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# The Integration of Sustainable Development Competencies in Irish Engineering Education: Findings of a Curriculum Content Investigation of Four Engineering Programmes

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# The Integration of sustainable development competencies in Irish Engineering Education: Findings of a curriculum content investigation of four engineering programmes

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## Abstract

This paper presents the initial findings of an investigation of the Sustainable Development (SD) content in five professional engineering degree programmes in a large Irish Institute of Technology.
A comprehensive investigation of the modules content was conducted to see to what extent the learning outcomes for SD as set out in the Barcelona Declaration and SD competencies were covered by the modules. It was found that 40% of the 137 modules included SD learning outcomes and/or addressed SD competencies. The modules have a focus on environmental issues and tend to address only one of the three dimensions, environmental, social and economic, of SD. The social dimension is inadequately addressed. There is a particular focus on inter-personal skills development. More advanced skills such as systematic and critical thinking are not comprehensively addressed. Opportunities for the development of an ethical commitment to SD seem to be missing. In general it is concluded that the integration of SD competences is inadequate and is not based on a holistic approach at a programme level but rather on individual modules.

### 1. Introduction

This paper presents the initial findings of an investigation of the Sustainable Development (SD) content in five professional engineering degree programmes in a large Irish Institute of Technology. This work is part of a wider project examining Irish Engineering Education for SD (EESD). The first stage of the project collected data from final year students regarding their knowledge of SD. It found that their knowledge of SD is inadequate, with significant gaps in regard to SD social issues and SD legislation, policy and standards; understanding of the complexity of SD is low and they relate SD mainly to environmental issues. It was also established that they see SD more as a professional requirement than a personal commitment. Arising from this findings the question was posed as to whether the students were "getting the general and broad education they need to fully understand SD" (Nicolaou and Conlon 2012). To answer this question content of the degree programmes was examined to see the extent of which SD content was integrated into the programme modules. This involved examining the extent which SD competencies and learning outcomes were addressed within programmes (Wiek *et al* 2011).

In considering the competencies that are required for SD we are required to consider how the curriculum (and extra-curricular activities) in higher education enables students to "develop the *values, skills and knowledge* that contribute to SD" (HEFCE 2005 in Jones *et. al* 2010). There is not space here to consider some of the debates around SD competencies. The tendency towards generating laundry lists, without any effort to develop conceptual frameworks for linking competencies to each other (Wiek *et. al* 2011), can be noted. There is some value to the framework provided by Wiek *et. al* (2011) with its emphasis on educating students to be agents of change. This is a common theme in the literature (see Guerra 2012, Svanstrom *et. al* 2008).

Although there is a great variety in the language used to describe SD competencies there is a significant degree of consensus about what competencies should be in the curriculum (see Guerra 2012; Jones *et. al* 2010; Segalas *et. al* 2009; Segalas 2009; Svanstrom *et. al* 2008; Wiek *et. al* 2011). This centres on the requirement for programmes to address competencies such as critical and systematic thinking, the capacity to work with and integrate the perspectives of others, SD values and ethics, as well as range of interpersonal skills. They can be listed the as follows:

- Systemic and critical thinking: promoting the development of critical thinking skills will help students to understand the complexity of sustainability issues and have the competence to move beyond the tradition of breaking problems down to disconnected parts;
- Integration of different perspectives (inter-trans-multi disciplinarity): Since sustainability is the tackling of complex problems the involvement of various groups of professionals and the integration of different views is essential. Stakeholder participation is important when trying to resolve sustainability problems;
- Skills: the development of transferable skills such as communication skills and the ability to work in multidisciplinary teams. These skills will enable engineers to become change agents for SD and facilitate stakeholder participation;
- Attitudes and Values: Develop both a personal and professional commitment and sense of responsibility for SD. Have a set of values as guidance towards sustainable engineering practices: The focus is generally on equity, human rights, justice, diversity, participation and empowerment.

Wiek et al (2011) argue that there is a requirement to turn "fairly abstract" competencies into "specific learning outcomes to be operationalized" for curriculum development. Within engineering education the Barcelona Declaration (BD) is probably the most influential and comprehensive statement of the learning outcomes (LOs) for SD, which need to be integrated into engineering education. They are:

*LO 1. Understand how their work interacts with society and the environment, locally and globally, in order to identify potential challenges, risks and impacts (Soc&Envir[1]);*

*LO 2. Understand the contribution of their work in different cultural, social and political contexts and take those differences into account (Contexts);*

*LO 3. Work in multidisciplinary teams, in order to adapt current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention and waste management (Multid/ Issues);*

*LO 4. Apply a holistic and systemic approach to solving problems and the ability to move beyond the tradition of breaking reality down into disconnected parts (Holism);*

*LO 5. Participate actively in the discussion and definition of economic, social and technological policies, to help redirect society towards more sustainable development (Policy);*

*LO 6. Apply professional knowledge according to deontological principles and universal values and ethics (Ethics);*

*LO 7. Listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures (Stakeholders).*

[11] The words in brackets are an attempt to summarise the focus of each LO. They will be used as shorthand of each LO in the rest of the paper.

While these LOs embrace the wide range of competencies required for EESD, a problem may be that these LOs do not move us on much from the general competencies identified within the literature and are not specific enough in identifying necessary curricular content. Within particular LOs different competencies are combined (e.g. Multidisciplinary teamwork is combined with knowledge of sustainability issues). Notwithstanding this they do provide a framework for examining the extent to which programme and module LOs address significant areas of learning which are necessary for the development of SD competencies. It is important to emphasise that the BD places great emphasis on a holistic approach to EESD and warns against higher education institutions restricting themselves to "generating disciplinary knowledge and developing skills".

It can be noted that Engineers Ireland (EI), the accreditation body for engineering programmes, has specified a number of programme outcomes which have relevance to SD. These are:

- *An understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment;*
- *The ability to work effectively as an individual, in teams and in multi-disciplinary settings together with the capacity to undertake lifelong learning;*
- *The ability to communicate effectively with the engineering community and with society at large.*

While SD is not mentioned specifically the Code of Ethics of EI specifies that engineers should promote and practice the principles of SD. It can be assumed therefore that modules which address the Code should include material on the principles of SD.

In looking at the literature on competencies and LOs it is relatively easy to identify the skills that are required for SD but it more difficult to identify requirements in relation to knowledge. One analysis identifies knowledge as relating to the "World current situation; causes of unsustainability; sustainability fundamentals; science, technology and society and instruments of sustainable technologies" (Segalas et al 2009). This is not very specific. Drawing on Svanstrom *et. al* (2008) and other work aimed at surveying students' knowledge of SD, discussed in Nicolaou and Conlon (2012), it was decided to focus on the *principles, issues and practices* related to SD. This included policy and legislation relating to SD with a particular focus on the Irish context.

Taking the above into account an analysis of the SD LOs and content of all modules in four professional engineering degree programmes was conducted. At this stage two points can be made about the analysis. Firstly we assumed that the extent to which SD competencies were explicitly included was not extensive. Mindful of the fact that while programmes may have "clear content, assessment and learning approaches …entirely consistent with ESD" they are not always "explicitly recognised or presented as such by programme leaders" (Hopkinson *et. al* in Jones *et. al* 2010 p.6). Often skills are developed within programmes to address aims related to the "employability agenda" (see Jones *et al* 2010a). So while skills were mentioned without a SD context the inclusion of that competency in the modules was noted.

Secondly, in analysing modules we draw on the approach of Arsat *et. al* (2011) who present a framework which categorises modules based on the extent to which they address the three dimensions (environmental, economic and social), of SD. Modules can be Singular (only one dimension of SD), Dialectical (two dimensions) or Consensual (deals with all three).

## 2. Methodology

Two key tasks were performed. Using the BD the LOs of all modules in four engineering programmes

were analysed to assess the extent to which their LOs included or addressed the BD LOs. Secondly the modules content was examined and all references to SD competencies were recorded using a standardised recording tool. This focused on the coverage of SD knowledge (principles, issues and practices including policy and legislation), values and skills. Details of teaching and assessment methods were also recorded but are not presented here.

The programmes are civil, mechanical, structural and building services engineering. The four programmes have four stages and they share a common first year (CFY) curriculum. A total of 137 modules were systematically examined. These included 12 modules in the CFY, 34 modules within the civil and mechanical engineering degrees respectively, 29 in the building services degree and 28 in the structural engineering degree.

While we have some reservations that all the details of each module are captured in the descriptors as there was some variance in the level of detail provided, this exercise provides a good basis for identifying key issues which can be explored further in interviews with staff.

## 3. Results

Aggregated results indicated that 55 (40%) modules out of a total number of 137 modules either address SD in their outcomes and/or deliver elements of SD competencies in their content (Table 2). 31 (23%) of modules had LOs related to the BD LOs.

**Table 2: The number of modules in each programme with SD LOs or competencies**

| Programme | Modules with SD LO's /content | LOs | Knowledge | Values | Skills |
|---|---|---|---|---|---|
| Common first year curriculum | 9 of 12 | 3 | 2 | 3 | 9 |
| Civil engineering | 13 of 34 | 8 | 6 | 4 | 8 |
| Mechanical engineering | 13 of 34 | 9 | 4 | 4 | 13 |
| Structural engineering | 9 of 28 | 5 | 3 | 3 | 6 |
| Building services | 11 of 29 | 6 | 6 | 0 | 8 |

Broadly it can be seen that, inclusive of the first year, 48% of modules in the civil and mechanical programmes address SD competencies or LOs, compared to 45% for structural and 49% for building services. The latter covers a small number of LOs. It can also be seen that a greater number of modules deal with skills (44) as compared to knowledge (21) and values (14). While 31 modules have LOs and appropriate SD content, 24 modules were identified that had no identifiable SD LOs but had content relevant for the development of SD competencies. The vast majority (22) of these modules dealt with skills. While 8 of these had LOs related to basic communication skills (mainly oral presentations and report writing) this was not linked to SD issues, aimed at developing the students as change agents or facilitating stakeholder involvement.

Based on Arsat *et. al's* (2011) framework for categorising modules it was found that only one module was Consensual and covered all three dimensions of SD, 7 were Dialectical and 20 were Singular with 17 having a particular focus on the environmental dimension rather than the social , or economic. The other modules addressed issues to do with skills development, mainly communications skills.

*2. 1 The integration of Barcelona's Declaration SD learning outcomes.*

Table 3 shows the number of modules that address each LO. It can be seen that the civil and mechanical engineering programmes address the LOs for SD more adequately than structural and building services. Mechanical covers the full range of LOs better than other programmes.

LO1, 3 and 6 are covered most. LOs 4, and 5 are covered to a lesser extent. LO2, which has a focus on the cultural, social and political context of engineers work, is hardly covered at all while LO7, which deals with stakeholder participation, is not addressed by any LOs in any module.

Table 3: Number of modules that address BD's learning outcomes.

| | | **BD's LOs for SD** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **N of modules** | **1 Soc& Envir** | **2 Contexts** | **3 Multid/ Issues** | **4 Holism** | **5 Policies** | **6 Ethics** | **7 Stakeholders** |
| CFY | 3 of 12 | 3 | 0 | 0 | 1 | 1 | 3 | 0 |
| Civil | 8 of 34 | 5 | 2 | 2 | 0 | 2 | 1 | 0 |
| Mechanical | 9 of 34 | 4 | 1 | 6 | 2 | 1 | 3 | 0 |
| Structural | 5 of 28 | 2 | 0 | 1 | 0 | 1 | 2 | 0 |
| Building Services | 6 of 29 | 1 | 0 | 5 | 1 | 1 | 0 | 0 |
| | 27 | 15 | 2 | 14 | 4 | 6 | 9 | 0 |

A number of other LOs are not addressed at all in some programmes: structural (2); building services and (2).

In line with the finding that most modules are singular in their coverage of SD it can be noted that many of the LOs that address LO1 have a particular focus on the environment rather than society. Those modules adjudged to address LO3 have a focus on the adaption of "*current technology to the demands imposed by sustainable lifestyles, resource efficiency, pollution prevention and waste management"* and not on multidisciplinary teamwork. These modules are focused on design, energy, pollution and waste. Modules that address, LO6 tend to have a particular focus on professional responsibilities arising from codes of ethics.

*2.2 The integration of SD competencies in module content*

*2.2.1 Knowledge for SD*

21 modules include knowledge content regarding SD (see Table 2). Inclusive of the CFY there are 8 in civil and building services respectively, 6 in mechanical and 5 in structural. In regard to the CFY, one module explicitly delivers content about the concept and the principles and values of SD while the second one, a chemistry module, deals with environmental issues such as acid rain and pollution and practices related with these such as waste minimisation.

The mechanical and building services degrees both show a focus on energy related knowledge. The modules deal with tools for SD that address energy efficiency and renewable energy technologies. SD legislation content covered deals with "Ireland's Renewable Energy Targets" and "Energy Performance in Buildings Directive 2002". In addition issues such as climate change are also covered. It was also found that modules within the mechanical engineering degree deliver knowledge regarding

the principles of "minimising the utilisation of non-renewable resources" and the "sustainable use of renewable resources".

The civil and structural engineering degrees show a particular focus on environmental protection. The SD Principles that are covered address "Soil, water and air quality" while elements of legislation include "Environmental Impact Assessment" and the "Protection of the Environment Act 2003". Students from these two programmes are taught about tools such as "Environmental Impact Statement"; "Waste minimisation" and "Design for Reuse".

Knowledge regarding the social dimension and issues such as equity, social inclusion and active participation in decision making are seldom mentioned. Moreover the range of the environmental issues covered by the modules is limited and important issues such as loss of biodiversity and ecosystems are not covered by these four programmes. It is also surprising to note that there is no specific reference to tools such as Life Cycle Analysis, or to the Precautionary Principle.

### *2.2.2 SD Values*

A total of 14 modules address issues to do with values (see Table 2). Other than the modules in the CFY there was no evidence that values were addressed at all in the building services programme although, like other programmes, there was reference to macro ethical issues (see Conlon 2011) such as climate change as context for discussing alternative energy technologies. This may suggest some potential for greater integration of ethical issues into some modules.

All the modules, regardless of degree or stage, have a particular focus on engineering ethics and engineers' obligations as set out in Engineers Ireland Code of Ethics. Three modules address "engineers' role in society" and address the impact of engineering on society. One module explicitly addresses the need for "social inclusion". The module deals with highway engineering which includes the design of scheme appraisals that require social consultation. No other modules address this issue. There is also little coverage of "stakeholder participation". However, a CFY module addresses the principles of SD which include both of these issues.

The modules that discuss ethical issues do not give any clear indication as to how ethical commitment is developed among the students or the extent to which macro ethical issues (see Conlon 2011) are addressed. The number of modules that deal with policy issues is quite small.

It can be noted here that the teaching methods used in these modules are fairly traditional with 6 using lecturing only. Seven also include discussion of cases while two others use project work in groups. It's also worth noting that most of these modules tend to cover a wide range of issues to do with engineering as a profession and do not have a specific focus on ethical issues. Some are called Professional Development. To investigate these issues further we plan to interview programme chairs and relevant staff.

### *2.2.3 Skills for SD*

The majority of the modules with SD content focus on skills development. In total 44 modules were recorded that aim to develop students' skills (see Table 2). Regardless of degree or stage, all the modules recorded show an explicit focus on the development of the following skills: Communication and presentation skills; ability to work in teams and self-directed learning. While some modules refer

in their LOs to the ability to work in heterogeneous teams there is no evidence that students worked with students outside their own discipline.

In regard to more complex SD skills such as critical thinking very few modules promote its development. Specifically one module was recorded in the CFY curriculum; two modules in civil and building services respectively; and one module in mechanical. These modules are mainly final year projects that aim to equip students with a set of skills to cope in professional environments. There were no modules in structural engineering that aim to develop these more complex skills.

Skills for SD such as "systemic thinking", "problem solving for complex SD problems" and "promoting social inclusion and stakeholder participation" are not addressed in the four programmes.

## 4. Conclusions

While there are limitations in relying solely on module descriptors to determine the content of programmes, the first and most important finding of this analysis is that the integration of SD competences is inadequate and is not based on a holistic approach at a programme level but rather on individual modules. The modules do not adequately address Barcelona's Declaration SD outcomes for engineers and seem to focus on "generating disciplinary knowledge and developing skills". There is not a focus on developing students as change agents for SD. The modules outcomes have a focus on students' environmental obligations as engineers and the practice of their profession based on professional engineering ethical guidelines.

Issues addressed by BD's LOs such as the importance of actively participating in decision-making; developing an understanding of how their work interacts with society and promoting social inclusion and stakeholder participation are not adequately addressed.

This may be due to the fact that the modules outcomes are designed according EI's accreditation criteria which do not explicitly promote the integration of the concept into engineering education. Irish EESD may lack a "bold legitimising catalyst for sustainability related curriculum development" (Jones *et.al* 2010). Programme outcomes are designed to prepare engineers for professional engineering practice with a strong emphasis on employability skills and the needs of industry. Thus there is a considerable focus on transferable skills development in the modules analysed. This may not be a good basis for designing programmes aimed at preparing students to be change agents for SD (see Conlon 2008). Addressing the needs of business and the need of society may not be the same thing. As Wiek *et. al* (2011) have argued "Coping with the complex sustainability problems our societies face requires a transformation of the job market, new business models, new professions, and societal change at large".

In regard to the integration of SD competences, it is apparent that the modules show a particular focus on skills development over the acquisition of knowledge and values. The skills development is focused on generic skills such as communication skills. More complex skills such as critical thinking and problem solving of complex SD problems are inadequately covered or not considered at all. There is no evidence of multi-disciplinary teamwork and little evidence of opportunities for students to develop an ethical commitment to SD. This issue will have to be investigated further.

Modules tend to be "singular" in their focus rather than "dialectic" or "consensual". The largest omission is in relation to the social dimension of SD. The knowledge that is delivered is discipline-

oriented with a clear focus on environmental protection and energy related issues. Knowledge regarding substantial issues such as the precautionary principle; principles of social equity; legislation that promotes social inclusion; and important environmental issues such as "loss of biodiversity" and "ecosystems" are not addressed by the four programmes. The analysis suggests that the four engineering programmes follow the path of conventional engineering education that is strictly-discipline oriented (Lehmann et al., 2008). It seems to be the case that our the students are not "getting the general and broad education they need to fully understand SD"

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