Integrating Sustainability into Civil Engineering Education: Curriculum Development & Implementation

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Abstract: The role of the civil engineer as a specialist, expert or generalist in society is constantly evolving to meet the changing demands of government and industry to achieve a global sustainable world. Consequently, it is imperative that third level institutions meet the challenge of embedding sustainability into curriculum, providing students with generic competencies required for future employment.

This paper describes the development and implementation of a curriculum for a new level 8 degree in Sustainable Civil Engineering in Ireland. The programme maintains the core outcomes essential for a civil engineering degree, reinforced by programme accreditation, while providing engineering graduates of tomorrow with the new technical and non-technical competencies to become active drivers for sustainable global innovation. The paper outlines how a number of complexities, including limited resources, lower enrolment figures and a changing student demographic were addressed to attract prospective students and provide quality assurance.

Keywords; Engineering Education, Sustainability, Curriculum Development, Industry.

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1. INTRODUCTION

Civil Engineers are increasingly working to achieve safe and sustainable development in a cost-effective, environmentally protective and socially responsible manner. Civil engineers of the future need to be equipped to account for all aspects of construction given their broad roles from design to deconstruction of the built environment (Angelides and Loukogeorgaki, 2005; Valdes-Vasquez and Klotz, 2011). Worldwide there is an increasing move to reform traditional engineering education programmes to incorporate the concepts of sustainability in undergraduate curricula. To acknowledge the shift in the societal expectations of the engineering profession it is essential that such programmes provide engineers with a sustainable vision of the world and provide the skills to allow engineer to evolve and meet the challenges that graduates will face when they enter the workforce (Augusti, 2007; Desha *et al.*, 2009; Lopez *et al.*, 2011). Therefore, the education of future civil engineering professionals demands the implementation of a holistic approach, enhancing sustainability through new approaches, methods, and information technology (Levitt, 2007; Augsburger, 2009).

Significantly this approach is underpinned by a number of national and international organisations. The Institution of Civil Engineers (ICE) believes that Sustainable Development is central to civil engineering and the ICE and the profession it serves must organise themselves accordingly (ICE, 2003). The United Nations proclamation promotes the years 2005-2014 as the Decade of Education for Sustainable Development (DESD) (United Nations General Assembly, 2002). While, The Summit on the Future of Civil Engineering – 2025, developed an aspirational global vision that 'In 2025, civil engineers will serve as master builders, environmental stewards, innovators and integrators, managers of risk and uncertainty, and leaders in shaping public policy (ASCE, 2007). As a result, there is significant impetus to review what we do and how we do it.

2. STANDARDS AND ACCREDITATION

In Ireland, Professional Institutes and Higher Education Institutions are responsible for the accreditation of engineering programmes. When establishing the National Framework of Qualifications (NQF) the National Qualifications Authority of Ireland (NQAI, 2003) made the following general statement in relation to Honours Bachelor Degree – NQF Level 8 programmes: '*Innovation is a key feature of learning outcomes at this level. The outcomes include an awareness of the boundaries of the learning in the field and the preparation required to push back these boundaries through further learning. The outcomes relate to adaptability, flexibility, ability to cope with change and ability to exercise initiative and solve problems within their field of study'*.

Guidelines concerning the expected 'Knowledge', 'Knowhow and Skill', and 'Competence' were published by the Higher Education and Training Awards Council in their 'Awards Standards for Engineering' document (HETAC, 2005).

Engineers Ireland (EI) accredits engineering courses in Ireland. EI are signatories to the Washington Accord Agreement (IEA, 1989) which benchmarks standards for engineering education, accreditation systems, policies and processes. Feedback from the EI 2006 – accreditation review panel for the level 7 BEng in Civil Engineering made clear the practice of engineering at a professional level requires the inclusion of sustainability and ethical standard as part of an education programme. Currently, EI accredited NQF Level 8 qualifications provide eligibility to apply for the title of Chartered Engineer. However, the requirement of a level 9 qualification to attain chartered status is to be implemented in 2013.

3. COURSE DEVELOPMENT

In 2008 the Department of Construction and Civil Engineering undertook the process of renewing its well established ab-initio three-year National Framework of Qualifications (NQF) Level 7 BEng in Civil Engineering. The programme prepares graduates to find employment as civil engineering technicians in the civil engineering sector and/or prepares them to continue on to a cognate NQF Level 8 programme. The programme is well regarded within the construction/civil engineering industry with high graduate employability within Ireland and more recently abroad.

However, in a rapidly changing world the programme team recognised that the course could not rest on its laurels. Commencing the review process the team were mindful of the findings of

Angelides and Loukogeorgaki (2005) who stated that *'Any changes to civil engineering education should be addressed with a strategic approach that takes into consideration world-wide trends, the societal requirements'*. The review focused on how the Department could supply a graduate that will meet the future needs nationally and internationally. Subsequently the programme team started to develop the BEng (Honours) in Sustainable Civil Engineering as a two-year add-on degree, principally for Level 7 graduates. Throughout the development of the programme the team were cognisant of EI, NQAI and HETAC requirements.

Consensus, amongst team members for a common understanding of twenty-first century engineering challenges and opportunities, and how to implement curriculum renewal in the department was not straight forward. The process involved developing and mapping desired graduate attributes and explored holistic mechanisms by which these attributes could be achieved through the delivery of the programme. Maintaining civil engineering at the core was imperative. Initially this resulted in a full traditional civil engineering curriculum with very little room to include volumes of sustainability related materials. The question them arose 'What to leave out?' Drawing on the learning of the course board in terms of personal experiences (example external examiners), SWOT analysis, specific challenges, barriers, the team developed an overall programme objective.

3.1 Programme objective

To provide an environment and robust educational path where students are encouraged to develop solutions to complex problems in a creative, sustainable manner and espouse an ethical ethos. Students will be guided to develop lifelong learning skills in technical and non technical fields. The graduate will be conscious of the vital influence that civil engineers will increasingly have on achieving the various sustainability targets at national, EU and international levels.

Key to the development of the programme was to ensure that the student does not just assimilate a lot of knowledge but is able to use it in an effective manner. Also, staff are very aware of being 'student-centred' (as espoused in the WIT Mission Statement) with an outcome-based education (OBE) approach.

3.2 Course Outline

The course is designed in a modular format to facilitate integration with other engineering and built environment courses. It is offered in the full-time mode but the modular structure enhances the flexibility in the methods by which the course can be delivered and taken. From an operations perspective the terminal examinations are normally taken at the end of each semester in December and May. Most modules are awarded 5 European Credit Transfer and Accumulation System (ECTS) credits, whilst strategic modules are more heavily weighed. One academic year corresponds to 60 ECTS-credits.

Figure 1 and Figure 2 illustrate the programme overview for the level 7 BEng in Civil Engineering and level 8 BEng (Hons) in Sustainable Civil Engineering. Modules are broadly grouped into mathematics/science, structures/engineering design, technology, management & economics, research/projects, industrial placement, hydraulic/hydrology and sustainable/energy sub-categories. A number of modules are shared with students from other disciplines, usually within the School of Engineering. A breakdown of the Continuous Assessment/Final Exam

STAGE 1 SEMESTER 1	STAGE 1 SEMESTER 2	STAGE 2 SEMESTER 3	STAGE 2 SEMESTER 4	STAGE 3 SEMESTER 5	STAGE 3 SEMESTER 6
Surveying 1 CA:50% EX:50%	**Surveying 2** CA:50% EX:50%	**Soil Mechanics** SM-P (CME2) CA:40% EX:60%	**Surveying 3** CA:50% EX:50%	**Surveying 4** CA:100%	**Energy Performance of Buildings** CA:30% EX:70%
Civil & Structural Graphics CA:100%	**Civil Engineering BIM** CA:100%	**Civil Engineering BIM 2** CA:100%	**Civil & Structural Draughting** CA:100%	**Research Skills** CA:100%	**Project** CA:100%
Civil Engineering Mathematics 1 PR-STAGE2 CA:50% EX:50%	**Civil Engineering Mathematics 2** PR-STAGE2 CA:50% EX:50%	**Civil Engineering Mathematics 3** PR-STAGE3 CA:15% EX:85%	**Fluid Mechanics** CA:30% EX:70%	**Civil Engineering Mathematics 4** CA:15% EX:85%	**Civil Engineering Mathematics 5** CA:15% EX:85%
Statics & Dynamics PR-STAGE2 CA:50% EX:50%	**Structural Mechanics** PR-STAGE2 CA:50% EX:50%	**Design of Structures 1** PR-STAGE3 CA:30% EX:70%	**Design of Structures 2** PR-STAGE3 CA:30% EX:70%	**Design of Structures 3** CA:30% EX:70%	**Structural Analysis 1** CA:30% EX:70%
Civil Engineering Technology CA:30% EX:70%	**Materials Technology 1** CA:30% EX:70%	**Management for Civil Engineers** CA:30% EX 70%	**Construction Health & Safety** CA:30% EX:70%	**Site Management Practice** CA:30% EX:70%	**Civil Engineering Technology** CA:30% EX:70%
Communications & Study Skills CA:100%	**Engineering Science** CA:30% EX:70%	**ELECTIVE** (SM-F): - Intercultural Communications - Spanish A1 - French B1.3 - Int'l English 1	**ELECTIVE** (SM-F): - Cultural Diversity ....Management - Spanish A2 - French B1.4 - Int'l English 2	**ELECTIVE** (SM-F): - Entrepreneurship - Spanish B1.1 - French B2.1 - Int'l English 3	**Environmental Engineering 1** CA:30% EX:70%
6 modules @ 5 credits each = 30 Credits	**6 modules @ 5 credits each =30 Credits**	**6 modules @ 5 credits each = 30 Credits**	**6 modules @ 5 credits each = 30 Credits**	**6 modules @ 5 credits each =30 Credits**	**6 modules @ 5 credits each =30 Credits**

Figure 1 BEng in Civil Engineering Programme Overview

Key: **Management & Economics** **Maths/Science** **Research/Projects** **Structures/ Eng. Design** **Hydraulics/Hydrology Engineering** **Sustainable/ Energy** **Technology** **Industrial Placement**

marking scheme is also shown. It is clear from the programme overview that not all subject areas are included. A strategic decision was taken to exclude many subject areas including highway and transport engineering, geology and specific environmental engineering topics.

4. INTEGRATING SUSTAINABILITY, ETHICS AND SOCIAL RESPONSIBILITY

As stated previously the course maintains the fundamental civil engineering curriculum, but focus is also placed on the overall understanding of the global ecosystem and limited natural resources. Lappalainen (2011) found that the key to sustainability is the inclusion of teaching social responsibility to engineers. At development stage it was recognised that teaching sustainability and ethics could not be mutually exclusive. Thus, there was a concerted effort from the outset of the course to make clear linkages between topics such as design and sustainability, ethics and sustainability by the inclusion of practical examples, problem solving and encouraging decision making. The importance of this was highlight by (Abbas El-Zein *et al.*, 2008) who found that ethics and sustainability overlap but do not coincide and thus need positive intervention to be effective. In addition to extending the traditional mathematics and structural design curriculum, new pertinent modules such as Clean Energy Technologies, Sustainable

STAGE 4 SEMESTER 7	STAGE 4 SEMESTER 8	STAGE 5 SEMESTER 9	STAGE 5 SEMESTER 10
Structural Analysis PR-STAGE5 CA: 30% EX:70%	**Mathematical Modelling** CA: 100%	**Structural Analysis & Design** CA: 30% EX:70%	**Structural Design** CA: 100%
Civil Engineering Mathematics 6 CA: 15% EX:85%	**Research Methods** SM-F(CME3, QS3) PR-STAGE5 CA: 100%	**Dissertation** SM-P (CME4, QS4) CA: 100%	
Statistics for Scientists SM-P (SCIENCE & SEE3) CA: 30% EX:70%	**Energy Performance of Buildings** CA: 100%	**Industrial Placement 2** SM-F (CME4, QS4) CA: 100%	**Geotechincal Engineering 2** CA: 30% EX: 70%
Geotechincal Engineering 1 PR-STAGE5 CA: 30% EX: 70%	**SCE Placement*** PR-STAGE 5 SM-P (CME3, QS3) CA: 100%	**Hydraulics** CA:30% EX:70%	**Hydrology for Sustainability** CA: 30% EX:70%
Construction Technology Systems SM-F (CME3) CA: 30% EX:70%		**Project & Corporate Management** SM-F (CME4, QS4) CA: 30% EX 70%	**Professional Practice** SM-P (QS4) CA: 30% EX:70%
Clean Energy Technologies CA: 30% EX:70%		**Sustainable Energy** CA: 50% EX:50%	**Innovative Technologies** SM-P (CME4) CA: 30% EX:70%
6 modules @ 5 credits each = 30 Credits	**Placement or Alternative* @15 credits + 3 modules @ 5 credits each =30 Credits**	**5 modules @ 5 credits each = 25 Credits**	**5 modules @ 5 credits each & 1 @10 credits = 35 Credits**

Figure 2 BEng (Honours) in Sustainable Civil Engineering Programme Overview

Energy, Construction Technology Systems, Innovative Technology, Building Energy Performance that include resource management, knowledge of environmental policies, law, and life cycle assessment were created.

It was felt that a standalone ethics module would be somewhat removed from other modules thus, all of the modules have an ethical component. This decision is supported by in a paper by Flynn and Barry (2010) who suggest that stand alone ethics modules can be a ‘tick box’ approach and students would perceive ethics as not being core to the curriculum. However, modules such as professional practice and project and corporate management have a particular ethical emphasis.

4.1 Complimentary Pedagogical Approaches

The civil engineering industry is adopting emerging concepts and sustainable technology and embracing new modes of design and information sharing such as building information modelling (BIM). With almost fifty percent of the architectural and construction industry using BIM in the US, to succeed, there is a real need for students to be proficient in a varied of BIM techniques (Becerik-Gerber *et al.*, 2011). Throughout the course students are encourage to use a number of software packages which and utilise the Autodesk suite BIM tools.

The department undertakes most of its teaching and learning in the traditional lecture environment but is constantly evolving. Industrial Placement is considered is a useful way for student to put into practice the skills learned in lectures. The six month placement addresses the issue by Sheppard *et al*. (2009) stating that *'Students have few opportunities to explore the implications of being a professional in society'*.

(Koehn, 1995) highlighted that students do not support the traditional formal lecture method but rated highly the links with the outside world. Throughout the year staff work hard to organise a number of external industry practitioners to deliver relevant keynote lectures. A number of local field trips take place and in year two students embark on an international study trip. In the 2011/2012 academic year students undertook a week long field trip to Poland, witnessing international construction techniques and different cultural approaches to construction.

To encourage problem-solving, decision making and presentation skills modules such as Building Energy Performance have adopted a problem based learning approach. In the studio-based module, problems are proposed in a manner to encourage alternative design approaches where resources and expenditure are limited, requiring students to prioritise waste minimization. This often results in open-ended solutions that spark debate and sharing of knowledge.

5. CHALLENGES

While the Civil Engineering programme is in a strong position, there are significant challenges at present, including reduced student numbers, student abilities in Mathematics and English, a reduction in resources, the need for improved education in design and BIM software, increasing academic diversity.

5.1 Reduced Student numbers

With the severe downturn in the Irish economy, the domestic engineering and construction industry has been decimated and the education sector is facing into a period of significant change. These issues pose serious challenges for the Civil Engineering programme in the short-to-medium term in relation to student numbers. However there is an upside; smaller student groups encourage a more open interactive learning space whereby students can express and discuss ideas and work together to solve problems.

5.2 Reduction in Resources

It is inevitable that there will be fewer resources in the short to medium term to deliver the Civil Engineering programme. This has been mitigated, to a certain extent, through the sharing of common modules with other programmes in the Department and School.

5.3 Academic Diversity

The traditional homogeneity of the student cohort studying Civil Engineering is now developing into a diverse group of learners. Seated side by side are students; from other disciplines and streams; whose first language may not be English; from broadly diverse cultures, economic backgrounds; of both genders those who fall closer to the template of grade-level expectations and norms; highly advanced learners; and students of widely varying interests and preferred modes of learning who underachieve for a complex array of reasons; motivated and unmotivated; with some fitting two or three of these categories. This change in the student profile leaves Civil Engineering Lectures with the need to address learner variance. This will require adaptation of teaching and learning routines to address the broad range of learners' readiness levels, interests, and modes of learning. Currently we are modifying curricula, teaching methods, resources, learning activities and assessment. Addressing the diverse needs of individual students is a new challenge and one that will be embraced with innovative and appropriate pedagogical differentiation methodologies.

6. CONCLUSION

It is essential that civil engineers develop a sustainable vision for the world of the future, as throughout their careers they will play a leading role. Developing this programme course did not mean that all parties involved in the process agreed entirely with the outcome but consensus was achieved. It is recognised that social sustainability is difficult to teach as it requires a departure for conventional thinking and may not be suited to the traditional classroom.

Arciszewski and Harrison (2010) propose that the scientific paradigm in civil engineering today is insufficient and needs to practice creativity and proposes a conceptual outline of what needs to be done. The paper proposed a new civil engineering education paradigm, called “Successful Civil Engineering Education”. We believe that the new BEng (Hons) in Sustainable Civil Engineering has broken the old paradigm and offers a dynamic approach that meets the needs of future civil engineers.

It is clear that all facets of sustainability including ethics, technology, social sustainability are included in the sustainable civil engineering programme, but benchmarking of Sustainability in Engineering Education is imperative for future development.

The course boards will continue to develop the undergraduate course and develop towards achieving the recommendations identified in the recently published *‘Engineering Research in Irish Economic Development’* (IEA, 2010). This will require us to build on our existing partnerships, collaborating with other institutions, interaction with future students through secondary school visits, modify and develop our education to reflect the current and future needs of the economy by fostering a more innovative and entrepreneurial culture. Future development will continue to increase student numbers by providing new industry specific courses.

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