The Contemporary Engineer: Developing Sustainability Attributes and Transferable Skills through Open-ended Activities

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Abstract

An essential aspect of engineering education is the provision of core competences in discipline specific knowledge and its application. Added to this, engineering education must equip its students with a range of transferable skills in order to facilitate their working within a variety of organisations, skills which are much valued by employers. Critically for the 21st century, engineering graduates entering the workforce must be equipped with knowledge and competences in sustainability / sustainable development, as this is becoming more and more important within organisations. More importantly it is an existential imperative for humanity, which is of particular relevance to young people, including newly graduated engineers who must be equipped with sustainability knowledge and competences to effectively contribute to the good of a society that needs to transition to a sustainable pathway. Such competencies are also required by professional accreditation organisations. This may require paradigmatic change in how we view both our profession and the world we inhabit.

This paper briefly highlights a number of proposed sustainability related skills and competences. It then focuses on the development of these through open-ended activities and problems. This is based on the active learning premise where students achieve better quality learning by actively doing things themselves. The paper outlines four examples of activities undertaken at University College Cork and at the University of Seville. They include a transdisciplinary group exercise, environmental consultancy role-play, sustainability / environmental debates, and converting a closed well-defined problem into an open-ended one followed by the addition of layers of complexity and holistic considerations. It highlights the learning outcomes, transferable skills and sustainability knowledge and competences that students may obtain from undertaking the highlighted activities.

Keywords: sustainability competences; transferable skills; open-ended activities; graduate attributes

1 Introduction

Conceptions of progress should be guided from a broader sustainability perspective rather than from a traditional perspective based on technologically enhanced efficiency and economic growth, worldviews which have served to exacerbate the contemporary crisis of unsustainability around so many issues including climate, biodiversity and energy (Byrne, 2017). The latest UN Environment Programme Emissions Gap Report (UNEP, 2019) warns that there is even still 'no sign of GHG emissions peaking in the next few years'. As a result of our continued inaction, 'deep and rapid decarbonization processes imply fundamental structural changes are needed', accompanied (paradigmatically) by 'deep-rooted shifts in values, norms, consumer culture and world views [which] are inescapably part of the great sustainability transformation.'

Byrne and Fitzpatrick (2009) previously argued for sustainability as a contextual lens for the formative education of chemical engineers. This requires active engagement with other disciplines and with wider society, and an elevated sense of 'contextual awareness' (Staniskis and Katilute, 2015), all in the wider context of increasingly elevated levels of societal and technological complexity, uncertainty and interconnection (Byrne and Mullally, 2014). Consequently, the contemporary engineer requires competences not just in the 'knowledge' domain ('the data base of the professional engineer'), but also that of 'skills' (analysis, communication, leadership, teamwork), and 'attitudes' of the profession, the values based the ethical framework of professional practice (Rugarcia et al., 2000; Jansen et al., 2008). Within this framework, graduate engineers require sustainability knowledge, skills and values. The successful incorporation of all these components into the curriculum necessarily requires more student-centred teaching/learning approaches, for example, through the use of open-ended activities. This can help students in the making of decisions taking into account the social, ethical, and sustainability related consequences of those decisions. This conception increases the expansive role that engineers can play, not just in addressing complex problems with societal and natural dimensions, but also in *framing* such problems (applying context and values). The aims of this paper are:

1) To highlight the need for engineering graduate attributes with enhanced sustainability oriented transferable skills, competences, and values, so as to enhance their employability and value within a society that is necessarily transitioning towards a sustainability informed paradigm.
2) To highlight and promote the key role that the application of open-ended activities and problems can play in engineering education to help better develop all the above, including to enhance the development of core engineering technical competencies.

2 Graduate attributes for employment in a society transitioning to a paradigm of sustainability

Contemporary engineering graduates must acquire the requisite disciplinary knowledge, transferable skills, professional values (through a sustainability informed context and lens) for a successful career and valuable contribution to both the organisations in which they work and society as a whole. This facilitates a sort of virtuous circle, as illustrated in Figure 1, resulting in a professional cohort and profession which is both more relevant to its society and its employers, while also demonstrating enhanced attractiveness to potential recruits.

The graduate attributes of a contemporary engineer are schematically presented in Figure 2. At its core is a engineering graduate who must possess a core competence in their discipline-specific engineering knowledge and its application. This has always been a key remit of engineering and will always remain so. In the contemporary workplace however, employers desire graduates that are also well equipped with a variety of transferable skills (for example, as outlined in Table 1). They also require engineers who engage with, reflect on and display professional values around safety, societal wellbeing, product and process quality, and sustainability.

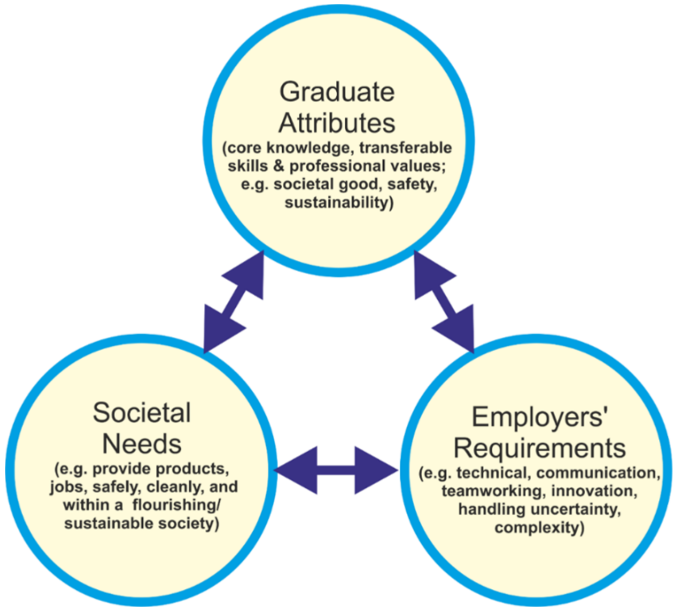

Figure 1: Coherence between graduate attributes and employers and societal needs

Now and in the future, employers require graduate engineers who demonstrate sustainability attributes (for example, as outlined in Table 2) across each of the domains of core knowledge/competences, transferable skills and values. This bundle of overarching graduate attributes all can (and do) thus feed into both employer's requirements as well as wider societal needs (Figure 1).

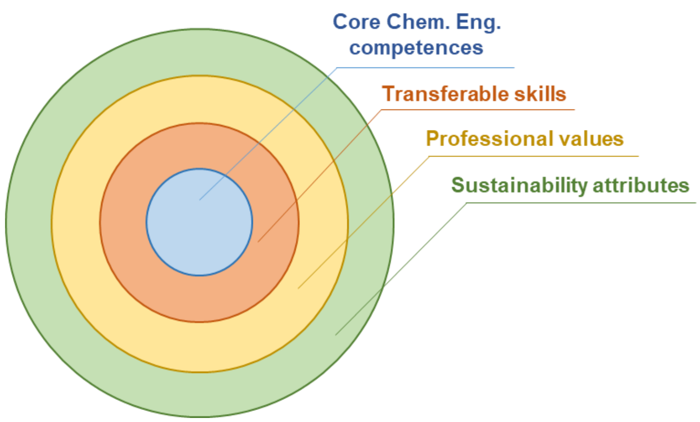

Figure 2: Graduate attributes of a contemporary engineer

Employers require graduates with requisite technical expertise and depth of knowledge, but also capable of engaging in teamwork, employing excellent communication skills (with both technical and non-technical audiences) and are capable of handling increased levels of uncertainty and complexity. Society requires engineers who solve engineering problems, but in a way which does so safely, cleanly and without environmental degradation to the benefit of society most broadly (and equitably); essentially, proactively contributing towards a flourishing society.

Engineering is intrinsically about trying to do good for society by facilitating the provision of goods and services that can make people's lives better; this is why many of us decide to become engineers! As we progress through the current century, just the third since the onset of the industrial revolution, there is a real worry about the unsustainability of our current dominant global techno-economic system and its impact on humanity itself and the ecological life support systems which envelop us. Consequently, the advancement of human flourishing itself has become a major contemporary concern, if not the dominant concern.

Table 1: Desirable transferable skills of a contemporary engineer

Communication	Life-long learning
Dealing with complexity / uncertainty	Problem solving / innovation
Entrepreneurial	Research skills
Information technology	Team working
Knowledge acquisition	Time management

This impacts on engineering (and engineering education) because engineering is about contributing to societal good, and to do so over time. Thus, sustainability related knowledge and values, as well as the ability of engineering to contribute to human flourishing is rapidly becoming a contextual lens or overarching paradigm through which engineering education can be posited, as illustrated conceptually in Figure 2. Furthermore, for business, employers and young people, sustainability is becoming more critically important.

Table 2: Some sustainability attributes of a contemporary engineer

- Knowledge and understanding of the sustainability issues and challenges.
- Ability to develop appropriate greener technologies, processes and approaches
- Ability to apply relevant transferable skills (Table 1) towards sustainability goals/contexts
- Sustainability values (*e.g. concern for the environment, commitment to sustainable development and social justice, empathy*).
- Deep appreciation of the importance of the social, ethical, ecological and economic dimensions of sustainability, and the interconnectedness of each.

A fit-for-purpose contemporary engineering graduate must acquire the requisite disciplinary knowledge, transferable skills, professional values and sustainability attitudes for a successful career and valuable contribution to both their enterprises and society. This requires an explicit reaching out and structural embedding of transferable skills, professional values and overarching sustainability attributes within and across our programmes as well as through the traditionally well-covered domain of instrumental knowledge, all in an integrative fashion. More explicitly, a pedagogical approach based on creative open-ended activities and problem solving is proposed as a means of enhancing technical competences as well as developing requisite transferable skills, professional values and sustainability attributes. For the most part, this can be delivered through relevant and bespoke continuous assessment exercises, as employed both extensively and progressively throughout the programme. In this light, the following section focuses on application of open-ended activities for the enhancement of technical competence, and development of transferable skills, professional values and sustainability attributes under a broader sustainability context and ethos.

3 Application of open-ended activities to help develop transferable skills and sustainability attributes

This section provides four examples of open-ended activities and problems from the Chemical Engineering Departments at University College Cork and University of Seville. These are presented to show how the aforementioned attributes, skills and competences can be developed and enhanced through open-ended activities and problem solving. These activities have many different facets that students have to think about, such as technical, environmental, ethical, economic and social, and are mainly carried out as group exercises.

3.1 Transdisciplinary sustainability assignment

This assignment brings together third year students of the chemical engineering module on sustainability and environmental protection with students on an analogous but separate third year module on 'Sociology of the environment', taken by sociology and government students. This novel arrangement also facilitates the bringing together of visiting students (taking each of the modules) on a transnational basis - including from Brazil, Denmark, Germany and USA. The task is for mixed groups (of chemical engineers, sociologists and government students) to frame, consider, research and present on some chosen aspect of sustainability, for example "the socio-environmental impacts of plastics"; "concepts of progress"; "sustainability in terms of consumerism and consumption" (see Byrne and Mullally (2016) for a detailed description). The exercise has resulted in some inspiring and innovative insights while transcending disciplinary silos in an ethos of open transdisciplinary. The following respective student comments on the exercise help elaborate their insights:

> *'working in a team with vastly different opinions is hugely valuable to our careers in the future' / 'a major learning point was taking on board alternative perspectives of problems, outside of engineering solutions.' / a 'transdisciplinary approach was enlightening; [an] engineering solution isn't always the only option' / and from a sociology student: I learned 'that it's harder than I had thought to find perspectival common ground between different disciplines – so this needs to be encouraged more across the university!'*

In this assignment the transferable skills and sustainability attributes developed by the students include inter/transdisciplinary work, communication, empathy and change of perspective, and critical thinking.

3.2 Environmental consultancy assignment

This is a group "role-play" assignment where each student group has to imagine themselves as employees of an environmental consultancy firm who are sent to provide consultancy to an organisation whose senior management representative is 'role-played' by the lecturer. The organisation could be a chemical processor or some other organisation such as a bank or a hotel, and some basic information is provided about the organisation. The senior management representative is somewhat environmentally conscious and has heard that an environmental management system (EMS) approach could help the organisation improve its environmental performance. He has heard of the environmental consultancy firm and has made some initial contacts. As a consequence, the student group has been sent as a team of environmental consultants by their firm to make a fifteen-minute presentation to the senior management representative of the organisation, followed by questions, answers and discussion.

The objectives of the group presentation are:

1. To explain to the senior management representative what an EMS is, and to enlighten him as to why he should seriously consider implementing an EMS in his organisation.
2. To outline the environmental performance issues for the organisation and to provide a rough outline of a plan of activities that could potentially improve environmental performance, while also including a business case for the plan.

The grading is based on both individual and group performance, and the quality of the slides presented. The assignment helps students develop a greater understanding of aspects of environmental sustainability in the context of an organisation. This is achieved by demonstrating an understanding of the implementation of an EMS in an organisation, and by creatively innovating ideas for activities that may help an organisation improve its environmental performance, while recognising both business opportunities and costs. The assignment helps each student enhance their team working skills and communication / presentation skills. Finally, the students gain an initial experience of working and thinking as an environmental consultant, officer or manager, which could influence them in their future careers.

3.3 Environmental/Sustainability debates

Student environmental/sustainability debates are held on topics of environmental/ sustainability interest that are somewhat controversial, such as "Nuclear fusion is an energy "holy grail" with widespread use by 2050"; "Human impact on biodiversity should be of major concern to humanity"; "Carbon capture, storage and utilisation will be a very important approach in the fight against climate change".

The students are divided up into teams where one team prepares and debates the pros side of the topic and the other the cons. The students are encouraged to investigate the topic from a broad perspective, which includes any economic, ethical and social issues in addition to environmental and technical. The first phase of the assignment requires students to research the topic and then each student must post a comment to an on-line discussion forum. Then, the students consider the comments posted on their debate and then each student posts a second comment, which may be a rebuttal to comments made by the other team. This process helps build up information on both sides of the debate. This acts as the basis for the debate itself, whereby each group must summarise their side of the debate and give a five-minute oral presentation during a regular class session. For each debate, there is five minutes for the pros, followed by five minutes for the cons, followed by five minutes of questions and discussion. Each group must then submit a final group written report, which has the following three parts: 1) summary of their side of the debate, 2) summary of the opposition's side, and 3) their final balanced opinion on the topic of the debate, considering both the pros and cons.

The assignment helps the students develop their ability to comprehend, present, argue and discuss issues of relevance to environmental protection and sustainability. The students are strongly encouraged to understand and appreciate the arguments made by the opposition and that trying to form a balanced opinion is very important is this assignment. This highlights that many environmental and sustainability issues are complex and multifaceted and that they need to be open to and appreciate the complexity and multifaceted nature of these issues.

3.4 Converting a closed-ended problem into an open-ended problem with additional layering of complexity and holistic considerations

The starting point may be a classical academic problem of overall mass balance with general chemistry. The solution is unique, and the students have all the data they need to solve the problem.

There are a number of possible ways to turn the above problem into an open-ended one. The easier way would consist of omitting some data or presenting the problem with an excess of data, as oftentimes occurs in the real world, so that students must learn to identify and use the necessary data, disregarding the rest. This is directly and easily implemented in the same subject and its extension in the second year, simply by changing some initial data to avoid the use of previous ones given in the first year. Normally, students are confused when dealing with more data than needed, and become worried when there is a lack of data. Initially, they are a bit exasperated, but ultimately they engage more strongly with the subject matter and discipline. Once we have the initial open-ended problem, which is focused on mass balance, a fluid-mechanics open-ended problem could be included, so students must compute the pressure drop of gas by deciding on the superficial velocity of gas in pipes. To solve the fluid-mechanics problem, the students need a set of data, need to look for some other data and make some assumptions, which must be justified and revised after finalising the problem, just as in the real world. Later, fans and boosters are added, which need to be selected and specified using different criteria that students will have to weigh with each other. At this point, process control and instrumentation may be incorporated to the problem, since there are a number of variables to be controlled (pressure, flow-rates or temperature in some equipment) which involve measuring these variables and others. These may include large disturbances which require the application of advanced regulatory control techniques such as feed-forward action or a cascade strategy, as often used in industry. Students select sensors and transmitters based on some constraints given in the problem, but then make decisions from a myriad of possibilities by identifying and following various criteria.

In addition, other disciplinary core competences could be added to these open-ended activities (overseen by lecturers in these areas), such as those relating to mechanical engineering (e.g. material selection e.g. corrosion effects, use of Standards, basic foundations of a particular unit or structure, pipe supports, thermal expansion studies) or in relation to electrical engineering (e.g. specification of electrical motors for the fans previously designed, or basic elements on the electrical circuits).

Once the technical knowledge core of chemical engineering is covered, along with many transferable skills, new criteria to make a decision on the best solution can be added based on an economic assessment and on an environmental assessment related to sustainability, using Life Cycle Assessment (LCA) of the installation. At this point, investment and operating costs regarding the environmental protection must be considered in order to obey the law that limits the impacts on environment, so transiting towards sustainability is possible. In fact, although a current business may have lower production cost than another one which is newer and more sustainable (so one could think that sustainability is good but expensive), the traditional and current business could have a short life if some commonly used resources are scarce or involve a way to obtain them that leads to a severe and irreversible deterioration of nature resulting in the depletion of those resources and, hence, in closing the business. In this situation, and taking a long term to develop the business, the sustainable option could be the best option and, in fact, a more profitable option if the business could be extended over time. This is a clear example of competing facets and trade-offs in the open-ended activity assignments. In fact, a trade-off is a common situation in real life, and open-ended (real) problems and activities give the students the opportunity of thinking about advantages and disadvantages of using one or another solution and the responsibility of making decisions.

4 Conclusions

This paper highlights how a fit-for-purpose contemporary programme can develop key knowledge, competences and values in a sustainability informed context, and, in doing so, can help meet employability requirements and societal imperatives. Open-ended activities and problems, in their many guises, represent a useful vehicle in this aspect as they require creativity, communication and leadership, as students working on them can express their insights and arguments to their classmates and lecturers, thus integrating knowledge and developing transferable skills, while facilitating sustainability values. The work may be both individual and collaborative across respective stages, to promote personal involvement and critical thinking skills, as well as interpersonal relations and collaboration. Through a framework of open-ended activities and problems, students can thereby readily communicate, critically analyse, work in teams, work within and across disciplinary bounds, and handle uncertainty, in an increasingly post-normal environment. Problem specifications can also be opened increasingly and progressively, to help students develop the skills to handle problems with multiple framings and multiple potential solutions or interventions. This can materially help develop the attributes that current and future engineers need to integrate disciplinary knowledge, transferable skills and appropriate values into professional practice, while embracing the incorporation of inherent uncertainty, amid social, ethical, sustainability and environmental contexts and paradigmatic change.

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