Embedding sustainable development into engineering education: showcasing a practice within an energy engineering module at NMITE

Embedding Sustainable Development into Engineering Education: Showcasing a Practice Within an Energy Engineering Module at NMITE

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Abstract

This paper aims to showcase a pedagogical approach to embedding sustainable development into engineering education based on the practice within a module at the New Model Institute for Technology and Engineering (NMITE), Hereford, United Kingdom. It is an innovative institution with the aim of disrupting engineering education, for efficient transmutation of students into engineering managers who would be work-ready and world-conscious imminently upon graduation. Based on a concise literature review conducted, energy and thermo-fluid contents are being leveraged to embed sustainability in higher education curricula, although their true impacts, in terms of learnings that students can translate into real-world practices, are yet to be quantified adequately. Thus, more research is needed to describe real practices in energy engineering modules, for systematic measurement of the qualitative/quantitative effects of sustainability embedment in them, which has necessitated this paper. Conscious efforts were made at the start to gauge students' prior knowledge in an Energy Engineering module delivered to FHEQ Level 5 (Second Year) students, via in-studio interactions and polling. A mix of evidence-based pedagogies were then adapted innovatively to deliver the module contents. In particular, the flipped-classroom, peer-instruction, problem-based learning and research-based learning approaches were intertwined for the delivery of the module syllabus, in a classical block model. Authentic assessments were leveraged specifically to spur students' awareness of sustainability issues and their responsibilities as future engineers. In the essay assessment, the students identified at least three hard-to-decarbonise industries and discussed the current roles and future potentials of some highlighted sustainable energy technologies in abating carbon emissions in those industries. In another assessment, a Design Proposal with Justifications, an industry partner presented a challenge to the students, as is the case with most modules at the Institute, aimed in this case at introducing the students to the energy trilemma within a typical food manufacturing plant and possible strategies to improve energy efficiency and reduce carbon emissions. Objective analyses of the students' works and results of a post-module survey revealed that real learning had taken place around energy recovery and equipment optimization in an industrial process, for enhanced energy efficiency and decarbonisation. Specifically, based on the survey with responses from 20 out of the total 26 module students, an average of 76% of the respondents rated the quality and depth of the knowledge acquired to be outstanding, about 75% considered their exposure to the industry excellent, while about 73% attributed the assessments set to be fit for purpose, which again were aimed at embedding sustainability in engineering education. In sum, embedment of sustainability in engineering education could be enhanced by setting real assessments that expose students to sustainability issues, giving them ample opportunities to reflect on their roles and responsibilities in tackling such issues in the real world.

1 Introduction

The New Model Institute for Technology and Engineering (NMITE, hereinafter referred to as the Institute) is a relatively new Higher Education Institution located in Hereford, with the aim of disrupting engineering education, to facilitate efficient transmutation of students into work-ready and world-conscious engineering managers. There are no lectures or lecture theatres. Teaching activities are primarily organised in studios with a maximum of 30 students per time. Here, students engage in active learning via seminars, workshops, debates, presentations, brainstorming sessions, etc., working in teams (of between 4 & 6) and individually. Each taught course module is worth 30 credits and is delivered in a block format over 8 weeks. To simulate real work environments, there are no traditional exams. Assessments take diverse forms such as presentations, technical reports, business plans, artefacts and artefact demonstrations. Sustainability is inherently embedded in the Institute's pedagogy (NMITE, 2025).

Sustainability is recognised as one of the most daunting challenges confronting humanity in the 21st century (Ramísio et al., 2019), and its embedment into higher education engineering curricula has attracted wide attention in recent times within the pedagogy research space (Gutierrez-Bucheli et al., 2022; Thürer et al., 2018). The reason for this is not farfetched, several scholars agree that engineers can only innovate to meet future societal needs if they are able to think critically beyond pure technical requirements of their designs and inventions (Egelund Holgaard et al., 2016). In fact, contextual awareness has been recognised as a critical part of modern engineering education, requiring a comprehensive integration of technical/scientific, socio-economic, legal and cultural aspects into broad views of actions, problems, solutions, and consequences (Staniškis & Katiliute, 2016). Three main approaches are being adopted in the state of the art to embed sustainability into engineering education, including embedding the concept of sustainable development into regular disciplinary courses, design of new elementary courses, and providing students with the option to graduate in a sustainable development specialization (Thürer et al., 2018). Although creation of new elementary courses and providing a graduation path in sustainable development are the most adopted approaches in core sustainability-related programmes, embedment in relevant existing courses is also growing and it must continually be explored to educate engineers to develop adequate skills and passion for sustainability (Thürer et al., 2018).

Several studies in the literature sought to leverage traditional thermodynamics and energy-related contents in higher education engineering curricula to embed sustainability. Recognising the paradigm shift globally in the energy sector, which continues to witness steep increase in renewable energy penetration, and the urgent need to comprehensively address sustainability concerns, Riuz-Rivas et al. (Ruiz-Rivas et al., 2020) underscored the need for revisions of energy engineering curricula, to focus on developing engineers capable of addressing current and future climate-related problems. Pailman and de Groot (Pailman & de Groot, 2022) proposed a framework for advancing SDG 7 on clean and affordable energy using an empirical case study of the Transforming Energy Access Learning Partnerships (TEA-LP), focusing on the development of energy-related master's programmes across eight African universities. Malkki et al. (Mälkki et al., 2015) proposed a new index, tagged relevance ratio (RR), useful for defining the relative weight of selected topics in a degree curriculum and able to reveal the strengths and weaknesses of such contents in the curriculum. The index was applied to appraise the level of integration of renewable energy and sustainability topics in the energy degree programme of Aalto University in Finland. The necessity for further research was highlighted as the study's conclusion, to explore the possibilities of entrenching more realistic working life skills into the learning paths of students as part of sustainability embedment into engineering curricula. Furthermore, Ott et al. (Ott et al., 2018) proposed a tentative approach that could facilitate the inclusion of solar energy education into the framework of the socio-cultural theory for learning, to advance sustainable practices in the society. Other energy-linked active steps are identifiable in the literature, aimed at promoting sustainability within engineering curricula, such as the development of partnerships on sustainable energy among engineering faculty, students and public/private entities (Pacheco et al., 2019).

It's clear from the foregoing that energy engineering in higher education is a credible tool for embedding sustainability. However, it's not obvious how such embedment has been able to impact future engineers over the years, in terms of learnings in energy modules that they're able to translate into real-world practices. Thus, more research is needed to describe real practices in energy engineering modules, including contents and delivery approaches, assessments and external engagement activities, for systematic measurement of the qualitative/quantitative effects of sustainability embedment in such modules. To that effect, this paper aims to showcase the practice within the Energy Engineering module at the Institute, and to describe the perceived impacts of such practice on students' awareness of sustainability.

2 Module Contents, Delivery, and Assessment

2.1 Cohort Description and Prior Knowledge

As aforementioned, the Institute operates a block delivery model for its mainstream Integrated Engineering programme. This implies that students learn one module per time (in block), and a typical FHEQ level comprises of 4 blocks. The Energy Engineering module being described here was at the second block of FHEQ Level 5, meaning that it was the sixth module the Cohort had taken in their academic journey at the Institute. The Cohort had 26 students going into the Energy Engineering module. The first 4 modules they learned at FHEQ Level 4 were aimed at introducing them to fundamental integrated engineering principles, designed around knowledge and skills required of a 21st century engineer, statics and dynamics of simple mechanisms, fundamentals of analogue and digital circuits, and thermodynamics and fluids. Next to that, the Cohort had an opportunity in the first block at FHEQ Level 5 to integrate their prior learnings to tackle real-world design challenges in a module entitled Creating Social Values through Engineering.

Although the students had encountered some fundamental principles of thermodynamics and fluid mechanics at FHEQ Level 4 and the initial discussions within the Energy Engineering modules showed some awareness of the multi-dimensional energy and environmental sustainability challenges confronting the world, they had little or no knowledge of how to harness understanding of thermodynamics and related topics to contribute meaningfully to solving real-world challenges. Besides, students perceived most of their prior knowledge on thermodynamics and energy-related topics to be abstractive, with little or no appreciation of their real-life applications.

2.2 Module Contents and Delivery Approach (Pedagogy)

The module has a syllabus typical of any undergraduate energy engineering module, comprising topics such as the thermo-fluid conservation principles, heat transfer principles, power and refrigeration cycles, energy sources and systems, power/energy equipment, amongst others. Additionally, unconventional topics on the applications of mathematics to engineering problem-solving are included in the syllabus, due mainly to the integrated nature of teaching mathematics at the Institute, which focuses on applications rather than theories (Knight et al., 2024).

Furthermore, the syllabus contains other unconventional aspects around energy systems as exemplars of integrated engineering and complex problems, contributions to sustainable development goals, amongst others. This is primarily to promote the Institute's Graduate Attributes that aim to produce work-ready and world-conscious engineering graduates, thoroughly exposed to industrial real-life problems and able to contribute meaningfully to solving them imminently upon graduation.

Several evidence-based pedagogies were adapted to teach the module contents. Specifically, the flipped-classroom (Castedo et al., 2019) and peer instruction (Mazur, 1997) approaches were blended to teach the necessary theoretical principles, while problem-based learning (Yew & Goh, 2016) and research-based learning (Arifin et al., 2022) approaches were leveraged to spur the students towards critical thinking, information gathering, and reflective thinking, while working with industry partners to tackle real-world problems.

To expose the students to fundamental scientific concepts in the syllabus, seminar and tutorial materials prepared by the instructors, including presentation slides and notes, were presented to the students well in advance of a scheduled instructor-led session in the studio, and independent study times were built into the studio schedule to allow students to attempt to learn the contents actively prior to their contact time with the instructor. Then, during the instructor-students contact time, a quick review of the topic is provided basically by using class participation questions, which are quizzes that students respond to, individually first, followed by some peer discussions, before attempting the quizzes another time as proposed by Eric Mazur (Mazur, 1997) in his famous peer instruction pedagogy approach. The slight difference introduced here was building self-study time into the nominal learning schedule of the students, made possible by the block delivery model operational at the Institute. No statistics is available yet, but this would be expected to contribute meaningfully to addressing a common challenge with the peer instruction/flipped classroom method in traditional universities, where large number of students fail to engage with the necessary materials prior to classroom sessions.

For the research-based learning approach implemented, the instructors would typically signpost students to several relevant published contents, including conventional research articles, technical reports, blogposts, etc., and students would be tasked to research on several themes relevant to the course materials, sometimes individually to prepare them for a summative assessment that required them to report literature findings (described hereunder), and other times in their teams to prepare them for formative assessments such as team presentations and debate.

Additionally, students were presented with a well-rounded, real industrial challenge (detailed hereunder) at the start of the module, which was a summative assessment worth 45% of the entire module mark, involving analysis of energy flow within a nearby chocolate production crumb plant and design of an improved process to enhance energy efficiency and environmental sustainability within the plant. To prepare the students for this assignment, several smaller problems were defined for them to tackle within the module, as part of the delivery, with regular direct feedback given by the instructors during studio sessions.

2.3 Module Assessments

Students' learning in the module was assessed using 3 distinct summative assessments, although several formative assessments (termed, "directed activities") were equally set to enhance learning.

The first summative assessment was an essay, aimed at assessing students' ability to synthesize technical and academic literature to inform critical evaluation of the sustainability of different energy systems, emphasizing the societal responsibilities of engineering. Students were to evaluate the advantages and disadvantages of applying renewable energy sources and technologies (such as biomass, hydrogen, geothermal, solar, wind, energy storage and hydropower) in manufacturing industries with high-temperature processes, which are difficult to decarbonize and still predominantly powered today by fossil fuels. Their analysis should consider the technical, economic, environmental, societal, and health/safety implications of applying these energy systems. The first specific task was for students to identify, through a concise literature review, at least three manufacturing industries where conventional energy systems powered by fossil fuels are still predominantly in use because of the increased difficulty in utilising renewable energy technologies to meet energy demands. Next, they were to identify, through a literature survey, relevant technical or academic articles that assess the possibilities of using biomass, hydrogen, geothermal, solar, wind, and hydropower energy systems in any of the hard-to-decarbonize industries identified earlier. Next to reading and succinct summarization of the relevant articles, students were to discuss the merits and demerits of using biomass, hydrogen, geothermal, solar, wind, and hydropower energy systems in hard-to-decarbonize manufacturing industries, emphasising the technical, economic, environmental, societal, and health/safety risks implications of each of the energy systems/sources. They were to clearly argue for, with justifications, any of the specified energy technologies as the most viable option in this context.

The second summative assessment was a controlled tutorial questions, where students were tasked with solving case study problems on power generation using conventional steam power plant operating on the Rankine cycle, and design of an off-grid solar photovoltaic system to satisfy specified load requirements. This assessment was also used to assess understanding of other basic concepts around heat transfer and quantification of useful energy (exergy) in a power plant.

Finally, the third summative assessment was used to introduce the students to a real-world problem, set by an external industry partner (client) as is the common practice at the Institute. Specifically, the design proposal with justification assessment had the main aim of introducing the students to the energy trilemma within the food manufacturing industry. The client was present on the first day to present process flow diagrams to the students that illustrate the flow of energy and materials within a chocolate crumb production plant, which they believe needs improvement. The client had given a general task to the students to study and analyse the manufacturing plant to identify opportunities for reducing energy consumption/carbon footprint and based on this analysis, to design an improved process that would also satisfy other production constraints such as product throughput and quality. In the first specific task, students were required to study carefully the given process flow diagrams and the factory energy balance data illustrating how energy is sourced and used plantwide. Using these data and making necessary assumptions, they were to estimate the existing heating, cooling, and vacuum utility demands of the process, as well as the associated carbon footprints. In the second assignment specific task, students were to analyse the process data with the view to identify opportunities and quantify energy efficiency improvement and decarbonisation inherent in the process material streams using industry-standard analytical tools. Students were then required in the third specific task to propose at least three conceptual design options for improving the manufacturing process, based on the identified energy efficiency improvement and carbon footprint reduction measures. Additionally, they were to narrow down to one design choice with detailed justifications, while also deploying appropriate model equations and digital tool(s) to size and select any one heat transfer equipment involved in the selected improved process.

3 Summary of the Real Learning Observed and Impacts on Sustainability Awareness of the Students

Quality of the submitted pieces of work and students' performance in the formative and summative assessments were analysed, to attempt to measure real learning that took place within the module and its impacts on students' awareness of sustainability practices.

For the first summative assessment (guided essay based on literature survey), compelling submissions were made by the students, identifying industries such as the steel production, glass production, cement production, and several other relevant ones to be hard-to-decarbonize, while citing relevant justifications for such submissions. Additionally, several students had discussed very well the relevance of the different energy systems highlighted in the brief to abating emissions in their identified hard-to-decarbonize industries, citing relevant literature to support such discussions. It was especially interesting to read about real-life examples in some cases, where the different energy systems are being applied within the relevant manufacturing industries across the globe. Furthermore, several students compared very well the applications of each of the energy systems under review across the three hard-to-decarbonize manufacturing industries they had identified, with some of the evaluation focusing not only on the technical perspectives, but also discussing adequately the socio-economic, environmental, and health/safety implications of applying each of the energy systems under consideration within the different industries.

Similarly, some good learning applicable to real-world situations were observed in the second summative assessment, with students able to provide easy-to-read analysis of how to compute different power plant parameters for a given case study, as well as sizing and selection of solar photovoltaic system components needed to satisfy given load requirements subject to local solar irradiation conditions.

Also, the team reports submitted at the end of the third summative assessment described above consolidated on how much the students learned about energy recovery and equipment optimization within an industrial process, to enhance energy efficiency and decarbonisation. In about 4 out of the 5 teams, students demonstrated good knowledge of how to estimate utility demands and carbon footprints in a process plant, including production of relevant graphical illustrations of all the key processes. For instance, technical tools such as the Sankey diagram typically used for illustrating energy flow within process plants were commonplace in the students reports. Suffice it to mention that, based on the reports submitted, most of the students at the end of the module demonstrated satisfactory appreciation of some real-life applications of basic thermo-fluid principles, for example on the use of basic heat equations and the energy balance principle to perform detailed pinch analysis that enabled identification of opportunities for energy improvement within the given process. Other technical details in most of the reports submitted that showed good learning include: adequate development of several design concepts and presentation of engineering reasoning behind such concepts, backed by technical information such as the composite and grand composite curves obtained from pinch analysis; satisfactory design (sizing/selection) of heat transfer equipment in their final process, mainly a heat exchanger, with the aid of any digital tool (mostly SolidWorks in this case).

Based on a final module survey conducted, with responses from 20 out of the 26 module students, an average of 76% of the respondents rated the quality and depth of the knowledge acquired to be outstanding, about 75% considered their exposure to the industry to be excellent, while about 73% attributed the assessments set to be fit for purpose, which again were aimed at embedding sustainability in engineering education. Although more data would be required to back this, the practices and experience within the module being reported here suggest that sustainability could be very well embedded in engineering education by setting real assessments that expose students to sustainability issues, making them to reflect on their roles and responsibilities to tackling such issues in their professional practice post-graduation.

4 Conclusions

The pedagogical approach adopted within the Energy Engineering module at the Institute has been described in this paper, to showcase a way of embedding sustainable development into engineering education. Although several authors had attempted over the years to leverage energy-related topics in higher education engineering curricula to raise sustainability awareness in future engineers, their real impacts aren't quite clear yet, thereby necessitating further research with the aim of gauging and describing such impacts. Thus, this paper reports not only the content, delivery approach and assessments set within the Energy Engineering module in focus, it also attempted to describe the Cohort the module was taught to in terms of their perceived knowledge of the technical and sustainability issues before and after the module. Analysis of students' submitted work revealed that majority of them had learned vital sustainability concepts within the module, based on their awareness of hard-to-decarbonize industries and roles of some sustainable energy sources, in one of the summative assessments. Furthermore, submissions in another summative assessment made explicit the application of advanced technical tools to analyse energy generation systems for given case studies and to propose viable means of improving energy efficiency and reducing carbon footprints in a real manufacturing plant which they had interacted with and visited during the course. A post-study survey was conducted to collect data on the perception of the students on their learning experience and results revealed satisfactory outcome in terms of the quality and depth of the knowledge acquired in the module, exposure to real-life industry problems, and the adequacy of the assessments set in raising their awareness of sustainability and their roles in promoting sustainable practices.

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