EMBEDDING ENVIRONMENTAL SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT GOALS IN MECHANICAL ENGINEERING DESIGN PROJECTS

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Abstract: Mechanical engineering plays a significant role in ensuring a sustainable future, because embedding environmental sustainability in the higher education curriculum is of vital importance for increasing the awareness and enhancing students' capability to contribute towards sustainable development. This paper summarises our effort and experiences in introducing sustainability and the United Nation's (UN) sustainable development goals (SDGs) in a third-year project-based undergraduate mechanical engineering design unit at the University of Manchester. Each academic year, a new open-ended design task is being devised, with the main objective of creating novel design solutions for challenging and timely engineering problems. Throughout the semester the aspects of sustainability and SDGs are integrated into the unit through lectures and by blending relevant information into individual/group discussions.

Students are required to demonstrate their awareness and understanding of the environmental impact of their designs and the sustainability of the resources at all stages of the design process. Sustainability-related technical design specifications are included in the design brief, which allows for the students' designs to be assessed according to their environmental credentials.

Integrating sustainability and SDGs in the unit has not only increased students' awareness of the close relationship between design and environment, but also improved their engagement with the unit and interaction within each design group.

Keywords; environmental sustainability, sustainable development goals (SGDs), engineering education, design projects.

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1. INTRODUCTION

Global problems, such as climate change, require an immediate attention in higher education curriculum in order to develop new skills, values, competences and attitudes in graduate engineers. The 2030 Agenda for Sustainable Development clearly highlights the importance of education as an indispensable instrument in achieving the sustainable development goals (SDGs), as shown in Figure 1 (UNESCO, 2017). Mechanical engineering education plays a major role in equipping students with necessary tools to cope with the current and future global challenges and to promote sustainable development. In order to fulfil this potential, relevant intended learning outcomes (ILOs) and course contents must be developed and introduced in the curriculum.

This paper presents a case study of introducing sustainability and the UN's SDGs in a third-year, project-based undergraduate design unit at the University of Manchester. Embedding sustainability into the curriculum provides an opportunity to expand higher education's contribution to society by preparing informed and competent graduate engineers. The importance which the University of Manchester places on these aspects is evidenced by the commitments that have been set at the highest strategic level (Millard, 2022).

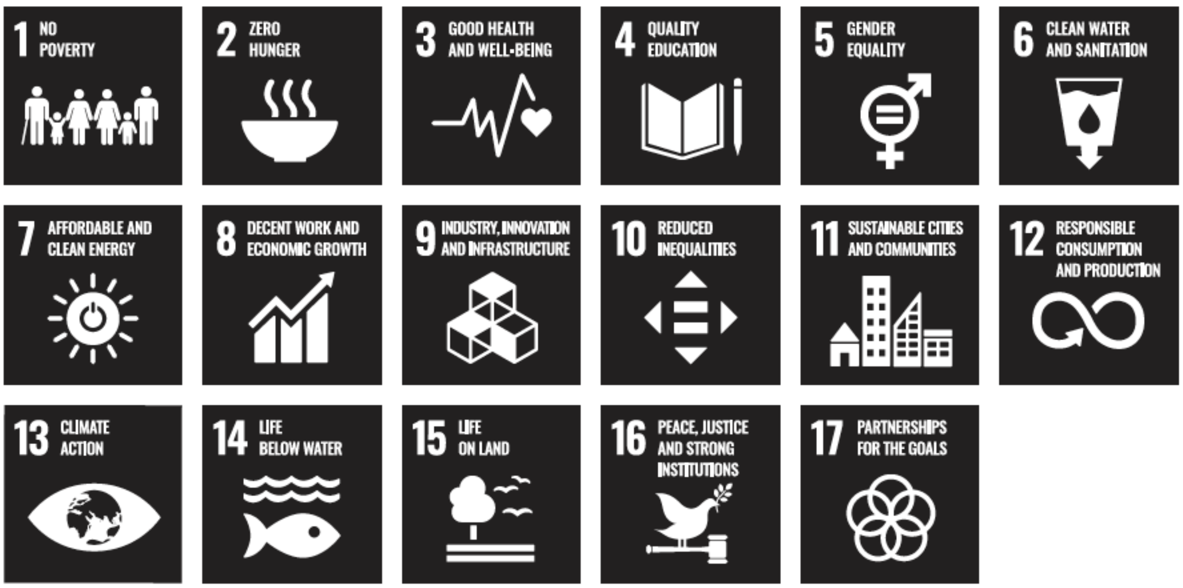

Figure 1. United Nation's Sustainable Development Goals (SDGs) (UNESCO, 2017).

In accordance with the University's commitments, an open-ended, real-life inspired and timely design challenge is developed each year and integrated into the curriculum of the so-called 'Design-3' unit. For example, during the outbreak of the Covid-19 pandemic, students were asked to develop test rigs for measuring the effectiveness of medical face masks. By targeting such global challenges, we aim to equip graduate students with an awareness and understanding of crucial subjects and essential skills towards a sustainable development (e.g., minimising the use of natural resources and considering the environment and sustainability of the resources at all stages of the design process) as well as helping students to develop employability-related transferable skills.

The Design-3 unit implements problem-based learning (PBL) methodology to develop the necessary skills to analyse and deal with real-life engineering challenges. It is well-known that PBL is an effective methodology for increasing student motivation, attention and retention rates, and students' awareness of sustainability (Biggs and Tang, 2011; Kolmos, 2021).

The following sections introduce the Design-3 unit, present details of an example of a design task and how both the aspects of environmental sustainability and the UN's SDGs were embedded into the curriculum and design process, and the analysis of the assessment.

2. METHODOLOGY

2.1 Outline of Design-3 unit

The aim of the Design-3 unit is to give students first-hand experience in designing a mechanical engineering device or system using a team approach, by utilising core course material assimilated in other units from previous years. This approach reflects the constructivist theory to learning and teaching (Brooks and Brooks, 1999; Biggs and Tang, 2011). According to this approach individuals construct their knowledge from active engagement and experience (Naylor and Keogh, 1999). In this unit, students work in small groups and act as an engineering design team tasked with solving a design problem. The intended learning outcomes (ILOs) of the unit are as follows:

1. Identify and understand the engineering principles appropriate to the design task, and acquire new knowledge where necessary.
2. Apply the design process to a new, open-ended problem with various functional, *environmental* and health and safety constraints.
3. Evaluate design ideas using a formalised method, and comply with standard procedures and design codes.
4. Use appropriate software for the design and modelling of an engineering component or system.
5. Apply (group) project management skills and produce technical reports.

In the UN's Education for Sustainable Development Goals Learning Objectives document (UNESCO, 2017), Education for Sustainable Development (ESD) is defined as an integral part of quality education. It is suggested that educational institutions including those in the tertiary education sector should consider sustainable development as their responsibility and support the development of sustainability competencies. As a response, amongst various supporting lectures sustainability related teaching and learning content aligned with the unit ILOs is included and assessed in Design-3 unit. This enables students to complement and demonstrate both specific competencies acquired in the core course materials and the transversal competencies (*competencies both related to the engineering degree and to the development of a critical citizenship* (Zamora-Polo et al., 2019) obtained in the Design-3 unit.

Continuous formative feedback was provided during the design sessions by answering students' questions on their design ideas, sustainability and SDGs, and through interactive group discussions on previous student submissions. Students had the opportunity to ask questions, interact with each other as well as the academics involved in this unit, and learn from the discussions through social learning (Biggs and Tang, 2011).

2.2. Embedding sustainability

Sustainability and SDGs were integrated in the unit during the semester by providing a number of lectures, blending relevant information into the individual/group discussions during face-to-face and online design sessions. Students were also provided with relevant materials via virtual learning environment (e.g., journal papers, textbooks, book chapters, videos of, for example, news and documentaries) for independent learning. General definition of sustainability, roles and responsibilities of design engineers on sustainability/environmental aspects of the design process, end-of-life product transformations (reuse, remanufacturing, recycling, combustion) were covered in the lectures and subsequent discussions. Eco-design principles (e.g., energy usage, material selection, recyclability, repairability) were also given a special emphasis to be considered in the design process. The ten golden rules developed for eco-design education (Luttropp and Lagerstedt, 2006) were introduced to students and extensive discussions on these rules held. Students were encouraged to integrate as many of those SDGs relevant to the design task as possible, including the impact on society and local communities, gender equality, sustainable agriculture, health and wellbeing, water resources, peace and justice, life below water and on land. As a result, students typically raised questions on the relation of these aspects to the design task and possible implications on their design decisions, which led to fruitful discussions.

Guidelines and/or principles developed by professional institutions were also used in the delivery of the unit. For instance, one of the four principles of the Institution of Mechanical Engineer's (IMechE) code of conduct is on promoting sustainability. According to this principle, engineers should engage responsibly with the environment by (IMechE, 2021):

- Recognising the importance of socioeconomic and environmental factors.
- Complying with obligations for health and safety and environmental protection.
- Taking account of the needs of a diverse environment, while never knowingly or deliberately exploiting natural resources.
- Balancing the needs of the present with the needs for future generations.

These principles were included in the lecture presentations because sustainability is a key subject aligned both with the University of Manchester's and IMechE's values.

2.3. A case study

The unit aims to develop comprehensive design tasks to ensure that students engage with a timely challenge by providing an engineering solution to a significant, global problem and, thus, making a positive contribution to the environment and society. For example, in the academic year 2021/22, the design task was to design an innovative technology to fight wildfires. This task was set in response to the fact that the world has been witnessing a dramatic increase in the number and extent of wildfires all around the world over the last few years, and it was felt by the academic team running the Design-3 unit that the students would be able to relate to such a design task, not only because of them having been made aware of the situation through the media, but also many students coming from countries that suffer from such wildfires.

A wildfire is defined as *'an uncontrolled fire in wildland vegetation, often in rural areas'* (National Geographic Society, 2022). They threaten the lives of people and animals, have a detrimental effect on air quality, crops, water supply and other resources, can interrupt transportation, communication and utility systems, and cause loss of property. It was reported that volcanic activity and wildfires globally caused nearly 2,400 deaths between 1998-2017 (WHO, 2022). The impact of such wildfires on a country and its population becomes obvious when considering the size that some of these have reached. For example, the 2019–2020 Australian bushfires covered an area of over 18 million hectares, an area equivalent to England and Wales combined, during which nearly three billion animals were killed or displaced (UNEP, 2020). Climate change appears to significantly increase the risk of wildfires mainly due to severe heatwaves experienced in several parts of the world. Even though wildfires can break out at various locations, increased temperature levels and reduced humidity associated with global warming have increased the risk of fire, in particular at higher elevations (Sadegh et al., 2021).

Wildfires have a significant impact on sustainable development, associated with all environmental, economic and social dimensions (Lang and Moeini-Meybodi, 2021). While they are directly related to seven of the SDGs (Goals 1-3, 6, 13-15), wildfires and their consequences can be associated indirectly with all the 17 Goals considering the transitivity of the negative impacts on the ground, air and water mediums (Martin, 2019).
Despite the efforts and progress made with regards to tackling climate change (COP26, 2021), the increased risk of wildfires at higher elevations requires devices that can operate in mountainous terrain. Several complex firefighting devices have been developed over the past decades, some are benefiting from cutting-edge technology such as robotics, artificial intelligence, and unmanned aerial vehicles (UAVs). However, the increasing extent of wildfires indicates that current technology is far from being sufficient to containing these wildfires. In response, a design task was formulated, and students were tasked to develop a novel firefighting equipment that provides improvement over the existing technologies.

2.4. Assessment
The assessment of this unit is in the form of two submissions, an interim report (submitted after 5 weeks) and a final report due in the last week of teaching term. Both reports are expected to reflect on the aspect of sustainability of their proposed design(s) in order to ensure that the students have engaged with and acquired an understanding of it. The assessment is aligned with the ILOs and with teaching and learning activities, in the sense that it is reflective and supports the learning process (assessment for learning) (Kolmos, 2021). The group-based nature of the assessment facilitates teamwork and strengthen research skills, supports peer- and self-assessment by encouraging engagement, and empowers students to monitor their own learning process (Biggs and Tang, 2011). Group work encourages students to be collaborative, proactive and reflective, as they need to work as part of the group, distribute workload and provide ongoing feedback to other group members. Moreover, the timely nature of the assessment and the fact that it represents a real engineering problem, simulates a potential employment environment and helps to increase students' motivation to learn by resolving a pressing contemporary engineering challenge.

For the interim report, sustainability was integrated into the design evaluation process for selecting the final design to be developed further. Students needed to apply a logical and systematic approach in the selection and evaluation of the design concepts developed by each group member using Pugh charts (Pugh, 1991). They had to explain the reasons for allocating the marks and weightings assigned to each individual design concept. Sustainability related selection criteria included in the design evaluation process were:

- Level of environmental friendliness, and
- Level of sustainability.

For the final report, each group needed to provide a justification on how their selected final design achieved the following technical requirements:

- The device must not cause any long-term contamination of the environment in which it operates.

- Eco-design principles (e.g., energy usage, material selection, recyclability, repairability) must be used to demonstrate the environmental and sustainability awareness during the design process.

3. RESULTS AND DISCUSSION

Assessing both the interim and final reports revealed promising evidence that students were able to identify a variety of links between their design ideas and processes and relevant SDGs. They and were able to offer innovative and alternative design solutions to reduce negative impacts of their idea(s) on the environment. The reports submitted demonstrate that the majority of students were able to conduct research on sustainability, utilise engineering knowledge and understanding acquired during other core course units, present their design ideas effectively, and develop SDGs-related specific competences. In addition, transversal competences were demonstrated such as critical thinking, research-based creative technical writing, and the ability to recognise the impact of their decisions. Including the aspect of sustainability had a positive impact on the students' awareness and understanding of the role it plays within a design task. Informal discussions with students revealed that the aspect of sustainability within the design unit enriches the syllabus and enhances their appreciation of design as a discipline.

The responses received from the students indicate that the SDGs related to health and safety (SDG 3), climate change and its impacts (SDG 13), conservation and sustainable use of marine and terrestrial ecosystems and biodiversity (SDG 14 and 15), and the sustainable use of water and sanitation (SDG 6) are considered to be of highest importance. In contrast, the SDGs related to global partnership (SDG 17), decent work, industrialisation and reducing inequalities (SDGs 8-10), gender equality (SDG 5), and the promotion of peace and justice (SDG 16) are less frequently mentioned or not mentioned at all for this specific design task. Even though all the SDGs were discussed during lectures, including the provision of examples of how they could be associated to the design task at hand, it is possible that several students were less sure about such connections, or were under the impression that other SDGs are significantly more important. This potential lack of understanding of the wide range of diverse aspects related to sustainability could be addressed by devoting more time to this topic in future years.

4. CONCLUSIONS

Based on the assessment of reports and student feedback, it appears that embedding sustainability in the curriculum of the Design-3 unit increases students' awareness of the importance that sustainability plays within the context of mechanical engineering design. Moreover, it also made students aware of the multi-facetted nature of the aspect of sustainability, which includes, amongst others, gender equality, poverty and biodiversity.

The assessment results, however, suggest that not all aspects are equally easy to identify, resulting in some aspects, e.g., climate action, to be mentioned more often than others, e.g., gender equality. This should be used as an opportunity for developing the curriculum further, thereby ensuring that all students fully understand the multi-facetted nature of the term sustainability. It should also be used to devise design tasks that require as many aspects as possible, ideally all aspects.

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