security

Notes

- ⁱ EPSRC 2014.
- ⁱⁱ See Forbes and Wield, *Followers to Leaders*; Kaplinsky with Posthuma, *Easternisation*.
- ⁱⁱⁱ Robbins et al., "Mapping engineering"
- ^{iv} Nowotny et al., *Rethinking Science*, 1.
- ^v Nganga, *Boundary Organisation*.
- ^{vi} De Solla Price, *Little Science, Big Science*; Vincenti, *What Engineers Know*.
- ^{vii} Juma and Yee-Cheong, *Innovation*.
- ^{viii} Clark and Frost, "It's not STI".
- ^{ix} Juma, *Redesigning African Economics: the role of engineering in international development*.^f Engineering: Juma, *Innovation and Its Enemies: why people resist new technologies*.
- ^x Petroski *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems*
- ^{xi} Juma, *Redesigning*; Guthrie et al., *Engineering Change*.
- ^{xii} Robbins, *The Reflective Engineer*.
- ^{xiii} Chataway et al., "Inclusive Innovation"; Heeks et al. "Inclusive Innovation for Development".
- ^{xiv} Radjou et al., *Jugaad Innovation*; Leadbeater, *The Frugal Innovator*.
- ^{xv} Neill, *Networks in Tropical Medicine*, 2012.
- ^{xvi} RAE, What is Engineering?, accessed RAE web site 10 March 2016.
- ^{xvii} Lundqvist, reported in Edgerton, *Shock of the Old*, 100
- ^{xviii} Edgerton, *Shock*, 208.
- ^{xix} Quality Assurance Agency, 6.
- ^{xx} Gibbons, et al, *The New Production of Knowledge*, 1994; Nowotny et al., op cit.
- ^{xxi} Bucciarelli, *Designing Engineers*.
- ^{xxii} Massey et al, *High Tech Fantasies* 1992.
- ^{xxiii} Meikins and Smith, *Engineering Labour*, 92.
- ^{xxiv} Smith, *Technical Workers*, 1987; Whalley, *Social production of Technical Work*, 1986.
- ^{xxv} Noble, *America by Design*.
- ^{xxvi} Darwin, *Unfinished Empire*, xii-xiii.

^{xxvii} Trevelyan, “Reconstructing Engineering from Practice, 175.

^{xxviii} Vincenti, *What Engineers Know*, 6.

^{xxix} Rogers, 1983, quoted in Vincenti, *ibid*, 6.

^{xxx} see Mackenzie and Wajzman, *The Social Shaping of Technology*; Bijker et al., *Social Construction of Technological Systems*.

^{xxxi} see Forbes and Wield, *Followers to Leaders*; and Kaplinsky, *Easternisation*.

^{xxxii} Levi Strauss, 2004, 11, quoted in Cleaver, *Development Through Bricolage*, 34..

^{xxxiii} Levi-Strauss, *op cit*, 11.

^{xxxiv} Robbins, “The Reflective Engineer”, 99.

^{xxxv} Robbins, *ibid*, 100.

^{xxxvi} Layton, *The Revolt of the Engineers*.

^{xxxvii} Dunn, *Appropriate Technology*; Schumacher, *Small is Beautiful*.

^{xxxviii} Robbins, *op cit*, 105.

^{xxxix} Faulkner, “Nuts and bolts and people”

^{xl} Mosse, *Cultivating Development*.

^{xli} eg Hirschmann, *Exit, Voice and Loyalty*; Rodney, *How Europe Underdeveloped Africa*; Amin, *Unequal Development*.

^{xlii} HEFCE, *RAE 2008*, 8-9.

^{xliii} HEFCE, *Research Excellence Framework*, 98

^{xliv} HEFCE, *RAE 2008 UOA 43 Subject overview report*, 5.

^{xlv} Mohan and Wilson, “The Antagonistic Relevance”.

^{xlvi} Hansson, “Interdisciplinarity: for what purpose”, 342

^{xlvii} Mohan and Wilson, *op cit*, 273.

^{xlviii} *Op cit* p, 273.

^{xliv} *Op cit*, 273.

^l Hirschman, *Development Projects Observed*; Hirschman, “The case against”.

^{li} Cleaver, *Development Through Bricolage*, i.

^{lii} Green, “Fit for the future”, 2.

^{liii} See Robbins et al., “Mapping Engineering ...”.

^{liv} Forbes and Wield, op cit, Robbins, 2007, op cit, Gibbons et al, op cit; Mohan and Wilson, op cit; Cleaver, op cit

^{lv} Robbins et al 2017., *ibid* for further details.