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TRANSFORMATIVE LEARNING METHODS IN INTERDISCIPLINARY POSTGRADUATE EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD)

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Abstract

*This paper explores the relationship between education for sustainable development (ESD) and interdisciplinarity in the context of architecture and engineering higher education, presenting a case study of the University of Strathclyde Glasgow's Sustainable Engineering (SE) postgraduate programme, within the wider context of common principles and practices present across HEIs. The paper - one of a series - offers an overview of the SE programme between 2004 and 2015 (coinciding with UNDES
D) and discusses its growing focus on interdisciplinarity and the introduction of transformative learning methods over the study period. The study uses a methodology of statistical analysis of enrolment and graduation trends on the SE programme alongside a discursive analysis of course and module provision specific to learning methods for ESD and interdisciplinarity. The study finds that, within the SE programme, both the courses and modules that have an SD focus exhibit the greatest longevity over the study period and are selected by students significantly more often than other courses and modules. The finding supports previous studies that report an increased appetite for such courses and classes. The learning methods employed on the modules align with those considered exemplary in the literature surrounding ESD, and demonstrate the programme's aspirations towards increased interdisciplinarity in postgraduate ESD. The paper provides insight into the practices and outcomes of a specific long-standing programme, offering opportunity for reflection, discussion and comparison with similar programmes.*

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INTRODUCTION

In December 2002 the United Nations General Assembly declared that 2005-2014 would be the United Nations Decade of Education for Sustainable Development (UNDES), a worldwide programme that sought to emphasise the role of education in moving towards a more sustainable world (Wals, 2012). UNDES was the UN's mechanism for progression towards a more sustainable global community, and the drivers they identified which would ensure this progression were innovations in education, public awareness, and training activities. The Assembly recognised the vital and critical role of education for building skills and knowledge which would enable communities to address poverty, social inequality and vulnerability in their own areas (Wals, 2012).

The UNDES has its roots in Agenda 21, the landmark agreement adopted by over 178 governments at the Earth Summit in Rio de Janeiro in 1992. Chapter 36 of Agenda 21 identified four goals for education, training, and public awareness centred around building knowledge, skills and values for sustainable development (SD); rethinking and innovating teaching curriculums and methods; and crossing the boundaries from education to trade and industry (Wals, 2012). UNDES built upon these goals, stressing the importance of changing the mind-set, values and lifestyles of global citizens and increasing their capacity to understand and implement what is necessary for a sustainable future. Technology, policies and legislations cannot succeed in meeting sustainability challenges without the simultaneous development of the people responsible for implementing and overseeing them.

Parallel to educators rethinking and restructuring teaching methods and curriculums for SD, there is an emerging expectation among potential students, current students, and future employers that universities and their graduates are equipped with skills for SD. A 2016 student survey by the National Union of Students (NUS) found strong student support for universities to actively incorporate and promote SD into their campus and business operations; in addition to strong support for universities to actively incorporate and promote SD in their course and module provision. Crucially the majority of students stated that they expect a university course to develop their sustainability skills, with some indicating that the institution's approach to environmental issues would be a significant factor in influencing their choice of university (Drayson, 2015b). The NUS also found strong support among potential employers for recent graduates with SD knowledge and skills, such as "considering ethical issues" and "problem solving using many subjects", with employers indicating that these skills would benefit the economic sustainability of their organisations (Drayson, 2015a).

Thus, there is now expectation and even demand from both the governmental and student-driven levels for education, which provides skills for SD, in addition to a growing acknowledgement from employers that these skills are appealing for the future employability of students. It is therefore increasingly essential and beneficial for universities to not only integrate SD into their campuses, curriculums and courses, but to do so using innovative teaching methods which will enable their students to adopt the necessary change in mind-set needed to meet sustainability challenges.

This paper presents a case study of the Sustainable Engineering (SE) postgraduate programme at the University of Strathclyde Glasgow between 2004 and 2015 (coinciding with the UNDES), offers an overview of the programme, and discusses its growing focus on interdisciplinarity and the introduction of transformative learning methods over the study period. It is one of a series of papers that will track trends in the structure, content, and outputs of the programme, identifying both its successes and shortcomings in contributing to the development of SD skills in its students. The work builds upon previous publications that presented the programme's structure as a potential template for pan-university sustainability



provision at the University of Strathclyde. It also reflects on a previous evaluation of the SE programme (Blake, Sterling, & Kagawa, 2013), as it stood in 2008, that drew conclusions around the extent to which interdisciplinarity and integration of sustainability were present. Further papers will focus in greater detail on the provision of SD-focused generic modules; on the specialist disciplinary education in architecture and engineering delivered through the programme within its dedicated course pathways; and will present student and staff reflections on the programme.

LITERATURE REVIEW

The period during and after the UNDES D has generated an expansive field of literature presenting case studies, pilot programmes, pedagogical innovations, campus developments, changes to policies and practices of institutions, and the challenges of implementing SD both within and beyond the educational system. Of necessity this paper primarily focuses on reference literature related to the context of this study; namely programmes and modules on SD in HEIs in the context of architecture and urban studies (Al-Hagia, 2012; Bina, Balula, Varanda, & Fokdal, 2016; Cubukcu & Eksioglu, 2009; Ismail, Keumala, & Dabdoob, 2017; Petts, Owens, & Bulkely, 2008; Salama, 2015 pp. 88-91) and engineering education (Brennan & Riley, 2016; Holgaard, Hadgraft, Kolmos, & Guerra, 2016; Khalil, 2016; Salvatore, Ellis, Nesbit, & Ostafichuk, 2016; Winkelman, Penner, & Beittoei, 2016). The challenges are not insignificant: a great deal of the literature identifies common barriers to the full implementation of education for sustainable development (ESD): a lack of conceptual framework (Holgaard et al., 2016; Ismail et al., 2017; Ramos et al., 2015); variations in commitment from higher education institutions (HEIs) in terms of their policies and campuses (Ismail et al., 2017; Ramos et al., 2015); cultural and political influences on institutions, countries and regions (Holgaard et al., 2016; Ismail et al., 2017; Salama, 2015 pp. 90; Tilbury, 2011); and a heavy reliance on the commitment of staff with interests in SD to influence faculties and universities (Bina et al., 2016; Ismail et al., 2017; Khalil, 2016). Despite these barriers the literature also identifies positive areas of commonality in architectural and engineering education in terms of the use of transformative teaching and learning methods, and increasing focus on SD in curriculum, and design and research projects (Al-Hagia, 2012; Allevato, 2016; Brennan & Riley, 2016; Cubukcu & Eksioglu, 2009; Holgaard et al., 2016; Khalil, 2016; Ramos et al., 2015; Salama, 2015; Salvatore et al., 2016; Tilbury, 2011; Winkelman et al., 2016).

The overarching aim of UNDES D was “to integrate values, activities and principles inherently linked to SD in all forms of education and learning and to help realise a change in attitude, behaviours and values to ensure a more sustainable future in social, environmental, and economic terms” (Wals, 2012). To achieve this, it was deemed essential that the provision of education moves towards a system which:

- represents the principles and values that underlie SD;
- deals with all three pillars of sustainability – environment, society, and economy;
- engages formal, non-formal and informal education;
- accommodates the evolving nature of the concept of sustainability;
- is interdisciplinary;
- and uses a variety of pedagogical techniques that promote participatory learning and thinking skills.

A significant area of literature identified was that of established and emerging learning methods considered to be conducive to ESD with a number of studies converging on similar



themes (Brennan & Riley, 2016; Holgaard et al., 2016; Ramos et al., 2015; Tilbury, 2011; Wals, 2012; Winkelman et al., 2016). These learning methods have been identified as transformative for both students and society, producing graduates with the skills and self-confidence to confront the complexity of SD in real-world situations, in turn improving the ability of the architecture and engineering industries they go on to work in to tackle sustainability problems. The following categorisations make use of Wals' (2012) definitions of learning methods, but are representative of consistent themes in the literature:

- *Discovery* or innovation learning: students are encouraged to be curious and exercise their curiosity by exploring various topics in innovative ways such as role plays, group discussions and debates;
- *Transmissive* learning: lectures, seminars, presentations where the content is determined by the educator;
- *Participatory/collaborative/active* learning: both educators and students directing and developing the learning process in unison;
- *Problem-based* learning: learning centred around resolving problems which have either an actual or a strong potentially actual, applicable solution;
- *Disciplinary* learning: applying SD principles to a single or main discipline to directly link those to the area of study, with the discipline as the main focus;
- *Interdisciplinary* learning: taking the same SD principles as in disciplinary learning, but using them as the main focus and considering them from the viewpoint of a number of perspectives, and finding an integrated solution;
- *Multi-stakeholder* learning: including those from different backgrounds beyond the academic environment, with different perspectives and priorities and working together to resolve issues;
- *Critical thinking-based* learning, or collaboration and dialogue learning: questioning assumptions and challenging perspectives with the view of encouraging debate and reflection; also encourages self-driven information gathering;
- *Systems thinking-based* learning: identifying relationships and dependencies between factors in order to understand how altering one part of the system affects the whole; understanding consequences and complexities.

In a 2012 review of UNDES D Wals interviewed 213 practitioners in education regarding their changes in teaching methods. Approximately 12% had implemented no new learning methods; while the least common was Disciplinary learning (21%) and the most were Participatory/collaborative learning (66%), Problem-based learning (63%), and Interdisciplinary learning (58%). Most people interviewed stressed the importance of utilising more than one method of teaching provision, and of identifying and implementing the provision most appropriate to the topic, level of student, and learning environment.

In addition to exploring the developments in the thinking of practitioners of ESD, the authors also considered the shifting perspectives of students. In a 2016 NUS survey into student and employer attitudes towards SD, when asked, "To what extent would you say that you personally agree that SD is something which university should actively incorporate and promote?" 87% of students indicated that they agreed or strongly agreed. This is a percentage which has remained consistently high since the first NUS survey in 2010 (85.7%) and the subsequent 2014 survey (87.5%), and indicates an expectation among students that the university's operations, business model and campuses themselves are approached from the perspective of SD. Additionally, when asked how sustainability should be included in



courses, 74% of students replied that it should be built into existing course content – thus on a disciplinary basis – and 69% indicated that it should be offered as a specific dedicated module (Drayson, 2015b). Finally, when asked to identify the skills which ESD would build which would be important to future employers, students selected “Communicating complex information clearly and effectively to different types of people” (91%), “Solving problems by thinking about whole systems – including different connections and interactions” (87%), and “Looking at a problem using information from different subjects or disciplines” (84%) (Drayson, 2015a). All three of these responses indicate a need, and expectation, for SD education to address issues from an interdisciplinary viewpoint, which can only be achieved successfully through innovating and rethinking traditional teaching and learning methods.

Table 1: Similarities between Approaches to Interdisciplinarity, and Learning Methods for ESD (Source: Authors).

		Learning methods for ESD ^a							
		Critical thinking-based learning	Disciplinary learning	Discovery/innovation learning	Interdisciplinary learning	Multi-stakeholder learning	Participatory/collaborative learning	Problem-based learning	Transmissive learning
Approaches for Interdisciplinarity ^b	Clustered and linked courses		X		X				
	Collaborative learning						X		
	Core seminars								X
	Discussion groups	X		X			X		
	Experiential and service learning					X		X	
	Game and role playing				X				
	Inquiry and discovery based learning	X		X					
	Interdisciplinary or integrative processes				X				
	Internships and field work					X		X	
	Projects and case studies							X	
	Team teaching/planning						X		
	Theme or problem focus		X					X	
	Theories from interdisciplinary fields				X				

^a Derived from (Wals, 2012)

^b Derived from (Blake et. al, 2013)

Throughout the literature relating to UNDES, SD, and sustainability, the necessity of interdisciplinarity is a common thread. Chapter 36 of Agenda 21 identified that in order for SD to be implemented in education, there must be focus on building knowledge, skills and values for SD, and that this must be done by rethinking and innovating teaching curriculums and learning methods, and by crossing the boundaries between education, trade, and



industry (Wals, 2012). According to Stock and Burton, by definition sustainability as a discipline is “a sub-discipline of multiple disciplines”: it is inherently trans-disciplinary. They quote Jerneck et al asserting that the essence of sustainability is to “rethink interactions across domains and scales; nature and society, science and democracy, the global and the local, as well as the past, present and possible futures”. However, although any education or research which deals with sustainability and SD consists of multiple disciplines by its very nature (Buanes & Jentoft, 2009; Stock & Burton, 2011) the degree to which they are successfully integrated varies. Stock and Burton refer to the “M.I.T.-disciplinarity” scale (Multi-Inter-Trans-disciplinarity) where transdisciplinarity represents the epitome of integration of not just academic disciplines but also non-academic perspectives, such as industrial stakeholders and the end users of a product or service. This is the essential characteristic which separates transdisciplinarity from interdisciplinarity (Blake et al., 2013; Petts et al., 2008; Stember, 1991; Stock & Burton, 2011).

The approaches identified to advance interdisciplinarity in HEIs share many characteristics with those learning methods deemed conducive to ESD (represented in Table 1) further consolidating the relationship between the two. However, it has repeatedly been documented that there are significant challenges for interdisciplinary education towards SD including: the historical viewpoint of disciplines as “silos” within HEIs (Buanes & Jentoft, 2009; Petts et al., 2008; Russell, Wickson, & Carew, 2008); the disciplinary focus of research councils and categories of disciplines in research assessments such as RAE and REF (Blake et al., 2013; Petts et al., 2008; Stember, 1991); organisation structures of universities themselves in both disciplines and finances (Blake et al., 2013; Petts et al., 2008); existing “culture clashes” between disciplines (Blake et al., 2013; Buanes & Jentoft, 2009; Petts et al., 2008; Stember, 1991); and the willingness of individuals to work between disciplines and see them as equally important (Buanes & Jentoft, 2009; Petts et al., 2008; Stember, 1991). Such difficulties have been prevalent for many years and symbolise the complexity of both interdisciplinarity and ESD, however, while it is important to acknowledge these, it is out with the scope of this particular paper to address these challenges.

CASE STUDY: SUSTAINABLE ENGINEERING AT THE UNIVERSITY OF STRATHCLYDE GLASGOW

The University of Strathclyde is located in the city centre of Glasgow, Scotland’s largest city, and is the 3rd largest university in the country (University of Strathclyde, 2016a). The Faculty of Engineering has approximately 5000 students enrolled from 100 countries, undertaking over 40 undergraduate, postgraduate and professional development courses, and is renowned for its strong industry links with students having the opportunity to work with external companies on real industry projects (University of Strathclyde, 2016c). The Faculty of Engineering comprises eight departments:

- Architecture
- Biomedical Engineering (BME)
- Chemical and Process Engineering (CPE)
- Civil and Environmental Engineering (CEE)
- Design, Manufacture and Engineering Management (DMEM)
- Electronic and Electrical Engineering (EEE)
- Mechanical and Aerospace Engineering (MAE)
- Naval Architecture and Ocean Engineering (NAOME)

The Faculty-wide postgraduate programme in Sustainable Engineering (SE) was first launched in the 1999/2000 academic session, and since 2004/05 has been directed by Dr David Grierson. It consists of various course Pathways, leading to a postgraduate degree award, in a range of sustainable architecture and engineering disciplines, delivered through both Specialist and Generic modules, industry-based group projects, and an in-depth individual project (University of Strathclyde, 2016b). The structure strives to give students who wish to take up built environment industry-based careers the ability “to think outside the box”:

“We need our future engineers and architects to be creative and flexible, to be curious and imaginative. We believe that by participating in this programme you will develop these attributes, abilities, and skills, and gain a thorough knowledge of modern sustainable engineering issues.” Dr David Grierson, Programme Director, Sustainable Engineering (Faculty of Engineering, 2016)

The SE programme is self-described as a cross-disciplinary programme which provides students with the opportunity to “develop sought-after understanding of sustainable approaches and practices” and meet the requirements to attain Chartered Engineer status, within a learning environment which integrates significant input from industry (University of Strathclyde, 2016b). In the 2016/17 academic session there were four distinct Pathways in the programme:

- Architecture and Ecology
- Chemical Processing
- Offshore Renewable Energy (ORE)
- Renewable Energy Systems and the Environment (RESE)

Students enrolled in these Pathways undertake a compulsory module in Sustainability, along with Generic and Specialist modules that they select from a range of classes, providing students a certain amount of customisation of their postgraduate qualification. The Generic modules are delivered by staff and attended by students from different design and engineering departments across the Faculty and address the principles, concepts and issues which underpin a sustainable approach to architecture and engineering, while the Specialist modules inform students about the specific key issues and existing and emerging technologies relating to their chosen field. Table 2 shows the structure of the SE programme over the academic year.

All students also partake in a semester-long group project, working in teams to achieve a response to a practical design or engineering problem that addresses environmental, social, or economic sustainability. The group projects are co-supervised by an academic supervisor and an industry supervisor, and the projects are based in an industry setting. As much as possible, the teams of students consist of students from different academic backgrounds and different Specialist Pathways, providing them with the experience of working with people from a range of architecture and engineering disciplines, with different approaches and perspectives to real design and engineering problems and solutions.



Table 2: Structure of the SE programme over academic year (Source: Authors).

		Pathways				
		Architecture and Ecology	Chemical Processing	Offshore Renewable Energy	Renewable Energy Systems and the Environment	
Semester 1 and 2 (Sept - May)	Compulsory Module	All students complete module in Sustainability Students select a minimum of 2 of the following:				PgCert (60 credits)
	Generic Modules	<ul style="list-style-type: none"> • Environmental Impact Assessment • Financial Engineering • Project Management • Design Management • Risk Management 				
	Specialist Modules	Student complete up to 5 modules specific to their chosen Pathway				
+						
Semester 2 (Jan - May)	Group Project	Students work across Pathways in groups of 3-5 on a real-life project based, and in collaboration with, industry partners. Students are co-supervised by academic supervisors and industry supervisors. Final assessment consists of group written report and group presentation at Faculty mini-conference.				PgDip (120 credits)
+						
Semester 3 (May - Sept)	Individual Project	Students complete an individual project on a topic related to their chosen Pathway, with final assessment being made through the submission of a report/thesis.				MSc (180 credits)

Some project titles from recent years include:

- “Towards Smart Cities: Energy Mapping to Identify Opportunities for Future Networks”, by students with backgrounds in environmental technology, aerospace engineering, physics, and electrical engineering (Diaz, Gray, MacFadyen, Singh, & Suresh, 2013).
- “BRE Innovation Park Visitor Centre: Energy Modelling & Efficiency Strategies for a Zero Energy Building” undertaken by students with backgrounds in civil and environmental engineering, electrical and computer engineering, and physics and electronics (Vrachimi, Anagnostou, Kyrou, & Enonche, 2016)
- “Hybrid Energy Systems in Future Low Carbon Buildings” by students from mechanical engineering, physical, interior design and electrical and computer engineering (Tamvakologos, Karnezi, Lefaucheur, Tsironis, & Rodi, 2010)

Finally, upon completion of the modules and group project, students undertake an individual project in the area of their distinct Pathway and are awarded an MSc based on the successful submission of a report into their individual project. The overall intention of the SE programme therefore is that the students graduate having gained skills in working in interdisciplinary groups, working with industry, and specialising in their chosen area of architecture or engineering.

The SE programme has been evaluated and profiled in the context of ESD on two previous occasions. In 2013 it was one of five case studies published in the “Getting it together: Interdisciplinarity and Sustainability in the Higher Education Institution” report by the Pedagogic Research Institute and Observatory (PedRIO) at Plymouth University. It was also included in “The EESD Observatory 2008”, a review of the provision of Engineering Education for Sustainable Development (EESD) in European higher education, where the



University of Strathclyde was the first university to be considered an inspiration in engineering ESD.

PedRIO: interdisciplinary and sustainability

The PedRIO report was published in 2013, but was based on information gathered during the 2008/2009 academic session. It briefly outlined the SE programme as it stood at that time: it had, to date, graduated 500 students and was offering 9 distinct course Pathways.

The approach of the PedRIO report was to establish the degree and nature of interdisciplinary in higher education, and therefore evaluated the SE programme under these terms. The course director, Dr David Grierson, described the programme at the time as “cross-disciplinary” with an ambition towards interdisciplinarity, involving input both from industry and across departments within the Faculty of Engineering. He acknowledged that cross-disciplinarity in the programme including across the industry-lead group projects was “not as consistent as I would like it to be” while also stating that “The more that we discuss the initiatives between us, the more we are able to find common ground”. The PedRIO report concluded that the SE programme’s approach to sustainability was “pluri-disciplinary”, and that in parts the element of sustainability was “additive” rather than “integrative”. However they also commented on “increasingly open channels of communication” between departments within the faculty facilitating a move towards increased interdisciplinarity and integration of sustainability (Blake et al., 2013).

The EESD Observatory

Table 3: Scoring System for each University in EESD 2008 (Source: Grierson and Hyland, 2011).

Indicator Score					
Research	Undergraduate Education	Postgraduate Education	Embedded Education	In-house EMS	Total Indicator
0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 10

In 2008, the EESD Observatory ranked the University of Strathclyde’s SE provision number one for Engineering ESD in Europe. The report “identifies the extent that sustainability is embedded in European engineering education” by looking at sustainability activities at education, research and management system levels. The University of Strathclyde was the first university to receive a ranking of over 9 and therefore be classed as an inspiration in its field: Table 3 shows the scoring system used for this assessment.

The EESD Observatory described the SE programme as “a flexible multidisciplinary postgraduate programme”. As with the PedRIO report, it outlined the structure and provision of the programme, through the blend of Specialist and Generic modules, industry based group projects, and particularly highlights the direct industrial involvement in Pathways and resultant knowledge exchange.

“In order to significantly contribute to change, engineering graduates, along with knowledge of sustainability, must have a social and political agency and an appreciation of the role of others within a multi-disciplinary working environment. Educational opportunities and the development of transferable skills are critical to this.” (EESD, 2008)



Table 4: Summary of Strathclyde responses to Scottish Government Objectives
(Source: Grierson and Hyland, 2011).

Scottish Government Objectives	SMS (SE) Actions
Enhance links with local businesses & communities	Encouraging direct involvement of local organisations in curriculum design and development & teaching through live projects etc.
Compensate for lack of R & D undertaken by business	R & D projects set by industry. Student gains work experience in live project, expert guest lectures. Industry gains expert knowledge, reputation among new graduates, access to CPD courses.
Enhance graduate employability	Foster relationships between student and industry through live project work & greater involvement of both parties in curriculum development meaning more relevant graduate skills. Involvement of students and external organisations in curriculum development;
Respond to changing workforce skills needs & provide flexible learning	interdisciplinary, problem-based, live, group projects alongside individual dissertations; development of student/industry relationship; use of VLE.
Integrate ESD into the curriculum	SMS (SE) is platform for interdisciplinary engagement and growth of ESD activity across the university. Flagship courses complemented by generic SD modules.
Sustain growth in postgraduate student numbers & enhance international student links	Through enhanced employability & more relevant & flexible course provision.

Additionally, the SE programme was presented in two publications proposing a pan-university sustainability programme at the University of Strathclyde. The publications presented a framework for the proposed Strathclyde Masters programme in Sustainability (SMS) which would build upon the SE programme, following a similar structure to provide interdisciplinary and inter-faculty learning across the University, and addressing the Scottish Government's key objectives within the second half of UNDES (Grierson and Hyland, 2011; Hyland and Grierson, 2010). Although the programme is as yet unimplemented, the publications highlight how the structure of the existing SE programme and the proposed SMS programme aims to meet the Scottish Government's objectives in line with UNDES: summarised in Table 4.

METHODOLOGY

All data was gathered from resources available to staff at the University of Strathclyde. The number of students enrolled and graduated from the SE programme between 2004 and 2015 was gathered from HESA data available from the University's Strategy and Policy team, and confirmed using archived class lists for SE classes.



The Specialist Pathways on offer in each year were made available to staff and students through annual Student Handbooks, and university Regulations: the university's Print Services hold a small number of student Handbooks from each year allowing changes to the SE programme to be traced through the years being examined, while the Regulations are available on the Strathclyde website. The number of students on each module, and the degree programme for which they were enrolled, was gathered through accessing current and former class lists on the university's staff and student online portal, "PEGASUS": these were obtained for each year and entered into a database to allow analysis and produce tables, graphs and figures.

The data collected will be discussed under the following headings:

- Enrolments and Awards: quantitative analysis of the numbers of students enrolled at MSc, PgDip and PgCert levels, and the resultant graduation levels of these enrolments;
- Specialist Pathways: quantitatively mapping the trends in successful Pathways through student enrolment numbers over 2004-2015, and discursively exploring where Pathways were developed or discontinued;
- Generic modules: quantitatively mapping the trends in successful modules through student enrolment numbers over 2004-2015, and discursively exploring where modules were developed or discontinued;
- Teaching Methods and Interdisciplinarity: drawing upon the described aims and teaching methods of the Sustainability module and the SE Group Project, and the literature on both ESD and interdisciplinarity, to explore where the SE programme aspires to these values.

DISCUSSION OF RESULTS

Enrolments and Awards

Between 2004/15 and 2014/15 there were 704 students enrolled in the SE programme with a graduation percentage rate of 85% overall. In 2004/05 the number of students enrolled was 74: in 2014/15 this was 48. The number of enrolments have fluctuated, with the 2004/05 figure of 74 being a peak and the lowest being 36 in 2013/14: the average number of enrolments per year is 54 (HESA & University of Strathclyde, 2016a, 2016b; University of Strathclyde, n.d.)

Overall, 88.4% of enrolments were at MSc level, 11.4% were at PgDip level, and 0.3% at PgCert level. However, this ratio is steadily changing as more students opt to register for an MSc from the start: in 2004/05, 14.9% of enrolments were for the PgDip award, but by 2014/15 this had fallen to only 2.1%, with the remaining 97.9% aiming to achieve an MSc from the outset. In terms of awards made, overall, 93.1% of the awards made were MSc, 6.7% PgDip, and 0.2% PgCert. This higher percentage of MSc awards made, when compared with enrolments, highlights the common occurrence of students registering for PgDip initially then progressing to MSc. This is further compounded by the overall enrolment-award percentage for MSc being 89.5%, but only 50% for PgDip (HESA & University of Strathclyde, 2016a, 2016b; University of Strathclyde, n.d.). The fact that an overwhelming majority of students on the SE programme opted to complete the full MSc is taken as representative of a strong interest and commitment among students to gain SD knowledge and skills through the completion of the in-depth individual project, although this



can only be definitively concluded following a forthcoming analysis of qualitative feedback from students.

Specialist Course Pathways

When the PedRIO research into the SE programme was conducted in the 2008/09 session, there were 50 students registered on the programme, across 8 Pathways (Blake et al., 2013). In 2014/15 there were 48 students registered, but this time across only 5 Pathways. In 2004/05 there were 74 students registered, across 11 Pathways. This equates to a “students-per-Pathway” ratio of 6.7, while by 2014/15 the ratio is 9.6. Thus, there has been a consolidation of the provision across the SE Pathways: those that remain are those that have proven to be both popular and successful. This is reflected in the relatively high MSc graduation rate for the four Pathways that remain: *Chemical Processing* has an MSc graduation rate of 90.6% over 10 years; *ORE* has 96.1% over 6 years; and *RESE* has 92% over 5 years. Contrastingly, *Integrated Product Development* and *Technology Management*, both of which ceased to run after the 2010/11 session, had MSc graduation rates of only 60% and 65.2% respectively (HESA & University of Strathclyde, 2016a, 2016b; University of Strathclyde, n.d.). The enrolment trends for the Pathways which are on offer in the 2016/17 academic session are shown in Figure 1.

The academic sessions immediately following the period of time where data was gathered for the PedRIO report were a significant time in the development of the SE programme. There are two key points of discussion in the provision of Pathways: first 2009/10, when *Energy Systems and the Environment* was re-launched as *Renewable Energy Systems and the Environment* and the new Pathway in *Offshore Renewable Energy* was launched; and second 2011/12, when the available Pathways and Generic modules underwent significant restructuring.

In the 2008/09 session *Energy Systems and the Environment (ESE)* was the most popular of the 8 Pathways in SE: of the 50 registered students, 15 (30%) of them were enrolled for *ESE*. In the 2009/10 session *ESE* was re-launched as *Renewable Energy Systems and the Environment (RESE)*. This signified a commitment for this Pathway within the SE programme to refocus and increase consideration of renewable energy over the traditional energy systems that the former title had implied. In the year following the name change *RESE* had 32 students enrolled – 48% of all students taking part in the SE programme, and a two-fold increase on the previous year. Thus, the implied commitment to renewable energy arguably had a significant appeal to those interested in pursuing a PgDip or MSc. To date, in the 2016/17 session, *RESE* remains the most popular of the SE Pathways, with 22 enrolees accounting for 54% of all enrolees (University of Strathclyde, n.d.).

In the same academic session, the Department of NAOME launched a new SE Pathway, *Offshore Renewable Energy (ORE)*. Since 2009/10 its numbers have grown significantly from 3 students in that first year, to 14 in 2016/17 (36% of all enrolees) (Figure 1). *RESE* and *ORE* combined make up 90% of the SE cohort in 2016/17, up from 53% in 2009/10 when they were launched. The re-launching of *RESE*, and the success of both *RESE* and *ORE* signified a renewed commitment within the SE programme in 2009/10, to focus on education which addressed not just on the skills for SD, but on the emerging design and engineering solutions for SD, and the reference in the Pathway names to recognisable terms for SD appears to have had an instant appeal to students seeking this knowledge and these skills.



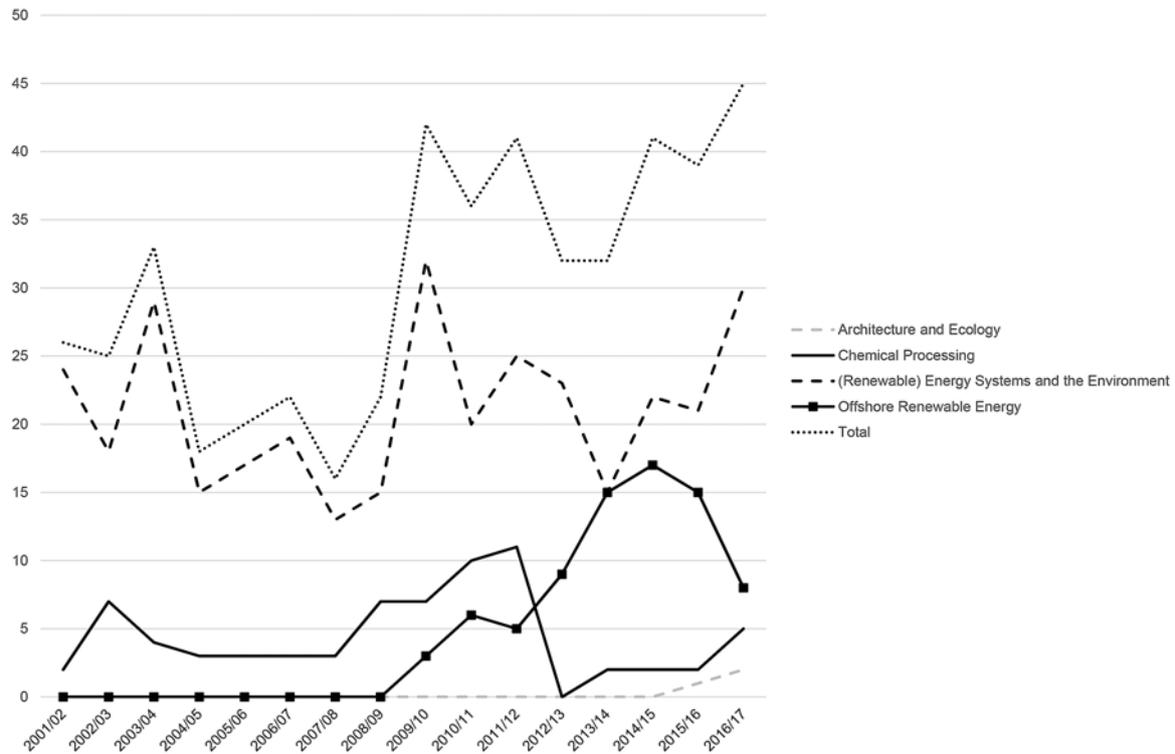


Figure 1: Graph showing enrolments trends for SE Pathways offered in 2016/17 (Source: Authors).

The other significant point in the development of the SE programme was in 2011/12. As previously mentioned, there are currently four Pathways on the SE programme, but in 2004/05 academic session there were 11 Pathways available. Between 2004/05 and 2010/11 there were slight alterations in Pathways:

- *Mechanical Engineering and Materials* was withdrawn after 2004/05 session;
- *Biomedical Engineering* was withdrawn after 2005/06 session;
- *Construction Management* ran in 2006/07 and 2007/08 only;
- Development of the *Urban Environment* was withdrawn after 2006/07.

Despite these alterations, in 2010/11 there were still 9 Pathways available: however, in the following session there were only 6. Table 5 shows the addition and removal of Pathways from 2004/05 to 2016/17. The reduction in Pathways resulted from a review of postgraduate provision within DMEM where 4 of their 5 SE Pathways were withdrawn as part of a process of re-evaluating and restructuring. Thus, *Engineering Design*, *Integrated Product Development*, *Management of Competitive Manufacturing* and *Technology Management* were all withdrawn. In their place, *Sustainable Product Development* was launched: as with RESE and ORE, the title did what the previous Pathways did not, and indicated an inherent commitment across the entire postgraduate course, to developing knowledge and skills for SD beyond a single module.

Table 5: SE Pathways offered between 2004/05 and 2016/17 (Source: Authors).

Dept	Sustainable Engineering Pathway	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Arch	Architecture and Ecology												x	x
BME	Biomedical Engineering	x												
CEE	Construction Management			x	x									
	Development of the Urban Environment	x	x											
CPE	Chemical Processing	x	x	x	x	x	x	x	x	x	x	x	x	x
DMEM	Computer Aided Engineering Design	x	x	x	x	x	x	x	x					
	Engineering Design	x	x	x	x	x	x	x						
	Integrated Product Development	x	x	x	x	x	x	x						
	Management of Competitive Manufacturing	x	x	x	x	x	x	x						
	Sustainable Product Development								x	x	x	x	x	
	Technology Management	x	x	x	x	x	x	x						
MAE	Energy Systems and the Environment	x	x	x	x	x								
	Mechanical Engineering and Materials	x												
	Renewable Energy Systems and the Environment						x	x	x	x	x	x	x	x
NAOME	Marine Technology	x	x	x	x	x	x	x	x	x	x	x	x	x
	Offshore Renewable Energy						x	x	x	x	x	x	x	x

Generic Modules

In addition to these changes to the Pathways in 2011/12, there was significant restructuring within the Generic Modules, most notably with *Sustainability* becoming a compulsory class across all SE Pathways.

The *Sustainability* Module is the sole compulsory module on the SE programme: the remaining Generic and Specialist modules are optional thus allowing students to tailor their own postgraduate programme to their career goals. The *Sustainability* module encompasses social, environmental, and economic sustainability, aiming to provide students with an understanding of the core concepts of sustainability and SD, their application in built environment studies, and provides a base from which the students' knowledge of and skills for SD can grow throughout their studies in their Specialist Pathways (Faculty of Engineering, 2016).

Environmental Impact Assessment (EIA) introduces students to the methods for identifying, evaluating, and mitigating the environmental impacts of their design and engineering projects. By understanding the process for considering the biophysical, social, economic, and cultural effects of their proposals students are equipped with the skills to make decisions throughout their design process. *Design Management* provides an introduction to “the processes, issues and tools” used to organise and manage design projects; *Financial Engineering* introduces elements of financial engineering that are essential to ensure financial robustness of business strategies and encompasses economic sustainability; *Project Management* provides students with the skills necessary to plan and execute projects, paying particular attention to the importance of effective and efficient use of resources; *Risk Management* introduces the theory and practical techniques for risk analysis and its role in informed decision making (Faculty of Engineering, 2016).

Table 6 shows how the provision of Generic Modules has changed from the 2004/05 academic session. As with the Pathways, there is a clear change in the structure at the 2011/12 academic session. In this year, there were three additional SD-focused modules introduced, and the structure was altered so that at least one of these modules was compulsory, with the remaining Generic module provision being selected from the rest of the modules (Faculty of Engineering, 2011). Additionally, Sustainability was made compulsory in 2011/12, therefore at this point all students on the SE programme were required to take, at minimum, two SD-focused modules. This represents a renewed and increased commitment from the Pathway directors to fully and holistically integrate the social, economic, and environmental aspects of SD to the SE programme, and a commitment to ensure that all students graduated with, at a minimum, the SD knowledge and skills that the Sustainability

Table 6: Provision of Generic modules from 2004/05 to 2016/17 (Source: Authors).

	Class Code	Module Name	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12 ^a	2012/13 ^b	2013/14	2014/15	2015/16	2016/17
Compulsory	AB975	Sustainability ^a									x	x	x	x	x
	EF912	Environmental Impact and Sustainability ^a								x					
	EF936	Sustainable Engineering Group Project	x	x	x	x	x	x	x	x	x	x	x	x	x
	EF900	Sustainable Engineering Individual Project	x	x	x	x	x	x	x	x	x	x	x	x	x
Generic	EF912	Environmental Impact and Sustainability ^a	x	x	x	x	x	x	x						
	CL956	Environmental Business Strategy								x ^b	x ^b				
	CL955	Environmental Management Systems								x ^b	x ^b				
	EV939	Environmental Impact Assessment								x ^b	x ^b	x	x	x	x
	DM 930	Knowledge Engineering and Management for Engineers										x	x		
	EF901	Design Management	x	x	x	x	x	x	x						
	EF927	Design Management								x	x	x	x	x	x
	EF909	Finance	x	x	x	x	x	x	x						
	EF926/EF929	Financial Engineering									x	x	x	x	x
	EF908	Information Management	x	x	x	x	x	x	x						
	EF930	Information Management									x	x	x	x	
	EF902	Project Work and Project Management	x	x	x										
	EF911	Project Management				x	x	x	x						
	EF931	Project Management									x	x	x	x	x
	EF910	Risk Management	x	x	x	x	x	x	x						
EF932	Risk Management									x	x	x	x	x	

Notes

- a "Environmental Impact and Sustainability" became compulsory in the 2011/12 session, and was renamed "Sustainability" in the 2012/13 session
- b In these years the Generic modules were split into List A and List B; List A comprised of Environment modules, and students were required to take at least one of these. List B comprised of the remaining modules, of which students could take no more than two.
- N.B.** In 2011/12 the programme was significantly restructured and the class codes for Design Management, Financial Engineering, Project Management, Information Management and Risk Management were all changed.

class aimed to provide. This restructuring of the Generic modules coincided with the restructuring of the Pathways provided in 2011/12, and further built upon the commitment towards integrating ESD that began in the 2008/09 with the introduction of ORE and RESE. The Sustainability and EIA modules will be discussed in more detail in an upcoming paper devoted to exploring the Generic module aspect within the SE programme.

Learning Methods and Interdisciplinarity

A number of the emerging transformative learning methods presented in the literature review were identified as being present in the structure and delivery of the SE programme. By way of exemplifying how these have been adopted in the programme during the study period, this section will discuss the application of the learning methods that are present in the *Sustainability* and *Group Project* modules.

The structure of the *Sustainability* module over the semester is shown in Table 7. The module uses *Transmissive* learning, *Discovery* learning, *Critical-thinking* learning, and to a lesser extent *Participatory* learning. The *Transmissive* learning is achieved through the initial lectures and presentations made to the class, where the content is determined by the course director and the guest lecturers. However when it comes to the online discussions and face to face discussions the module shifts to a mix of *Discovery* learning and *Critical-thinking* learning. The students are given basic resources around the topic of the seminar and encouraged to build upon these through self-directed reading and research which allows them to follow the particular points of the topic which interests and intrigues them most: this amounts to *Discovery* learning, and is also present to some extent in the essay assignment,



due to the ability of the students to choose their own essay topic. The *Critical-thinking* aspect is delivered through both the online and face to face seminar sessions, and the essay assignment. The essay is by definition a reflective essay, which encourages the students to be critical of the SD resources they have been exposed to over the module, and the seminar sessions encourage debate and critical thought in both online and face-to-face format.

Finally, there is an element of *Participatory* learning: this requires that both educators and students are involved in the direction and delivery of the content through the module. While the students are able to direct the content of the module through the seminar sessions, in that they are able to bring issues that interest them to the discussion, they are restricted by the broad topics of the discussion sessions that are determined by the educator.

The *Group Project* module uses *Participatory*, *Problem-based*, *Interdisciplinary*, and *Multi-stakeholder* learning. As much as possible, the groups of students are able to select their own project, and within the project determine their aims, objectives, and outcomes: all of which pertains to *Participatory* learning as the students have a say in their project. It also uses *Problem-based* learning through the application of theoretical knowledge to resolve a real life, industry-based, practical problem. There is also *Interdisciplinary* learning although less consistently: as much as possible the students form mixed disciplinary groups and use these diverse backgrounds to bring different perspectives to the problem and solution they are working towards, attempting to address all of the perspectives. Finally, there is an element of *Multi-stakeholder* learning through the bridging of education and industry: the projects are supervised jointly by an academic supervisor and an industry supervisor thus the students are encouraged to consider both of these perspectives when reaching their solution to the problem.

Table 7: Structure of Sustainability module (Source: Authors).

Sustainability			
Semester 1	Weeks 1-4	Lectures	Students attend a series of lectures and presentations delivered by experts in the themes of sustainable development specific to engineering.
	Weeks 5-10	Online/face-to-face seminars	Students are separated into 12 groups of 7-9 students, from different disciplines and initially complete a short team-building exercise. They are asked to access resources on the university's VLE system "MyPlace" and take part in a week of online discussion forums on a defined topic. They then attend face-to-face discussion sessions as a group where they meet with another group to debate the resources. This process is repeated three times for three different topics: <ul style="list-style-type: none"> • <i>Limits to growth: populations</i> • <i>Limits to growth: economies and cities</i> • <i>Green perspectives</i>
	Week 7	Individual assignment issued	Question paper for 1500-2000 word individual reflective essay is released halfway through this process. Students are allowed to choose their own essay topic to examine for the perspective of sustainable development; students are allowed to select a topic from beyond their own discipline if they desire, and asked to state their reason for doing so.
	Weeks 10-12	Individual assignment submission	Students are encouraged to use the discussion forums to discuss their individual reflective essays with their fellow students. They then submit the final piece through the "MyPlace" system at the end of Semester 1.



LIMITATIONS

The data presented relies primarily on quantitative data gathered through the university's systems: while some trends and patterns are clear, there lacks a qualitative insight into the reasons behind them (Tilbury, 2011). Additionally the data lacks a qualitative understanding of the views of the students, staff and external partners who have been involved in the SE programme since 2004, particularly in terms of their perspectives on the programme's ultimate ability to deliver skills for ESD and interdisciplinarity. This work will be the focus of a forthcoming paper that will report on a structured qualitative review involving those directly associated with the SE programme, following the completed process of quantitatively identifying trends.

CONCLUSION AND FUTURE RESEARCH

The UNDESSED advocated that in order for ESD to be achieved, there was an innovation in teaching methods and curriculum provision necessary in order to strive towards interdisciplinarity. Concurrently there is a constant presence of demand and expectation from both students and employers that students leave university with knowledge, skills and experiences that are necessary to address the complex issues inherent in SD. The literature review of this paper presented how ESD and interdisciplinarity complement each other and can work together towards delivery of both goals in the context of architectural and engineering education.

The SE programme was established prior to the commencement of the UNDESSED, and has undergone a number of significant restructures in a display of commitment to providing students with the SD knowledge and skills essential to help them succeed in their careers and contribute to a sustainable future for the built environment. It is considered a flagship model for ESD within the University of Strathclyde (Blake et al., 2013; Grierson and Hyland, 2011; Hyland and Grierson, 2010) and it continues to attract design and engineering students interested in obtaining both these skills, and their chartered engineer status. While this paper has touched upon some of the changes to the SE programme involving its growing focus on interdisciplinarity and the introduction of transformative learning methods over the study period, the forthcoming papers will explore in more depth how the SE programme has developed against the backdrop of the UNDESSED. This paper has introduced how the structure of the Sustainability module intends to encourage and facilitate *Interdisciplinary* learning: future work will explore the impact this has on the students' outputs from the class through analysis of their assignment discussion topic choice, and through the aforementioned qualitative study of staff and students perceptions.

The SE programme has been self-described as cross-disciplinary (Faculty of Engineering, 2016): in the PedRIO report it was concluded to be "pluri-disciplinary" with the SD components being more "additive" than integrative (Blake et al., 2013). However, the course has undergone significant restructuring since the 2008/09 academic session in which the information was gathered, including the restructuring of both course Pathways and Generic modules. A significant purpose of this ongoing work is therefore to update this conclusion, identifying the extent to which the SE programme has improved in its integration of SD aspects into the wider Specialist curriculum of the individual Pathways, and describe the movement towards greater interdisciplinarity within its Generic modules and course Pathways.

Although the UN Decade of Education for Sustainable Development has ended, this does not signal the end of the striving towards a sustainable future. UNESCO has officially endorsed



the UN's follow-on project, the 'Global Action Programme'. It aims to scale up actions which were implemented during DESD, continuing the focus on changing educational contexts, learning methods, and teaching environments with the goal of empowering students to think critically, work collaboratively, and transform their local and global societies. The SE programme aspires to these same aims, in addition to striving to remain an inspiration for ESD and interdisciplinarity both within the University and beyond. It is vital for universities to continue this process of appraising and critiquing how they provide skills for SD to their students, and strengthen their commitment to preparing graduates to participate in building a sustainable future.

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