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Into the Deep: The Role of Paradigms in Understanding Engineering Education for Sustainable Development

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Abstract

This article presents summary findings of a mixed methods research project exploring the provision of education for sustainable development (SD) in seven Irish engineering degree programmes. Drawing on Sterling's (2004) iceberg metaphor and Critical Realism it seeks to identify the underlying socio-cultural barriers preventing a holistic integration of SD in engineering education. It argues that the current focus is predominantly on the environmental dimension of SD and that there are a set of reinforcing mechanisms facilitating the provision of disciplinary education aimed at producing technically proficient, employable graduates in which the social dimension of SD is marginalised. This is underwritten by a paradigm of engineering education located between science and market driven approaches as identified by Jamison and others (2014). It is argued that unless there is change in the underlying paradigm towards a more socially driven approach a full integration of SD is unlikely to occur or be sustained.

Keywords: engineering education, sustainable development, critical realism, engineering education paradigms.

Introduction

Our Sustainable Future – A Framework for Sustainable Development in Ireland sets out a key role for Education for Sustainable Development (ESD) in moving towards sustainability and argues that “education for sustainable development needs to be embedded at every level of the formal and informal education system” (Department of Environment, Community and Local Government 2012, 77). Within engineering there is now a requirement that engineering programs provide graduates

with “an understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineers towards people and the environment” (Engineers Ireland 2014, 16). The Code of Ethics of Engineers Ireland (EI), the professional body with responsibility for accreditation professional engineering programmes in higher education, requires engineers to “promote the principles and practices of sustainable development and the needs of present and future generations” (Engineers Ireland 2009). EI has endorsed Comhar’s¹ Principles for Sustainable Development which deal with a wide range of issue from resource use and conservation to social inclusion and public participation in decision making (Comhar 2002). This aligns with the approach adopted by many engineering bodies which is to see SD as a broad concept. So, for example, the World Federations of Engineering Organisation (WFEO), in its Model Code of Practice for Sustainable Development and Environmental Stewardship, calls on engineers to “Seek innovations that recognise environmental, social and economic factors” (WFEO 2013).

Within engineering education there has been some debate about the integration of sustainable development (SD) into engineering programmes. In 2002 a biannual conference in Engineering Education for Sustainable Development (EESD) was initiated. The 2004 conference adopted what is now known as the Barcelona Declaration which sets out a comprehensive set of learning outcomes which should guide EESD and which embraces a broad approach to SD incorporating its environmental, social and economic dimensions (EESD 2004). In 2003 Engineers Ireland called for the “development of appropriate detailed sustainability curriculum material for use in third level education programmes ...In this area, priority should be given to engineering programmes because of the significant responsibilities engineers carry in ensuring sustainable development.” (Institute of Engineers in Ireland 2003)². Despite this call there has been no research which attempts to evaluate the extent to which it has been met.

¹ Comhar, The National Sustainable Development Partnership was set up in 1999 with “the aim of advancing the national agenda for sustainable development, and contributing to the formation of a national consensus regarding this very important process.” (Comhar 2002, 2) Its function were absorbed into the National Economic and Social Council in 2011. In 2002, it published principles for sustainable development “to relate the concept in a practical way to the Irish situation.” (2002,2).

² In October 2005 the Institution of Engineers in Ireland adopted the operating name of Engineers Ireland.

There is a considerable literature examining the integration of SD into engineering education which identifies appropriate competencies (knowledge, skill and values) for engineers; their pattern of integration and barriers and enablers for EESD (see for example Ashford 2004; Boyle 2004; Mulder, Segalas and Ferrer-Balas 2012; Svanstrom, Lozano-Garcia and Rowe 2008). The overriding message is that while some progress is being made there are significant barriers to a holistic integration of SD. One key issue is whether engineering education needs a paradigm shift in order to address what some have called “the overarching sustainability challenge” (Jamison, Kolmas and Holgaard 2014, 254).

Our approach to examining EESD in the Irish context was influenced by Sterling’s (2004) argument for the requirement to see education as a complex system with a number of different layers. He analyses higher education using an iceberg metaphor and argues that “the deeper levels of paradigm and purpose guiding policy and practice...tend to be hidden from view and... most debate” (64). In light of this the project drew on critical realism (CR) (Collier 1994) to examine different dimensions of EESD in seven professional engineering programs in three higher education institutions. Data was collected through student surveys, analysis of programme modules and in-depth interviews with programme chairs. Some results of this work have been reported previously (Nicolaou and Conlon 2012, 2013, 2015, Nicolaou, Conlon and Bowe 2015) so are not repeated in detail here. The focus here is on integrating the findings and how they can help us identify underlying paradigms guiding practice and how they might need to change.

We proceed as follows. Firstly some arguments in relation to a focus on paradigms and the usefulness of CR for examining such paradigms are provided. Then we set out what we actually did and provide summary results from the earlier phases of the project. We then turn our attention to the interviews and what they tell us about the mechanisms shaping EESD. Drawing on Jamison’s work (Jamison, Kolmas and Holgaard 2014; Jamison 2013) we conclude there are a set of reinforcing mechanisms facilitating the provision of disciplinary education aimed at producing technically proficient,

employable graduates in which the social dimension is marginalised. We conclude by considering the implications of this for engineering educators.

Into The Deep

There are interesting similarities between Sterling's call to investigate the deeper layers of education systems and the depth ontology offered by CR³. CR argues for the primacy of ontology and that the nature of what exists cannot be unrelated to how it is studied (Archer 1995). In seeking to explain phenomena CR offers a depth ontology: a notion of a stratified reality which includes a distinction between the domain of the real (generative mechanisms), the actual (events) and the empirical (experiences). Structures of objects at the level of the real generate mechanisms that facilitate events. They are not observable but their effects are felt nonetheless. They can be inferred through empirical investigation and theory construction. Realist explanations consist of connecting experience in the empirical domain with structures and processes in the real domain. This is potentially emancipatory in that it forces us to consider "that certain states of affairs cannot be ameliorated within existing structures" (Collier 1994, 10). They must be changed.

Causal mechanisms must be studied as part of open systems where their effects may be blocked by the operation of other mechanisms. Thus their impact is conditioned by the context in which they operate. Realist seek to show how it is that in the particular situation in which research is taking place "there was a particular configuration involving a set of mechanisms that had the particular pattern of results achieved" (Robson 2011, 37). Further, as social structures are maintained through the activity of people, critical realists are committed to an explanatory model "in which the interplay between pre-existent structures, possessing causal powers...and people possessing causal powers...of their own results in contingent yet explicable outcomes" (Carter and New 2004, 6). They argue that the transformative potential inherent in human agency can only "begin to bite when structural contexts

³ Indeed Huckle (2004) has argued that critical realism (CR) can provide a philosophical framework for higher education for sustainability. Given the restrictions of space there is only a cursory treatment of CR here. Some further detail is provided in Conlon, Nicolaou and Bowe (2016).

...are generally supportive of those potentialities being actualised in some durable form.” (Reed 2005, 302).

This approach encourages us to examine the deeper structures of education and the underlying socio-cultural barriers that can hinder educator’s efforts to realise strategies for ESD (Guerra, Holgaard and Smink 2016). While there has been much debate about the need for change in engineering education, Jamison, Kolmos and Holgaard (2014) argue that a key issue is that different approaches to change are based on different perceptions of engineering and engineering education and therefore tend to pull attempts to change engineering education “into opposing, even contradictory, directions” (254). They highlight the need to clarify the underlying philosophy that will drive the development of holistic engineering education focused on the broader social role of engineers. They say that responses to the demand to integrate sustainability have been underwritten by either a science driven approach, which seeks to reconfigure established engineering fields into sub disciplines in new areas of specialisation with the aim of educating engineers who can serve as professional experts while upholding a traditional engineering identity, or a market driven approach, the dominant approach, focused on the cultivating of technological innovation and entrepreneurship. The latter envisages a social role for the engineer as that of entrepreneur or business manager with a focus on educating engineers who can take part in networks of innovation. There is also a strong emphasis on employability and the provision of transferable skills. They argue that these approaches have competed within engineering education “often at the expense of a more balanced or comprehensive approach to educational reform” (255). The result is that students “have not been given the opportunity to understand the broader social and cultural aspects of the challenges facing engineering” (Jamison 2013, 21).⁴

⁴ Jamison’s example from Denmark summaries the argument well: “While many engineers in Denmark have learned how to build wind energy plans and connect the electricity into the power grid, very few of them have learned how to make Denmark sustainable. Their education has, for the most part, been far too technical, and in recent years, far too market-driven, for them to be able to contribute to a transformation of Danish society into a more sustainable direction. While they have learned to solve problems with technical solutions, they have not learned much about the problems that need to be solved. More specifically, they have been given too few opportunities in their education to learn about social and cultural contexts in which their scientific knowledge and engineering skills are actually used” (2013, 39)

They identify a third approach which, although less prominent historically, focuses on public service and role of engineers as change agents. It requires significant engagement with the humanities given its emphasis on the requirement for social and cultural understanding to be added to the theoretical and practical components of engineering work. In this approach the curriculum is focused on the development of a hybrid identity and the exercise of social responsibility and includes the “scientific, the technical, the social, and the environmental dimensions of engineering in one comprehensive form of education” (264).

Their analysis thus leads to the identification of three modes of engineering education, the Academic, Market-Driven and Integrative (or Social). These ideal types usefully link different perceptions of engineering identity with different approaches to engineering education and provide a “frame of reference for engineering educators as they reflect on their perceptions and practices of institutional reform and curricular improvement” (255). In the context of the work discussed here they provide a useful way to understand the underlying approach to engineering education which influenced the manner in which SD was integrated in the programmes in the study.

Research Methods

CR is not committed to any particular research methods but rather argue for the use of “critical methodological pluralism” (Danermark et al 2002). Given their rejection of the ontologies underpinning qualitative and quantitative methods critical realists prefer to talk about combining extensive and intensive methods given their different roles in identifying generative mechanisms and how they manifest themselves in different contexts. Mixed methods are necessary to reveal different features of the same layered reality and offer a robust option for uncovering generative mechanisms while also identifying which phenomena occur most frequently (Hurrell 2014). As reality is stratified data collected at the empirical level can shed light on the operation of mechanisms. Extensive methods need to be complemented by intensive methods focused on processes and *how* a mechanism works in a concrete situation.

In light of this it was decided to focus on a small number of programmes (7)⁵ in a small number of institutions (3) of different types. Four of the programmes were in one institution. The other three were in similar and different disciplines in the other two. Thus three programmes in civil engineering were examined and one each in mechanical, chemical, building services and structural engineering. The institutions included an institute of technology, a traditional and long standing university and a university of more recent standing. This allowed us to gather both extensive and intensive data on a small number of cases and also allow us to consider whether the disciplinary and institutional context was significant in shaping the pattern of integration of SD.

The data collected was based, firstly, on a student survey of 371 students with 193 (70% response rate) in their final year and 178 (85%) in their first year. In order to allow for comparison with international data the questionnaire built on Carew and Mitchell (2002) and Azapagic, Perdan and Shallcross (2005), but also included material relevant to the Irish context, and mainly asked students to rate their knowledge, on a scale of 1 to 4, of a variety of SD principles, tools, issues and policies. In all 70 items were included covering all dimensions of sustainability including the environmental, economic and social. In addition, students were also asked to describe SD in their own words. We also sought to establish their commitment to SD and their opinions on issue related to strong and weak sustainability.

Secondly, programme documents were analysed and all modules were examined (296 in all) to identify coverage of learning outcomes for SD as set out in the Barcelona Declaration (BD) and SD competencies as identified in the literature (e.g. Svanstrom, Lozano-Garcia and Rowe 2008; Wiek, Withycombe and Redman 2011). Finally, interviews with the seven programmes chairs/leaders were conducted. They were designed to explore issues that had arisen in earlier stages of the project, their views of SD and the integration of the concept in their programmes, as well as their views about the

⁵ Initially eight programmes were part of the study but response rates were so low for the student survey in one programme that it was decided to exclude it.

factors that impact programme design. An interview was also conducted with a representative of EI (REI from here).

The first two provided considerable data which allowed us to extensively map the pattern of integration while the latter allowed us to intensively explore what shaped this pattern. When the project was initially conceived the plan was to conduct a survey of staff but this was abandoned, in favour of in-depth interviews with programme chairs, given the need to explore in greater depth what the underlying mechanisms might be. These were unlikely to be captured with predetermined response categories (Mc Evoy and Richards 2006). We needed to move from the empirical to the real and explore the mechanisms that explain the pattern of EESD.

What Do We Know?

As most of the data has been presented previously, what follows is a short summary of the data gathered using extensive methods followed by a discussion of the mechanisms identified from the interviews with programme chairs. The data from the earlier phases of the project are presented in Tables 1 and 2.

Table 1: Summary Results of Student Survey

Final year students rate their knowledge somewhere between “Heard but could not explain” and “Have some knowledge” : 2.49 on a scale of 1 to 4. First year students average score was 2.24.
The score for final year students is comparable to that found internationally (see for example Azapagic, Perdan and Shallcross 2005).
Students rate their knowledge better in relation to environmental issues and tools with relatively high scores found for issues related to resources use and pollution. But their knowledge of key principles such as Polluter Pays (2.06) and the Precautionary Principle (1.66) was low.
They do not report the same degree of knowledge about social issues with consistently low scores for issues such as equity, social inclusion and public participation.
While relatively high scores were reported for some economic issues particularly “innovation and entrepreneurship”, “sustainable consumption” and “clean production” very low scores were recorded for issues such as “economic externalities”, “triple bottom line” and “tradable permits”.
Final year students’ descriptions of SD are focused on the environmental dimension. Less than 10% mentioned the social dimension in their descriptions.
Final year students tend to focus on one dimension when describing SD. Those who see it as multidimensional describe it as an environmental and economic concept.
When final year students’ self-reported data were compared with new entry students’ data it was found that there are similarities regarding their perceptions of their knowledge Differences were identified on issues, such as energy, resource management and environmental protection, directly related with final year students’ discipline.
There was evidence to suggest that students’ knowledge of the social dimension did not differ significantly from new entry students’ self-reported level of knowledge. For both sets of students, very low scores were

reported for issue such an intra and inter-generational equity, social inclusion and public participation.
Students' self-reported knowledge is significantly related to their programme of study. There was a significant statistical correlation between the programme of study and 60% of the items examined. The Institution of study was only related to 14% of the items examined.
Two thirds of final year students agree that the environment should be protected but not at any cost. Two thirds also agree that natural resources "should be priced, bought and sold".
While almost half strongly agree that "global resources should be distributed in favour of poor people" only 7% strongly agree that "national resources should be distributed in favour of poor people".
They are more likely to see SD as a professional requirement rather than a personal commitment.

Whilst perhaps unsurprising, there is a clear alignment between both sets of data. The evidence would suggest a fragmented, rather than a holistic, approach to SD. While students say they have some knowledge of important components of SD their knowledge is focused on the environmental dimension including the use of resources and pollution prevention. The focus is on those aspects of SD close to the disciplinary core of the different programmes with, for example, a greater focus on resource use in mechanical engineering and pollution prevention in the civil programmes. While some modules can be seen to be addressing outcomes for SD, they do not specifically address SD in their learning outcomes or content descriptions. Others have content relevant for SD but no reference to SD in their outcomes. The focus tends to be on delivering engineering fundamentals though a consideration of issues such as energy and environmental protection. When issues related to SD are addressed in modules they are often not linked to wider discourses related to SD. This is also the case for many of the modules which focus on skills development. They are not contextualised by the need, for example, to foster stakeholder engagement or public participation in decision making about technology. Rather the focus is mainly on improving the communication and teamwork skills of students in the context of improving their employability.

Table 2: Summary Results of Curriculum Investigation

Programmes' overall focus is on transferable skills (such as communication) development over knowledge and values for SD. While there is some evidence for the development of critical thinking, the higher domain (evaluation) of critical thinking is developed to a lesser extent.
Programmes from Institution 1 focus on skills while programmes from Institutions 2 and 3 focus more on knowledge for SD. This is related to the aims of the programmes in Institutions 2 and 3 which tend to have a greater focus on preparing students for careers in research as well as in industry.
Despite this difference overall there is a focus on a similar range of issues within all programmes. Modules that deliver content for SD focus on the environmental aspect of the concept
Regardless of the degree the programmes focus on elements from two BD outcomes which address engineers' social and environmental obligations and the need to keep abreast with SD technologies. In relation to the former, the emphasis is on their environmental obligations.
The social dimension of SD is not evident in the programmes. Only one module addressed the issue of stakeholder participation in its learning outcomes. Only four addressed the BD outcome focused on

understanding their work in different cultural and political contexts.

It is not evident how commitment to SD values is generated in the programmes. Modules that focus on ethics focus on micro ethical issues and professional responsibilities as set out on the code of ethics

The knowledge that is delivered for SD is related to each discipline. Hence, based on the discipline different elements of knowledge about principles, legislation, tools and issues are covered

There is very little evidence of inter or multidisciplinary in the programmes

This disciplinary focus, which is reinforced by students having very little exposure to teachers who are not engineers, especially in the later stages of their programmes, is creating an unbalanced approach to the integration of the three dimension of SD. Analysis using Arsath, Holgaard and de Graff's (2011) framework shows that only four modules across the institutions are consensual: they address all three dimensions of SD. They are all in the early stages of the programmes. In summary it can be suggested that the focus is on "generating disciplinary knowledge and developing skills". The Barcelona Declaration specifically cautions against such an approach. The general approach, regardless of institute type and discipline, has the character of what Sterling (2004) calls a "bolt-on" approach "of sustainability ideas to existing systems, which itself remains largely unchanged". Optimistically he notes that this is "much better than nothing, and can open the door to deeper change" (59).

We wanted to explore deeper issues in the interviews with programme chairs. We wanted to raise a number of issues which had arisen from the previous stages of the project. But we also wanted to explore these issues in light of key factors that arose in the literature which were deemed to have an effect on programme design. The data was analysed using thematic analysis with an iterative analysis leading to the identification of key latent themes which focused on the professional identity of the respondents and their philosophy of engineering education and, within that, their views about SD. Some key findings are:

- All of them had an engineering focused education and significant industrial experience: SD was not a part of their engineering education;
- The majority of the programme chairs describe SD as a concept that relates economic development with environmental considerations that are mainly focused on energy, materials and resource issues. Only one described it as a three pillar concept;

- Their views about SD lead to a generally positive assessment of its integration in their programmes;
- There is a strong disciplinary focus on core engineering competencies in programme design; when asked to discuss any particular focus on content for SD, the majority of them identify elements directly related to the discipline of each programme;
- They agree, when prompted, that the social dimension is not well integrated: although ethics were identified as an important characteristic of engineers who want to contribute to SD, this was limited to engineers' professional conduct in relation to materials, safety and the environment while the broader social context of their practice was identified to a lesser extent;
- SD is not an active consideration in programme design;
- Concern about professional accreditation was identified as the most significant influence on programme design;
- All of them value the autonomy they enjoy in designing their programmes and oppose the imposition of an institutional policy for EESD;
- The majority of the programme chairs argue strongly that the role of their programmes is to educate employable graduates that will have the competencies needed to work in industrial environments which include some elements related to SD.

What emerges from this is the focus on core engineering competencies in programme design. As one respondent said *"We take the top down approach from the science foundation, the mathematics, the technology and the design theory and I suppose the design practice but then everything else is added on to the core competencies"* (Participant 3, Institution 1). Even when efforts are being made to expand sustainability content the focus remains on core disciplinary competencies: *"The last accreditation included a proposed introduction of a new stream... that was titled Sustainable Energy Systems. Of course that was talked about a little bit but the emphasis wasn't on sustainability, the*

emphasis was more meeting the requirements of the mechanical degree... So EI seemed to look at the criteria irrespective of the SD title of the stream and just focus whether or not the graduates coming from that stream would equally be applicable to a mechanical engineering award” (Participant 3, Institution 1).

It is quite clear (and REI agrees) that SD is not a key driver in programme design. Indeed, he suggests that perhaps SD is not necessarily a concern for all engineers: *“If there was a programme that’s in the sustainable area or the renewable resources we would get experts in that space and focus on that particular area during accreditation”*. According to him *“discipline specifics”* are dealt with most and there would be a danger that *“sustainability is involved now but in five years’ time it might be something else”*.

Sterling’s framework suggests that in considering the integration of SD there is a requirement to focus on the purpose of education. In terms of purpose the chairs support an emphasis on core engineering competences and provision for skills for employability, which is supported by accreditation processes, which emphasise the development of employable graduates for industry. While their responses show that the integration does not follow a multi-disciplinary approach and a neglect of the social dimension, the programme chairs say that they do not see any weaknesses in the way their programmes deal with SD. Only one programme chair was critical about how SD is treated. Their descriptions of the concept suggest that the majority of them see SD as a *guarding concept* that is based on a sense of techno-optimism and traditional engineering practice focused on guarding exploitable resources, waste minimisation and environmental protection and supports a disciplinary emphasis in knowledge for SD (Carew and Mitchell, 2006). This allows them to claim that SD is adequately addressed. Seeing themselves as members of the industry which they serve, as well as of their professional body, leads to them espousing a set of values which endorses an employability agenda as a criterion of the effectiveness of their programmes. In the main they were satisfied that their programmes met the goals for which they were designed.

The structure of engineering education, based as it is on disciplinary based programmes and schools and their own experience of education reinforces their commitment to disciplinary education. This is reinforced by a strong commitment to academic autonomy. This has the effect of reinforcing their professional identities as engineers as they are resistant to the idea of an institutional policy to guide the integration of SD, but yet had no difficulty with a policy emanating from their professional body. It might be suggested that the autonomy they value is from non-engineers. This may be a block to institutional initiatives aimed at developing interdisciplinary engagement. At a deeper level the approach of the chairs is dominated by a commitment to a paradigm of engineering education located somewhere between the science and market driven approaches as identified by Jamison, Kolmas and Holgaard (2014). As part of this they see SD as mainly a technical issue focused on environmental and energy related issues with little attention to the social dimension. In CR terms there are a set of reinforcing mechanisms facilitating the provision of disciplinary education aimed at producing technically proficient, employable graduates in which the social dimension is marginalized.

Conclusion

Given the findings presented here it must be a concern that the accreditation criteria do not explicitly mention SD. As a result Irish EESD may lack a “bold legitimising catalyst for sustainability related curriculum development” (Jones *et.al* 2010). It seems particularly important that EI would promote such a learning outcome given the allegiance of the engineering academics to the professional body as a part of their professional identity. But this would not resolve all issues. The data presented here suggest that there are problems in the ways that SD is understood within engineering education arising from the underlying paradigm shaping engineering education. There is evidence to suggest that sustainability and engineering are decoupled discourses within engineering education (Guerra, Holgaard and Smink 2016) and that staff can find it difficult to link sustainability, in its broadest sense, to their discipline.

Jamison, Kolmas and Holgaard's (2014) typology of engineering education is useful in that it emanates from a concern to educate "green engineers" and links specific views about engineering education to different engineering identities and views about what it means to be an engineer and therefore what the goals of engineering education should be. In arguing for a socially driven model and the creation of hybrid identities for engineers they are pointing to the need to focus on "deeper things" in fostering educational change. The research reported helps us understand why approaches focused only on policy and practices (particularly those of individual lecturers) are likely to fail. While we can see that there is some engagement with SD and evidence that some issues are being addressed our use of CR has helped us to identify some of the locks (mechanisms) which are preventing the door being opened to deeper change.

This concern with professional identity in engineering education has been echoed in recent work on EESD (Minster et al 2013). For Minster and his colleagues, the challenge is the requirement, not just to add or include sustainability in the curriculum, but to redefine what it means to be an engineer so that the "the very concept of professional identity... (is) reformulated with sustainability at its root, stem and blossom" (Minster et al 2013, 115). From the United States they are restating what a review of "ten years of discussion" of EESD, mainly in Europe, concluded when it argued that we need to make SD the "leading principle for curricula" but at the same time we need to ask "what does it actually mean to be an engineer?" (Mulder, Segalas and Ferrer-Balas 2011, 216). It seems there is some consensus that engineering needs to be redefined, to include a broad social purpose, if engineers are to meet the challenge of sustainability. Without engagement with the culture and structures that maintain and support current practices and a challenge to market and science driven models of education deeper change is unlikely to occur and be sustained.

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