Embedding Education for Sustainable Development in the Engineering Curriculum through Challenge-Based Education

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Abstract: An international objective to create a net-zero economy means it is essential that the engineers for tomorrow are fully literate in sustainable engineering, have the agility to engage in large-scale challenges, can identify actionable problems and deliver fit for purpose designs. As the needs of tomorrow's engineers change, so must their education today. The Department of Electronic and Electrical Engineering (EEE) at the University of Strathclyde, in the 21/22 Academic Year, have embedded Sustainable Development (SD) into year 1 of all of degree programmes using the Engineers Without Borders Engineering for People Design Challenge as our case study activity. This paper presents a learning framework for integrating a challenge-based sustainability engineering activity into core curricula demonstrating the appropriateness of a Challenge-Based Learning (CBL) and Education for Sustainable Development (ESD) approach.

Keywords; education for sustainable development, engineering education, scaffolding, authentic assessment.

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1. INTRODUCTION

We are now in the third year of the UN's Decade of Action to achieve the Sustainable Development Goals (SDGs) and progress is still not "at the speed or scale required" (United Nations). With a drive for net zero influencing all sectors of society and industry the needs for tomorrow's engineers are changing, then so must their education today. It is essential that the next generation of engineering graduates are literate in SD, understand the role of engineering to meet this agenda and hold the core SD competencies, as identified by (UNESCO 2017). Evidence also shows that students in Higher Education expect sustainable education as part of their studies (Advance HE and QAA 2021).

The Department of Electronic and Electrical Engineering at the University of Strathclyde has embedded SD into year 1 of all of all its degree programmes through a challenge-based learning approach. The Engineers Without Borders (EWB) Engineering for People Design Challenge (EWB UK 2022) is used as the real-world challenge through which students are able to develop knowledge, skills and experience, in an active learning environment. Students who participate in the challenge work to identify a problem statement from a wide project brief, and then propose a solution. Through this challenge-based learning approach, students develop multi-disciplinary project experience and SD competencies that will be key to their role as tomorrow's engineers.

This paper will begin by presenting the pedological approaches used to design a framework for challenge-based sustainable development education to facilitate student engagement in, and attainment of SD competencies. The paper will then go on to detail the chosen methods of integrating the EWB challenge into the curriculum across delivery and assessment. The paper will conclude with challenges faced, benefits, and options for future development.

2. PEDOLOGICAL APPROACHES

Backwards Design (Wiggins and McTighe 1998) was the core approach used for framework development – education aim and Learning Outcomes (LOs) were defined, and then assessment methods, student engagement activities and lastly teaching activities were created. A comprehensive list of sustainability LOs and competencies were gathered following the approach of (McClarty and Gaertner 2015) from both the fields of Engineering (ECUK 2020) and SD (UNESCO 2017). The three LOs for this SD project were defined as:

LO 1: Understand the role of Engineers for Sustainable Development
LO 2: Participate in collaborative engineering projects
LO 3: Appreciate and prioritise designing for the people and context, to ensure appropriateness and sustainability of ideas

The stages of backwards design were applied such that students may interact with a real-life engineering problem that requires whole system and multidisciplinary thinking to be able to articulate and demonstrate engineering competencies and the importance of the UN's SDGs. The following sections will outline the use of challenge-based learning to deliver a real-life engineering problem, the use of scaffolding to support students' growth and the use of patchwork assessment to make the assessment programme authentic and accessible.

2.1 Challenge Based learning

The drive for net zero will mean that the engineers of tomorrow will need consider complex, and multi-discipline problems that require a broad set of skills, competencies and knowledge. Utilising a Challenge Based Learning (CBL) approach allows students to engage in large real-life problems to acquire and apply a wide range of knowledge, skills and critical thinking in (Johnson, Smith et al. 2009, Portuguez Castro and Gómez Zermeño 2020). CBL builds on project based and problem based approaches, but focusses on allowing students the opportunity to engage in real-life challenges in an active environment, that if delivered and supported properly, can be authentic to future professional practice (Johnson, Smith et al. 2009).

2.1.1 The Engineers Without Borders Engineering for People Design Challenge

Every year EWB work with a partner organisation to develop an engineering brief based on real-life problems that people within their country face (EWB UK 2022). The project brief focus on eight broad topics, including water, sanitation, energy, digital, transport, built environment, food and, land management and waste. Importantly, alongside the demographic and geographical information on the area in focus the brief also includes case studies and testimonials from people living and working within the community.

Students must first gain understanding of the challenge community's history and demographics and embed themselves in the needs of the community across the broad range of topics to identify a detailed problem statement. Teams then work to propose a solution to the identified problem that is not only well thought through and reasoned, but critically that is appropriate to the economic, environmental and social context- appropriate across the three pillars of SD. The EWB Engineering for People Design Challenge therefore aligns well with the LOs and sustainability competencies to be gained by students as identified in this work.

2.2 Scaffolding a learner journey

The scale of the EWB Challenge, the depth the design brief, the need to first identify and fully describe a problem statement, and then offer a solution, is no small task. This is especially true for the 1st year UG students that the work herein was delivered to – who have little to no previous experience of SD, the SDGs, sustainable engineering, or even long-term group projects. It was therefore required to support student attainment of the LOs to use a staged, or rather, scaffolded approach (Wass, Harland et al. 2011) in the determination of learning activities.

Leaning too on the method of constructive alignment (Biggs 1996) there needed to be a clear and purposeful connection between teaching activities and learning. Meaning minimising 'disconnect' in helping students achieve the necessary LOs through a clear and connected learner journey. A scaffolded learner journey was designed that was founded in the *Engineering Process* as in Figure 1, a proposed approach by EWB in the project proposal.
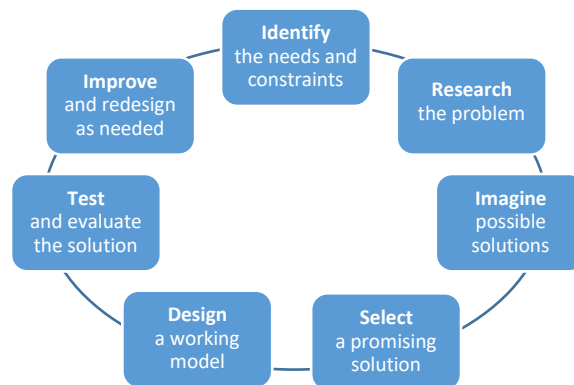
Figure 1 The engineering Process. derived from (Teach Engineering)

The Engineering Process was utilised as the baseline iterative problem-solving technique for problem identification and solution interrogation. It allowed a touchstone map for students, and staff, to refer back to and ready identification of work done, work to be done, and importantly highlighting the iterative nature of sustainable engineering problems –in a manner that steps and stages scaffold the student through their learning journey.

2.3 Authentic and Patchwork Assessment

The learner journey was given clarity and increased validity by utilizing scaffolding to stage the student through activities on a long-term (two semester) project. Assessment too required a clear purpose, path and connection to the work. The engineering process is utilized to ensure the students' practice is closely aligned to professional practice and therefore authentic – a key Quality of Assessment (Brown and Race 2012). The assessments, and language of assessments, also used professional approaches and vocabulary. *Milestones* are in place through each of the project stages to scaffold students through the project and keep them on track, and *deliverables* expected at regular intervals to allow students to demonstrate the attainment of competencies.

Utilising the Patchwork Assessment approach (Winter 2003) allows students experience, and outputs, to build through project work. In the application here, continuous assessment pieces (short reports and presentations) act as *patches* which are brought together to form the core of the final deliverables, forming a larger picture from individual pieces.

The introduction of self-assessment and peer assessment in a structured and fully facilitated manner allows students to regulate their learning and their learning process (Panadero, Jonsson et

al. 2016). This approach draws on the 'Rethinking Feedback' strategies of (Boud and Molloy 2013) placing the agency of the student at the centre of the proposed assessment and feedback framework - the student a key actor in their own learning.

3. DELIVERY METHODS

A challenge-based sustainability engineering education project was delivered to around 230 students of the EEE department at the University of Strathclyde. The following details the components of the students' learning experience across teaching and learning activities and the assessment and feedback methods used. This framework is offered for institutions to use and adapt to best fit their students' needs.

3.1 Student learner context
The 1st year student cohort in the EEE department at Strathclyde come from multiple degree programmes including joint degrees with mechanical engineering, computer science, biomedical engineering, and business. Centring SD into the core of the 1st year of all these degree programmes sets a clear intention that SD competencies become a core practice for our learners, and places ESD at the heart of the department's curriculum.

Project based learning is threaded throughout the degree programmes, though tend to be focused on design and delivery of a solution and not on problem specification. The EWB global Design Challenge offers the opportunity for students to *design for people and context* ensuring social, economic, and environmental appropriateness of their ideas. This is well aligned to UK SPEC vr 4 (ECUK 2020), and the skill sets that are demanded for today's graduates - tomorrow's engineers - and a highly useful project to base students' learning in SD.

3.2 Scaffolded Learning Programme
The programme of ESD activities is designed to scaffold a student's journey through the intended LOs and competencies centred on the engineering process. Through research, problem specification, generating solutions and iterating round problem statements and solution designs student teams find the most appropriate solution to an identified problem statement.

The programme took place in weekly seminars, over the full academic year and replaced a previous set of transferrable skills tutorials. The cohort were split into 19 seminar groups of around 10-15 students, each with their own staff mentor. Students were supported through groupwork, open discussions, feedback from their peers and staff mentor and a framework of activities that broke their large project into smaller, achievable sections. Alongside staff input in seminars there was continual support and advice available via forums and additional material on the virtual learning environment. The framework of activities, including milestones and deliverables across four key stages., can be seen in Table 1.

Wk	Stage	Milestone	Deliverable

4-7	**Stage 1**	Understanding of SD	
8-10	**Stage 2**	Understanding of challenge area	
11	**Stage 3**	1st Draft Problem Statement	Problem Statement Presentations
12			
13		Problem Statement++ & initial ideas	Problem & Interim Solution Presentation
14		Interrogated Design Solution	Design Brief & Initial Design Description
15	**Stage 4**		
16			Implementation & Maintenance strategy
17			
18		Completed Reporting	Presentations & Final Reports
19		*Feedback and next steps*	

Table 1 ESD Challenge-Based Learning Framework

Semester 1 seminars (weeks 1-10) focussed on team building (Stage 0), staff lead discussions, and delivering a short course to ground students in SD (Stage 1) and introducing the EWB Challenge, and then teams identifying problem statements (Stage 2). Stages 0 to 3 included:

- **Stage 0: Team Building (weeks 1-3)**
  - Introductory and team building activities for new students
- **Stage 1: Context (weeks 4-7)**
  - SD activities including introduction to the UN SDGs
  - Activities/discussions focussing on responsibility and purpose of individuals and engineers to SD & how to create equitable, inclusive and appropriate solutions
- **Stage 2: Defining the Problem (weeks 8-10)**
  - Introduce tools to investigate project briefs and understand project context alongside how to explore and define a problem statement and ideation of multiple potential solutions to a problem. These were applied to short examples.
  - Introduction of the EWB Challenge and Case Study Brief
  - Building teams (of 3-6 students) based on common areas of interest in the brief
  - Identification of problem statement and criteria for success (using previous tools)

Semester 2 seminars (weeks 11-19) are project focused and led now by the student teams with scaffolding in place to move teams through the work. Activities are introduced by staff, but work is team focused and student led. The role of staff moves from delivery of content (tools and techniques) and moderation (of discussions) to student support and team mentoring through iterations of problem specification and solution design and development. Stages 3 to 4 included:

- **Stage 3: Exploring Options (weeks 11-14)**
  - Ideation of initial ideas
  - Interrogating ideas with respect to the problem statement and criteria for success
  - Interrogating design solutions for inclusivity and appropriateness
- **Stage 4: Justifying your choices (weeks 15-18)**
  - Design Development including technical detail
  - Implementation and maintenance considerations and strategies
  - Final presentations and reporting.

Students used the EWB challenge as a long-term case-study to apply tools and techniques across problem specification, ideation of solutions and interrogation and development of design. Teams are encouraged to identify a problem statement that would address the greatest or most pressing needs of the brief's community. This meant that teams did not always ID a problem statement that would traditionally align with their degree programmes. This adds an extra dimension of challenge to the project, and was met with enthusiasm. It meant students were able to bring new perspectives to development areas not traditionally seen as within their discipline's purview as well broadening their knowledge base and understanding of the multidisciplinary fields of SD.

3.3 Assessment and Feedback methodologies

Formative continuous assessment pieces (milestones and deliverables in Table 1) were designed to scaffold the teams through the engineering process and key project stages. Importantly, all assessment was feedback focussed and the patchwork approach used such that student experience would build. Reporting took place every 1- or 2-weeks making room for early intervention if teams strayed too far from the intended programme or extra support was needed.

Work completed in continuous assessment was be utilised in summative final deliverables and vitally feedback gained through continuous assessment could be applied to the final assessment. Clear milestones and deliverables alongside timely, useful and actionable feedback avoids duplication and allows students to build on what they have done previously. The three main themes of feedback and assessment in place across the programme were:

1. **Peer Feedback and Assessment:** Put in place for students to assess how they have worked as a team. Students teams also assessed each other's presentation deliverables such that teams received additional feedback as well as increase awareness of rubrics.
2. **Self-Assessment:** Students were asked to take note of feedback given and reflect on what that meant for their practice going forward. When submitting the consequent piece of work, students highlighted how they have acted on previous feedback.
3. **Staff Feedback and Assessment:** Of continuous assessment pieces is made with respect to the attainment of competencies. of final deliverables is made with respect to criteria aligned to the LOs via a rubric.

4.   CONCLUSIONS

It is clear, that as the demands on tomorrow's graduate engineers are changing, so must the educations of today's undergraduates, and the underpinning pedagogical approaches. The integration of challenge-based ESD is one way of making this change. This paper has presented a framework for integration, where the EWB Engineering for People Design Challenge has been used as a sustainability case study. Through a scaffolded programme of activities students have engaged in a real-life SD activity within the context of their degree disciplines and developed a set of core sustainability competencies.

Across the proposed challenge based ESD framework there are four major benefits for learners:

1. With a more authentic approach to assessment students are now participating in assessment that is expressly for the purpose of learning. Assessment plays an active role *in* the learning process rather than in a passive role *of* learning at completion.
2. Collaborative learning and working alongside the reflective nature of self-assessment processes put the agency of the student at the centre of the module and helps the students learn from each other, reflect on the learning practice of themselves and their peers and therefore deepen their capacity for self-motivated learning.

3. Assessments are structured and aligned so all activities in the module scaffold students through their learning, where one activity builds upon previous assessment and learning.
4. Consistency in the assessment approach and clear messaging creates an environment where gaining the intended LOs is an inevitable consequence of taking part.

From the experience of applying this challenge based ESD framework there are 4 key challenges in implementation that must be address to ensure the highest quality leaning experience possible:

1. It is important that ESD is introduced to students without overburdening the students (or staff) across a programme. It is therefore a challenge across all HE institutions to make room for activities supported by this challenge based ESD framework.
2. The activities of students in this framework are supported by staff mentors in weekly seminars. It is essential that all staff are proficient in ESD, indeed ESD is an emergent theme that is included in the new draft of the UK Professional Standards Framework (Advance HE).This means staff development needs to be properly considered and an associated overhead in the first iteration of delivery to ensure all staff are up to speed.
3. The assessment strategy utilised here relies on a level of assessment and feedback literacy (of students and staff). Assessment guidance must be clear and the process well signposted. The use of rubrics for students' self and peer assessment as well as staff assessment it highly promoted for this reason (Jonsson 2014).
4. When integrating self-assessment it is key that students are properly prepared to participate in the practice (Wride 2017). It is essential that students are given an opportunity to gain literacy in the approach and the benefits of self and peer assessment are explained and demonstrated (Harris and Brown 2013).

It is important that all in HE consider how to integrate ESD into our students' curricula. It is vital that in opening 1st year students up to the experiential learning opportunities of challenge-based ESD, that further opportunities for engagement exist throughout their University career. Students at Strathclyde have moved on from this project the VIP4SD programme (Strachan, Logan et al. 2022), meaning students have the opportunity to engage in challenge and research based ESD in every year of their degree. Therefore, offering a high-quality and holistic SD learning experience for our students and building a readiness for the workplace for them, tomorrow's engineers.

5.   ACKNOWLEDGEMENTS

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