Ever deeper and wider: incorporating sustainability into a practitioner oriented engineering curriculum

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Abstract Whilst valuable debates about how best to plan, promote, and evaluate sustainable futures for our communities are conducted by governments and NGOs at global gatherings, there is an equal, and possibly more pressing, need to inspire and equip engineering graduates with the means to design and implement the required solutions. However, incorporation of sustainability as a subject into existing syllabi is problematic, primarily because of the need for students to acquire both holistic and context specific skills. This contribution first considers the reasons why we should be concerned with the integration of sustainability concepts into graduate and post-graduate curricula. We then go on to discuss the significance of cross-disciplinary thinking and skills as a key element of sustainability relevant knowledge. Finally, we report the design and deployment, within a water engineering degree course, of a post-graduate module in "Process design for sustainability". The implications of our experiences for the theory and practice of engineering education are examined and suggestions made concerning best practice.

Keywords Cross-disciplinary working; engineering education; sustainability

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Introduction: drivers for new thinking about sustainability

The global debate surrounding sustainability in general and sustainable development in particular has been strongly influenced by concerns about the environment. However, routes to sustainable development are not achievable through consideration of environmental issues alone; for two often overlooked reasons. Firstly, the connectedness of our world and the increasing rate at which such connectedness is global in scale, compels us to consider the multifarious relationships between environment, society, economy, technology, and knowledge. Secondly, whilst it would be unrealistic to suggest that current environmental problems are irrelevant with regard to sustainable water management, environmental degradation is clearly undesirable in terms of ensuring access to natural resources in the future. However, it would be equally nonsensical to propose that solving the current problem set will assure sustainability for all time. New problems and threats will emerge, variations of previously addressed problems will arise, and today's problems will evolve new dimensions. The specifics of tomorrow's challenges are thereby both unknown and largely unknowable.

It is for these reasons (the inherent and unavoidable uncertainty of the future) that there is a need to seek out knowledge concerning sustainability that is more generic in nature i.e. relevant across all temporal and spatial scales. As *"we cannot . . . guarantee the persistence of any particular system in perpetuity" we are led to a view of sustainability as a "normative ethical principle" which has "no single version" and is "a process, not a state."* (Robinson *et al*., 1990). The implementation of sustainability will therefore be local and relative rather than global and absolute. In particular, if we are to instil an understanding of sustainability and prepare people for decision making which is sensitive to sustainability issues, we need to expand this narrow view to address what has been described as the "triple bottom line" (Elkington, 1997) or three pillars of environmental, economic, and social sustainability. Water industry professionals need to be both aware of the "sustainability debate", and capable of applying concepts, methods and tools to problems which exhibit a sustainability dimension. Likewise, pedagogic frameworks need to communicate an interpretation of sustainability which is pluralistic and not restricted to environmental concerns, single discipline analysis or unilateral responses.

Equally, if students are to graduate from our universities armed with the tools to contribute towards sustainable development, we need to provide them not only with relevant concepts, but also with the techniques and skills to design and implement appropriate change. Given the need for such a broad and comprehensive knowledge profile, how are we to formulate, structure and deliver educational activities to support its development in individuals and knowledge communities? A partial, but by no means comprehensive, resolution to this query can be found in the literature on, and experience of, cross-disciplinary working.

The significance of cross-disciplinary knowledge and skills

It is said that Gottfried Leibnitz (1646–1716) was the last man to have known everything. The increasing breadth and depth of scientific knowledge has resulted in the emergence of a myriad of branches of learning, each one requiring many years of study to reach the forefront of research. However, many practical problems typically cut across disciplinary boundaries. Indeed, it has almost become an axiom that *"unless the output of most specialities becomes the input of others, knowledge breaks up into a mere aggregation of isolated entities and ceases to be a single body"* (Boulding, 1968).

The emergence of sustainability as a concern within engineering should radically change the problem solving model used by the profession. The triple bottom line mentioned in the previous section acts as a set of limitations on desirable engineering solutions. Hence, in addition to the traditional engineering criteria such as performance, reliability etc. which might be applied as criteria for solution selection, an additional set of environmental, social and economic criteria are also pursued. Problem diagnosis, option generation, solution design and deployment thereby become negotiated between several professional and lay communities (engineers, economists, politicians, environmental scientists etc.). Such a reflexive and inclusive model of engineering practice is being driven both by legislation (Kakebeeke and Bouman, 1999) and by a public desire for more socially responsible and accountable intervention. The need for cross-disciplinary knowledge and knowledge about cross-disciplinary working is crucial if engineers are to both manage the contributions of different science and engineering fields to desired engineered solutions, and engage in meaningful and mutually informative dialogue with other stakeholders (Figure 1).

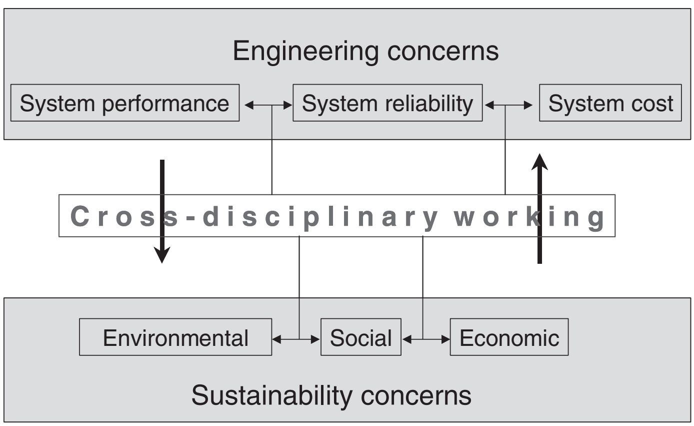

Figure 1 A reflexive model of sustainability and engineering practice

In today's industrial and commercial environment, knowledge is primarily held by individuals, but exploited by people working together. Professional training typically takes place within sharp disciplinary boundaries, providing the individual with a comprehensive understanding of one field of knowledge. Colleagues and supervisors are from the same discipline and problem solving takes place within an epistemological framework that is familiar to everyone. However, once in the workplace, individuals from different professional backgrounds are expected to work together to a common end.

However, there are a number of weaknesses in the way in which cross-disciplinary issues are typically addressed. As Michael Gibbons and his colleagues have stated; *"precisely because it [transdisciplinarity] is so universally acclaimed as something positive, everyone believes it can be brought about by just aspiring to it."* (Gibbons *et al*., 1994). All too often, cross-disciplinary working is interpreted as multi-tasking or excellence in generality! As noted above, a sound training in one discipline is an essential preliminary to an appreciation of the relevant problems of cross-disciplinary problem solving. It is difficult to understate the importance or significance of this conjecture; the strength of cross-disciplinary contributions is in maintaining the keenness of each contribution and not dulling the edges to make an easier fit between knowledge sets.

In an educational context, this infers that training for cross-disciplinary practice should be a post-graduate undertaking, carried out in tandem with advanced instruction in a specialist field. We would note that, unfortunately, the current trend is towards encouragement of cross-disciplinary approaches increasingly earlier in students' educational experience. Whilst this is not altogether a negative development, there is a danger that we produce fewer specialists who can bring leading edge knowledge to cross-disciplinary teams, and more generalists who understand the problem but lack the tools to propose practical, integrated solutions.

Cross-disciplinary working is certainly not an issue to get fixated or obsessed about. Our curricula should continue to reflect the key principles of relevance and excellence, balancing academic rigour with practical application. However, we can take the response to cross-disciplinary issues (particularly in the context of sustainability) beyond the nominal and the placatory by providing academic depth to students' understanding. For example, a useful agenda for delivering cross-disciplinary skills should cover issues such as: why there are disciplines, barriers to effective cross-disciplinary working, the design and resourcing of cross-disciplinary activities, and effective methods for information and knowledge integration.

Incorporating sustainability into the curriculum

Water treatment has usually been considered in four sectors: clean and dirty; and public and industrial. In particular, the technology requirements for the potable or clean water industry have normally been considered to be separate from the technologies needed for wastewater treatment.

However, these requirements now have greater complementarity due to an overarching need to enhance treatment standards. For wastewaters, this is in order to improve the environment due to more stringent legislation, e.g. the Urban Wastewater Directive in Europe (Council of European Communities, 1991) and increased public awareness about pollution; for potable water, tighter legislation and guidelines (World Health Organisation, 1993); and for industry, the requirement for high purity water for the manufacture of microchips and pharmaceuticals, in particular (Lorch, 1987). These factors have driven the need for better technologies and it is now more appropriate to consider treatment of water at three levels (Stephenson, 1992):

Level I: treatment of polluted wastewaters to a quality acceptable for discharge.
Level II: treatment of water from the environment to potable quality.
Level III: treatment of potable quality water to specified qualities for industrial applications.

This philosophy is put into practice on the full and part-time master's degrees in water and wastewater technology, and water and wastewater engineering, run by the School of Water Sciences, Cranfield University, UK. In order to teach unit operations before application at each of the three levels, three core skills are needed: fundamental science and engineering, technical knowledge and management. This then needs to be followed up by the application, which involves selection and design of unit operations, to fit in the overall flowsheet. Finally, practical skills for new technologies are applied during the thesis project. This approach is described in more detail by Stephenson (1996).

Students on the course come from a diverse background, so it commences with an introductory studies section that includes biology, chemistry and process engineering fundamentals. This is followed by the taught modules on the fundamentals of unit operations. The fundamentals are then applied to the three levels of treatment identified above during the design projects. These are undertaken in multi-disciplinary teams of about 5 people, usually including a biologist, chemist, engineer and environmental scientist. Each written report contains a full process design with details of how unit operations were selected and sized, predicted performance under the expected range of conditions and estimated capital and operating costs. Students also have to make an oral presentation to an audience of invited industrialists, academics and peers to practice communication skills taught earlier (Allison and Bramwell, 1994).

As is true of all tertiary level educational institutions, the School of Water Sciences at Cranfield University is committed to continuous course development based on leading edge research and anticipation of developments in the international water sector. However these motivations might be characterised as "problem oriented" in that they emerge from the world of work. But what about the other side of the equation? It is certainly relevant at this juncture to enquire as to the "subject oriented" drivers for incorporation of course material on sustainability into an existing post-graduate programme. In particular, was the initiative market driven? The honest response to such a query is "yes", in so far as there was a perceived need to bring to the fore the concept of sustainability in relation to process design. The primary barrier in this respect is that in some professional quarters "sustainability" has been seen as merely a fashionable term.

In considering sustainability as an additional theme to an existing course, two debates surfaced which are worthy of some discussion here. The first of these was selection of an appropriate format for incorporation of the new theme; specifically, should there be a special module on sustainability or should appropriate material be integrated into existing modules? In terms of several key criteria (including resource [in particular time] requirements and flexibility), the first of these options had significant appeal. However, a strong case was made for the latter alternative on the grounds that the holistic nature of sustainability demands to be reflected throughout the existing material. The adopted strategy possesses aspects of both positions in that a specific two-week module on "Process design for sustainability" has been introduced towards the end of the existing course together with a series of sustainability signposts being used in preceding modules to identify issues which are to be addressed later.

The second point of debate during module design was how to ensure the engineering relevance to the material. As noted in the opening paragraphs of this text, sustainability is a theory-laden subject area; much thought and theory, yet little prescription and practice. Our response to this challenge has been to ask ourselves the question: what are the implications of the sustainability agenda for engineered systems diagnosis, design, and management? In responding to this query we were greatly helped by consultations with our Course Advisory Committee drawn from industry, and colleagues in the fields of engineering and management. Some of the responses to the query involve modifications to current practices and guidance, other responses dictate that novel technologies and evaluation techniques be developed and applied.

The stated aim of the module is to provide students with *"an understanding of sustainability issues as they relate to the water industry and develop practical skills to support the application of sustainability principles to system analysis and design."* With reference to the need for a cross-disciplinary emphasis, the module management team has focused on: (a) promoting an understanding of why cross-disciplinary working is beneficial, (b) providing opportunities for students to explore the contributions of disciplines outside their immediate acquaintance, and (c) imparting knowledge of techniques which can be used to structure and manage cross-disciplinary working. Our intention has not been to force students to work "outside the box" but to provide an environment within which such work is facilitated, supported and its utility made clear. The syllabus includes taught sessions and seminars on the following subjects:

- Sustainability concepts/advanced sustainability concepts
- ISO14001/BS7750/EMAS
- Urban water recycling principles
- Urban water recycling and rainwater harvesting systems
- Sustainable sludge management
- Sustainable urban drainage
- Ecological sanitation
- Life-cycle assessment
- Heat exchange networks
- Industrial water recycling
- Valuation of environmental services
- Water pinch analysis
- Struvite recovery and reuse
- Environmental management systems
- Demand management
- Power management in the water industry
- Environmental impact asessment

Cross-disciplinary dimensions to the module include the variety of disciplinary elements (including physics, chemistry, biology, environmental science, economics, anthropology, psychology, history, and energy analysis), a focus in the examinations on knowledge integration, the setting of complex problems and seminar questions requiring diagnosis and solution formulation involving several disciplinary skills.

One of the key facets of the course which supports the integration of sustainability into the curriculum is the design project. During the design projects, students have to make decisions on the most appropriate flowsheet from knowledge gained during the taught modules. Primarily, this will mean treating a wastewater to meet an acceptable discharge standard. It is arguable that the overall flowsheet will therefore meet one of the tenets of sustainability, that of environmental sustainability. As, say, municipal wastewater treatment is providing a service to society, this meets the criterion of social sustainability. However, the third tenet, that of economic sustainability, will usually be interpreted as "at least cost", as is the habit of water industries worldwide, whether privately or publicly owned. Principles taught in the new module will enable students to take a broader view of the sustainability of unit operation selection for the flowsheet. For example, environmental considerations will mean selecting sludge treatment and disposal routes that have less impact. Energy consumption of mainstream unit operations, as well as life-cycle costs, will also be incorporated. This means that economic sustainability will not merely mean least capital and operating costs solutions being selected.

Conclusions

Naturally, the inclusion of sustainability as a core theme increases the appeal of courses to undergraduate students whose motivation is to apply their education to the benefit of the environment and society as a whole. Their desire to engage in "good works" throughout their careers has presented a marketing opportunity that is allied to one of our own key educational objectives: to provide the water sector with mature, process literate engineers and scientists.

Analysis of student feedback forms suggests that the new module is performing well and has been successfully integrated into the existing curriculum. In terms of improved student understanding, the new module ranks third out of the twelve core modules and individual sessions are amongst the most highly regarded of the whole course. The same feedback does suggest, however, that ongoing care needs to be taken in the design and presentation of learning materials. As might have been anticipated, although sustainability is a stimulating theme for study, effective communication of its central concepts and implications remains a challenge.

Our experience suggests that the integration of sustainability concepts into an existing post-graduate engineering course is a non-trivial undertaking; one which involves matching the need for deeper understandings of physical, biological and chemical processes with a wider appreciation of appropriate methods to support problem diagnosis, option generation, and solution selection. We would encourage others who embark down this path to avoid the simplistic alternative of appending sustainability to existing courses and take on the challenge of thinking through the implications of sustainability for their subject: bringing breadth to their students' experiences without compromising excellence; encouraging the application of sustainability concepts based on sound engineering principles.

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