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POLICY ARENA

THE REFLEXIVE ENGINEER: PERCEPTIONS OF INTEGRATED DEVELOPMENT

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Abstract: The professional ideology of engineers is said to be 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. This paper outlines the views of another group of engineers, labelled 'reflexive engineers', having a much more integrated view of socio-technical systems. Interviews were conducted with engineers working in the Global South in fields such as community water supply and sanitation. The paper aims to uncover how they make sense of the social and how they perceive factors shaping development practice. Copyright © 2007 John Wiley & Sons, Ltd.

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1. INTRODUCTION

This paper grows out of the literature in science and technology studies (STS) that looks at the ways in which scientists and engineers engage with society, as well as my own experience as a sociologist working for 4 years on interdisciplinary projects with water and sanitation engineers on projects in the Global South. Research in STS suggests that many scientists and engineers view society as a kind of 'black box' (Irwin and Wynne, 1996). For example, many see the public's rejection of some technologies, such as genetically modified crops, as stemming from their insufficient understanding. A better engagement of science and technology with society, for such engineers and scientists, would come from more effective communication by experts of scientific results and benefits of technology to the public. This notion of a one-way interaction focusing on a transfer of information lacks an awareness of the complex ways in which different groups of publics make sense of and

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take up new technologies, and the fact that people do not always trust experts. In other words, it is not reflexive.

The idea of reflexivity refers to ‘our human capacity to “reflect upon” the events and forces within and around us, and through the very process of this reflection, to have at least some part in changing them’ (Van Leeuwen, 1983, p. 162). Sociologists of the reflexive modernisation school suggest that a breakdown in trust is characteristic of high modern societies; and individuals and institutions that are able to adapt are those that can reflect on and flexibly adapt to changing social and technological conditions (Beck *et al*., 1994; Waterton *et al*., 2001).

This paper reviews the literature on ‘traditional’ engineering, providing a contemporary example of the traditional engineer’s view of society as evidenced in Lord Alec Broers’ Reith Lectures, delivered in 2005. It then discusses results from in-depth interviews with more ‘reflexive’ engineers, mostly working in water and sanitation in the Global South, outlining how they see themselves as different from traditional engineers. An example of reflexive engineering is then provided by examining the mission and approach of Engineers without Borders in the USA (EWB-USA).

The argument in the paper is that, although some types of engineering may be more consistent with taking a reflexive approach than others, many of the challenges faced in the South are as much social as they are technological, and therefore reflexivity is an important way in which engineers can engage with real problems in developing countries. Core components of reflexive engineering involve: having a holistic and flexible understanding of socio-technical dynamics; seeing publics as a resource and partners in decision-making processes; viewing education as a two-way process between engineers and communities; striving for a multifaceted understanding of social, economic and environmental barriers to uptake of new technologies; and having an integrated approach to technological problems and solutions. Thus, reflexive engineers approach development problems with a fluid understanding of the ways in which technologies fit and co-evolve within social systems.

2. TRADITIONAL ENGINEERS

A literature on the sociology of engineering was particularly well developed in the 1970s and 1980s (Layton, 1971; Ritti, 1971; Noble, 1984; Whalley, 1986). In recent years however fewer works have been written with direct relevance to this area (for notable exceptions see Vicenti, 1990; Bucciarelli, 1994; Faulkner, 2000; Ferguson, 2002; Van de Poel and Verbeek, 2006). Many contemporary studies have been influenced by the debates around socio-technical systems of which engineers are one part, such as the social construction of technology (Bijker *et al*., 1987), and actor-network theory, which emphasises the mutually constitutive nature of technology and society (MacKenzie and Wajcman, 1999).

Two studies from the 1970s capture something of the professional ideology of engineers. Layton (1971) suggested that engineers saw themselves in three ways, as:

- agents of technological development;
- impartial and logical;
- responsible for ensuring positive technological change.

He also wrote that professional ideology emphasised engineers’ intellectual supremacy, and that this was combined with a frustration over low status and lack of job autonomy.

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Engineers saw themselves as being appropriate leaders of society, and managers of public infrastructure, possessing abilities to solve social problems using science and logic. Thus, engineers' world-view was elitist and hierarchical. They also did not value democracy and believed that engineers had greater capacity to make decisions than laypeople. Sewell (1976) similarly found that the water engineers of the 1970s viewed the public as irrational with such a wide range of views that well-informed decision-making was impossible. The engineers in his study believed they were more effective leaders because they were 'precise and accurate', having practical solutions, rather than being guided by idealism and imprecise thinking.

In addition to having a professional identity rooted in feelings of self-importance, studies also suggested that most engineers accept the *status quo*. Prandy (1965) wrote that professional identity among engineers was linked with their status as being connected with the exercise of power in organisations, and a feeling of being close to managers. Thus, engineers tended to support social systems, which gave power to educated elites. They also accepted 'the structure, power and basic ideological principles of business' (Layton, 1971, p. 67). Noble argued further that traditional engineers not only adopt capitalist values, but also expressly serve capitalism. He suggested that technical workers rely on powerful institutions and people as it gives them the opportunity to have their designs built (Noble, 1984). Noble wrote that science and technology have always been concerned with human control and manipulation of nature. For him, engineers are 'propelled by enthusiasm and a will-to-power' (Noble, 1984, p. 46).

Other studies of that period reported findings that engineers incorporate the values of business and economics. Zussman pointed out that 'cost itself is a criterion of technical efficiency' to be considered alongside material properties and engineering can help further corporate goals (Zussman, 1985, pp. 121-123). Ritti found that engineers placed greater importance on increasing company profits than technical or professional goals (Ritti, 1971, pp. 48-49). Whalley went further in suggesting that engineers working in organisations 'are socialised and selected from the beginning to accept the legitimacy of both bureaucratic authority and the dominance of business values' (Whalley, 1986, p. 124).

Echoing studies from the 1970s and 1980s, Meiksins and Smith wrote that 'engineering... far from having an autonomous scientific rationale is structured to match the needs of accumulation and profit' (Meiksins and Smith, 1996, p. 9). Indeed, engineers themselves often speak of the economics of design. The noted engineering historian, Henry Petroski, when asked about responses to Hurricane Katrina said 'Of course we can rebuild New Orleans. "At what cost?" will be the question. Engineers are prepared to rebuild, but they can only do so much with so much money' (Petroski, 2005). Engineers often describe their work as balancing cost with the levels of risk that users are prepared to accept (Petroski, 1992b, p. 6). As well as cost and market drivers, engineers and inventors are also said to be compelled in their work by the desire to rectify failures in existing products or processes. In other words, engineers see themselves as driven by a desire to make things work better. Petroski observes that 'fault-finding with the made world around them and disappointment with the inefficiency with which things are done appear to be common traits among inventors and engineers generally' (Petroski, 1992a, p. 38).

This desire to make things work better is constrained in industrial settings where engineers are often functioning in conditions of 'partial ignorance' or bounded rationality. This means that they often can neither see, nor take account of, the second order effects of what they produce. Hammond (2004) describes his work developing refrigerators, which used CFCs in the 1970s. He states that his main aim at the time was to find ways of

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preserving food, but he was unaware of the long-term impacts of CFCs. In relating this story, he concludes that because of such unforeseen second order effects, environmental, health and safety systems need to be put into place, and engineers and industry need to be monitored by the wider public, and its elected representatives. To him, this will ensure the development of sustainable technologies (Hammond, 2004, pp. 201-202).

3. EXAMPLE OF A TRADITIONAL ENGINEER: LORD BROERS

Lord Alec Broers' Reith Lectures provide a useful illustration of one engineer's view of technology and society. Broers is a Professor at Cambridge, President of the Royal Academy of Engineering, Chairman of the House of Lords Science and Technology Committee, and a pioneer of nanotechnology. His lectures, delivered in 2005, began with an evocatively titled first instalment 'Technology will determine the future of the human race' where he argued that civilisation itself would be impossible without technology, and that modern society faces a crisis because publics are increasingly unable to understand or appreciate the technology on which modern life is based.

In a vision of society which resonates with the findings discussed above, Broers argues that when humans became civilised, they 'surpassed instinct' and entered an era when they were able to 'impose themselves on their environment', and move from 'mere existence to a way of life which enabled them to take increasing advantage of their intellect' (Broers, 2005a). Broers then criticises the inability of the public to appreciate modern scientific and technological advances. Describing an opinion poll in which the UK public was asked to rank the country's greatest discoveries, including electricity generation, the jet engine, and DNA structure, he indicates that respondents to the survey instead chose another British invention: the bicycle. The key point of this example, to Broers, is that it demonstrates the public's 'profound misunderstanding' of the contribution of sophisticated technologies, and the advances that underpin them, to human life. He labels this a failure, which will disadvantage human society in the long run. To him, technology, and by implication those with technical expertise will determine the future. As such, technology should be given the 'profile and status that it deserves' (Broers, 2005a).

For Broers, engineers and scientists are part of the problem as well as the solution. They have not explained their work in ways that can be understood by non-experts. This, to him, is an historical problem arising out of a tradition that guards knowledge closely for its own purposes. Today however, he sees more of a tradition of free and open access to information, which allows knowledge to grow exponentially. But, this is a mixed development, because vehicles such as the Internet do not always carry information that is 'true', and even where it is true, it 'may not be believed or understood'. He observes that 'the difficulty the public has in understanding science grows rather than shrinks in the age of unlimited information' (Broers, 2005a). Thus, scientists and engineers have an important role as gatekeepers to what is accepted as true. Broers believes that people's lack of trust in experts is due to individual expert's 'mistakes in judgement' and secrecy. Therefore scientists and engineers need simply to be more open about their work and its implications. Focusing on dissemination of information, he suggests that 'knowledge of technology brings with it great personal satisfaction and pleasure'. Presumably, to Broers, if people had knowledge of technology they would not have selected the bicycle as a great British invention, but would have chosen something more advanced such as the structure of DNA.

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However, this leaves aside the question of why most people find the bicycle so useful that they would have selected it as the greatest British invention. It also ignores the social context in which technologies are produced. Broers' vision is expert-led; if scientists and engineers were only more open, publics would be educated and supportive of new technologies. In terms of how engineers should interact with publics 'we must communicate more and better, be more transparent in what we do, and be prepared patiently to debate public concerns, even if we believe that these concerns are based upon prejudice or ignorance' (Broers, 2005b).

Addressing the South in his last lecture, Broers argues that technology is the means by which a country develops, and is the key to ending poverty, pointing out that 'the most idealistic amongst us will surely accept that application of some technologies is the likeliest, even the only, means by which the endemic poverty, disease and desperation in which a majority of the world's population live can be alleviated' (Broers, 2005b). This is true, but the level of technology required in, say, the slums of cities in the South may be quite simple. The social forces which allow technological advance may nonetheless be quite complex and of central importance. These are the concerns of many of the engineers to whom I now turn.

4. ENGINEERS REFLECT ON ENGINEERING

I conducted informal interviews with 20 water, sanitation and structural engineers, and in-depth semi-structured interviews with 12 engineers working in community water supply, river hydrology, agricultural and mechanical engineering. Though most of the informants were male and from the North, all had spent considerable time working in the South especially in poor communities. They were asked about their perceptions of the engineering profession, understandings of sustainable development, and experience of working in interdisciplinary teams. The aim was to uncover how their vision of the role of engineers differed, if at all, from that of traditional engineers.

4.1. Engineering and Control over Nature

Noble (1984) wrote that engineers had a will-to-power and a desire to control nature, which was evidenced in Broers' lectures. A couple of the interviewees spoke of their own self-awareness of this wish, and where they thought it came from. When asked 'What is an iconic design for a water engineer?', a Water and Sanitation Engineer replied:

> I would say the Hoover Dam. It is an iconic...it is a fabulous sense of... every engineer wants to put their imprint on nature, and have their monument. What is more iconic than perfectly filling up, a bit like the Glen Canyon Dam as well, perfectly filling up that space and damming all behind it? It is the archetypal hydraulic design. Dams are fabulous in that sense. Just like these beautiful bridges. The suspension bridge is a similar thing.
>
> [Interviewer: It's because it's able to harness the power of the river...?]
>
> I think it's more than that; it's the control aspect. In engineers, the studies show, autism is slightly higher. In the engineering cohort you can see that recognition, and that the male desire for control is intensified in an engineer. He tries to control his

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> environment. I think control is a greater driver than sustainability. The Hoover Dam is just archetypal controlling nature. We have caught it.

It is interesting that the interviewee points to studies that have found that rates of autism have been found to be significantly higher in the families of engineers. Psychologists have proposed that the brain contains two basic cognitive domains, which they label 'folk psychology' and 'folk physics', thought to reflect inborn attention biases towards different classes of information, social and inanimate objects, respectively. Research suggests that many autistics, including those of average and superior intelligence, have normal or exceptional folk physics, including a good understanding of object properties and causality, a fascination with machines, physical systems (such as planets), and systems with mathematical or spatial regularities (such as calendars and transport networks), and impaired folk psychology, which includes among other things, the ability to predict and explain human behaviour (Baron-Cohen, *et al*., 1998). The interviewee's comment about the masculinity of engineering is also supported by Kleif and Faulkner's findings that many men like the feeling of certainty that engineering provides, though they point out that this sentiment is also shared by women engineers (Kleif and Faulkner, 2003).

Most of those interviewed see tendencies towards such modes of cognition as typical of traditional engineers. They suggest that, in contrast, they are less driven by the mechanics of controlling nature, and more in working together with communities, or with colleagues in interdisciplinary teams, to find integrated solutions to problems.

They differentiate themselves from traditional engineers in specific ways. One is around thinking processes. Those working on hydrological questions, such as river engineering and community water supply, have a vision of how technology has a place within broader concerns. Most see large dam projects as dominated by the engineering, with less concern for social and natural systems, such as Three Gorges in China. As one River Engineer said: 'I guess I had always been a good holistic thinker and the thought of just being 'an engineer' filled me with horror'.

They resist what they see as the traditional engineer's desire for certainty, a numerically 'right answer', which they find elusive when dealing with complex systems, such as catchments or ecosystems. They also feel that they are treated differently by other engineers. A Coastal Engineer noted: 'I was far too cross beam for them. I could understand electricity transmission and turbines, which was what they were working with, and I couldn't quite grasp why they didn't understand what I was doing but it seems that it was far too imprecise'.

This is due in part to their subject of study. Many of the engineers I interviewed are working with systems where, because of their complexity, there is uncertainty about how they will behave. This is different from much of engineering, which is design-based, such as bridge building, which operates with much higher levels of confidence. Still, while the engineers I interviewed may show evidence of more reflexivity due to their areas of work, most believe that traditional engineers can become more reflexive and some even actively try to 'force (traditional engineers) kicking and screaming into a new way of thinking' based on a more holistic approach (pointed out by a Hydrological Engineer).

4.2. The Process of becoming Reflexive: Work in the South

Many of the engineers interviewed describe a process by which they came to differentiate themselves from other engineers. This is particularly the case when working in the South.

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Having seen Western technologies 'failing all over the South because engineers had no idea of technology transferability and acceptability by users', they resisted becoming 'an arrogant engineer who goes in and knows what's best' (Hydro Geologist–Civil Engineer).

This is what drew many of them, at least initially, to the appropriate technology movement, begun in the wake of the publication of EF Schumacher's *Small is Beautiful* in 1973, which was based on the idea that technology should be in keeping with the environment and culture of its users. However, informants also employed a business discourse when speaking of 'differentiation, in marketing terms, to get the right technology to match a particular society' (Water and Sanitation Engineer). The use of the marketing paradigm by some is an attempt to find ways of bringing about the development of sustainable socio-technical systems which will last rather than a technically driven approach that merely implements an 'appropriate' or the 'best available' technology, without evaluating whether people have the will, the capacity or the funds to maintain it.

As such, the engineers I talked to were disillusioned with traditional development initiatives, which they saw as too often introduced only for economic reasons. In particular, they criticised the introduction of unsustainable technologies linked with outside interests, such as tied aid where state-based development organisations, like (the former) ODA and USAID had 'much more to do with selling tractors and building tomato canning factories for tomatoes no one actually wanted to grow' (Irrigation Engineer).

When asked whether they thought work in the South had forced them or their colleagues to think about social issues more deeply, some said they thought that it either reinforced other engineers' sense of arrogance, or in their own cases they saw social differences and were 'challenged and interested to think about their place in the world a little more clearly' (Irrigation Engineer). Their own desire, in project work in the South, was to help facilitate sustainable development.

4.3. Engineering for Sustainable Development

Those interviewed spoke of their distress at some traditional engineers they knew who often thought of crises, such as the Asian tsunami or Hurricane Katrina, simply as business opportunities. They believed engineering for sustainable development was about advising decision makers about the location and method by which the most environmentally benign development can unfold, including how and where projects should take place. Too often they thought traditional engineers lobby for particular development, simply on the basis of whether it might provide them with employment.

There was the view that 'sustainable development' was taken more or less seriously by different types of engineers, which some saw as a problem that could be addressed in refashioning the engineering curriculum. As one Mechanical Engineer said:

> Engineers from first principles tend to be biased towards technology, not towards the sustainable application of that technology, so they have to learn to make that adjustment. So if you're working in an area like community water supplies, where you're in the village, it's easier to learn that than if you're building bridges, which are designed to carry people.

A Structural Engineer working in housing construction said the degree of environmental efficiency designed into a building is determined by the employer, in

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this case the architect, rather than the engineer, who merely has to implement the architect's plans: 'If the architect is not interested in saving energy, then the engineers design it according to what the architect has said so the end product will not be a sustainable product'.

In terms of community water supply, sustainability was discussed in technical terms, and connected with social, economic and environmental factors. The working definition of a sustainable system for such engineers is one which 'continues to work over time', normally conceptualised as around 20 years.

> If community water supply systems continue working and being maintained there will be underlying financial, NGO, benefactor and community support. It also means that someone thinks it's worthwhile and the most obvious reason is because they want to use it. So, there is much that is implicit in the definition of something "working over time" (Water and Sanitation Engineer).

In this notion, the environmental sustainability of the system is also important; for example how to locate and construct pit latrines so they do not pollute groundwater supplies. Thus all parts of the design and use of a system are viewed as parts of an integrated whole.

4.4. Team Work: Holistic and Interdisciplinary Approaches

Many of the engineers interviewed work in interdisciplinary teams with scientists and social scientists on solutions to problems that bring together social, technical and environmental components. Such teamwork and the social skills it demands are a key part of the work of traditional engineers (Kleif and Faulkner, 2003). However in much traditional engineering teams are largely comprised of technical experts, such as architects working with engineers who then interact with a customer, rather than the more broadly composed teams of many of the engineers interviewed. Such engineers view socio-technical systems as interlinked and holistic, because for them engineering only forms part of a solution. As one Hydrological Engineer said: 'I don't think you can solve a problem with one discipline. It is never just an engineering problem or an ecology problem. There are always other aspects to it; you have to work in teams to make anything truly work'.

The successful operation of teams comprising members with such wide-ranging expertise depends upon 'a mutual willingness to understand each other's languages and professional cultures' (Irrigation Engineer). Interviewees spoke of specific examples where teams did not work because one or more members were rooted in a specific epistemological approach and were unwilling to understand where others were coming from in order to come up with an integrated solution. One informant, an Irrigation Engineer, describing the design of an irrigation system involving an interdisciplinary team of water engineers, agronomists and social scientists, recounted a meeting where:

> The engineers said "this is the answer... [water] flow has to be 5.64 metres per second into the field," and the managers said "well, surely it depends on how you manage the system and whether it is looked after and maintained, and how it is

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operated by those using it'' and the engineers were saying ''well look, that doesn't matter; this is the answer''.

This highlights the need to balance the technical requirements of a system, with its operation and maintenance.

At the heart of their notion of successful teamwork is the commitment to the concept of integration, which many draw from the communities in which they work. At the level of an African village people must deal with daily life in an integrated way. Farmers 'have to know about the soil, the weather, the crop varieties. . .there's an endless list of things they have to know a bit about, and in many cases, a great deal about'. Such engineers are driven by 'wanting to respond to reality, the field reality, and not just theorise. . ..What is it like for the man or woman or child in a rural community in a developing country? What are the challenges they face?' (Irrigation Engineer).

4.5. Example of Reflexive Engineering: Engineers without Borders

One well-articulated vision that reinforces many of the interview findings is that outlined by EWB-USA. EWB-USA's mission is to bring about 'a new way of thinking for the engineering profession' built around engineers working in partnership with different stakeholders, including communities, social scientists, public health officials, businesses and international development organisations.

A key part of their work is to build 'partnerships with developing communities to improve their quality of life through the implantation of environmentally sustainable, equitable, and economical engineering projects while developing internationally responsible engineers and engineering students'. (EWB-USA, 2006) The organisation's vision is based on a world where everyone has 'access to the knowledge and resources to meet their basic human needs', promoting sustainable development in areas such as water supply and sanitation, food production, housing and construction and energy, transportation and communication 'income generation, and employment creation' (EWB-USA, 2006).

Meeting EWB-USA's vision requires six elements: change, culture and people in host communities, partnership, sustainable projects, education and understanding. Change refers to positive development over time, with new 'solutions' that 'interrupt the cycle of poverty'. Culture and people in host communities 'define development projects and ensure ownership, appropriateness and long-term effectiveness; and people who can solve their own problems and build new skills with reasonable financial assistance' (EWB-USA, 2006). Partnership denotes a 'broad cadre of institutional, academic, development and engineering professionals who are willing to assist in building a more equitable and sustainable world'. Sustainable projects are 'symbiotic with the environment, society and culture and help build capacity for people to solve their own problems'. Education focuses on host communities, as well the next generation of engineers who benefit from 'seeing the many facets of engineering solutions to problems in developing communities, beyond the technical skills obtained in their basic education'. Understanding is about developing an awareness that 'non-engineering components of local needs are almost always more complicated than the engineering aspects'. Finally ethics are multidimensional. They require integrity, honesty, communication and forthright disclosure. They promote human dignity, values and

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respect of diversity. Ethics include the endorsement of social responsibility, fairness and equality, and sharing skills and resources, and the rejection of exploitation. The closing sentences of the vision statement, in bold, are:

> Engineers have a central role in building a sustainable future for ALL. They have an obligation to provide leadership in that direction; it is no longer an option (EWB-USA, 2006).

When comparing Engineers without Borders' vision with that of Lord Broers, it is evident that the former is socially rather than technologically focussed. It speaks of the relationship between nature, society and technology, and emphasises that education is not just about disseminating or absorbing technical information; it concerns both engineers and communities learning about complex socio-technical dynamics. It also has a strong ethical component rooted in a commitment to fairness and equality. The vision is therefore much more fluid in its multidimensional understanding of development.

4.6. Traditional and Reflexive Engineers

Table 1 outlines some of the differences between traditional and reflexive engineers, summarising some of the differences outlined in this paper.

Whereas traditional engineers view knowledge and society in terms of expert-led systems, reflexive engineers' views are rooted in response to public demand. Reflexive engineers' understandings of innovation are therefore more people focused, seeing publics as resources and partners in decision-making processes, and viewing education as a two-way process between engineers and communities. Reflexive engineers strive for a multifaceted understanding of the social, economic and environmental barriers to the uptake of new technologies, having an integrated approach to technological problems and solutions. When they engage with engineering challenges the conceptual starting point is socio-technical systems rather than designs.

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

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5. CONCLUSION

Traditional engineering treats society as a type of ‘black box’. This is not surprising given its technical nature. However, some engineering challenges, especially those in the South, can be more complex because of the social contexts they inhabit. Reflexive engineering is based on an integrated ethical and systems-based approach to development which values communities and the environments in which they are sited as well as the technology. Some types of engineering may be more suitable to a reflexive approach than others. However, all engineers could gain from integrating broader concerns into their work. Engineers strive to find ways to serve the needs of people in the North and South more effectively, and increased reflexivity could contribute to this goal.

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