Teaching Sustainable Energy Systems to engineering students

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Abstract

This paper presents the learning outcomes, syllabus, delivery, and assessment strategy for a module of 'Sustainable energy systems' for master-level engineering students. The paper is based on three stages of 'action research.' The first stage is a critical reflection on the planning and the process, based on the experience in delivering the original module and literature review. The second stage is based on semi-structured interviews of 4th-year students, focused on the collection of feedback to improve the module. The third stage is the redesign and peer-review of the module. The key outcome of this work is an approach which further enables students to move from 'surface learning' to a more profound 'deep learning'. Further steps forward toward a true 'constructivism' are also envisaged. Several enhancements are discussed, including an improved syllabus, new methods of delivery, fine-tuning of the learning outcomes, and finally revisiting the assessment strategy. The holistic teaching of 'Sustainable energy systems' is becoming commonplace in higher education engineering courses. Other lecturers planning or delivering a masters-level module on the topic of 'Sustainable energy systems' can gain practical and useful insights for their teaching from this paper.

Keywords: Sustainability, Energy Systems; Deep learning; Constructivism; Energy Projects

1 Introduction

Several professional activities of engineers involve the transformation, transportation, and usage of energy. As energy is such a critical facet, engineering students need to go beyond the simple physical laws (e.g. thermodynamics) and learn, at least, about other three key aspects: energy economics, environmental impact, and implications for society (Mälkki, Alanne, & Hirsto, 2012). As common in several university curricula (Kishita et al. 2018; Withycombe et al. 2016), there is a need for a module on sustainable energy systems for engineering students. This module needs to fit in a specialist-oriented program for expanding the perspective of students, opening their mind from a single discipline toward the concept of sustainability and, at the same time, enhancing their specialities (Kishita et al., 2018).

This module has two key goals:

- Enable students to think about energy as engineers, with numbers, physics laws, and facts.
- Develop a mindset to rationally and scientifically analyse other complex systems and their stakeholders (Benn, Rusinko, Benn, & Rusinko, 2011).

Sustainable energy systems deal with energy systems focusing on meeting the human energy needs for this generation and the forthcoming generations in a sustainable manner (MIT, 2010). The module, delivered in a British university, includes the review of several renewable and non-renewable production technologies, energy usage and consumption across countries. Students will study several qualitative and quantitative frameworks for the assessment of energy systems considering economic, engineering, environmental, social, and political goals. The contextualisation in the professions is one of the success factor integrating sustainability in mechanical engineering courses (Ramanujan, Zhou, & Ramani, 2019).

This paper presents the learning outcomes, syllabus, delivery, and assessment strategy for a module entitled 'Sustainable energy systems' attended by master of engineering students.

Following the appeal of (Kandpal & Broman, 2014) about improving the education on sustainable energy systems, the paper discusses how the original module has been redesigned to foster deep learning and constructivism in students. This paper has five sections: section 2 presents a literature review focused on deep learning and the constructivist approach. Section 3 presents the original module and the original motivations for design. By leveraging constructivism, section 4 shows how it is possible to improve the design, delivery and assessment of this module. Section five summarises the key takeaway messages of this paper.

2 Literature review

2.1 Surface learning vs deep learning

Marton and Säljö (1976) wrote a seminal text that played a relevant role in the understanding of the deep learning nature. In their study of Swedish university students, the authors found a remarkable difference in what is learned rather than in how much. Different level of outcomes containing different conceptions of the learning tasks can be recognised. The key differences in processing and therefore learning are described as “deep level” or “surface level”. Under this perspective, the authors discuss the two different levels of processing, called “surface level” and “deep level” processing. With surface learning, the student is focused on learning the text “as written”; the student uses a reproductive interpretation of learning, in several cases a mere rote-learning strategy. Counter, with deep-level, the student understands and interprets what is reading, listening or observing. (F Marton & Säljö, 1976)

A more elaborate view is presented by (Ference Marton, Watkins, & Tang, 1997). According to (Ference Marton et al., 1997), surface learning is mainly characterised by the student concentrating on “the sign”, i.e. on the information (mostly a text) as such. In contrast, deep learning is characterised by the student’s attention going beyond, appreciating “the signified”, i.e. the intimate understanding of what the learning material truly refers. The authors further elaborate on the concept distinguishing two different levels of learning:

- learning a commitment to memory (words or meaning),
- learning as an understanding (meaning or phenomenon).

As explained in section 4, this last section is the target of this module.(F Marton & Säljö, 1976) assert that learning must be defined according to its content. A very significant characteristic of learning is the uniqueness about what is learned, i.e. the very different ways in which students learn an identical concept (e.g. sustainability), phenomenon (e.g. climate change), or principle (e.g. a Netwon law). (J. B. Biggs, 1987) provides a level even higher than deep learning: achieving, i.e. to improve self-esteem and to ego achieving the possible highest grades. (J. B. Biggs, 1987) overviews the student approach to learning, including “presage factor” and “process factors”. The realising approach, combined with deep learning, promotes excellent performance in examinations and even personal satisfaction.

According to (Shephard, 2008), effective learning connects to student attitudes, values, behaviours and even emotions. Cognitive learning is linked to the concept of “knowledge” and its operationalisation. In the case of this paper, teaching sustainability would promote the design and delivery of a more sustainable energy infrastructure. According to (Warburton, 2003), science students could be exposed to disproportionately frontal teaching because science lecturers stress pieces of evidence and particulars about specific circumstances, therefore creating narrow specialisations. A consequence is that engineering students could be uncomfortable when studying sustainability because this discipline necessitates them to move across many different disciplines, from engineering to economics and other social sciences. This will change the way that they learn (Mulder, Segalàs, & Ferrer-Balas, 2012). Focusing explicitly on sustainability, (Shephard, 2008) clearly shows as, in case of deep learning, the cognitive domain is not enough, and the complementation with the affective domain is very important. The affective domain concerns our attitudes, core values, and even behaviours. It includes, in order of importance, the capacity to listen, to interact with others, to prove attitudes or values suitable to particular circumstances, to prove consideration and balance, and ultimately, to commit to righteous practice on a daily basis (Shephard, 2008).

2.2 Deep learning and constructivism approach

The module needs to enable students to undertake a constructivist approach (J. Biggs, 1996; Quartz & Sejnowski, 1997). As explained by (Toohey, 1999), if knowledge comprises mostly information, facts and conception, the job of the lecturer is to examine it, choose what is the most significant for a learner to know and help them to understand the key concepts. The lecturer might also provide exercises or tutorials for students, designed to confirm what is known or to give practice in the mode of inquiry of the discipline. As recommended in (Staniškis & Katiliūtė, 2016), the lecturer can include different activities (promoting different deep learning approaches), such as traditional frontal lectures, cases discussion (with the support of video), role-play, presentations, case studies analysis, etc. Case studies are particularly useful for teaching sustainability to engineers (Burke et al., 2018).

The entire module needs to deal with the challenges of teaching engineering for sustainable development (Ashford, 2004). In particular, the module needs "external consistency" to fit in the program of mechanical engineering and take advantage of the "trans-disciplinary teaching" (Lozano, 2006, 2010). The constructivism is what enables this approach.

Students need to be conscious of the quality of information and the reflection on the vested interest in the person/company/association that is giving them the information (Bates, 2013). The lecturer can present examples of the nuclear industry and the wind industry. The "World Nuclear Association" (i.e. the association of industries involved in the nuclear power business) has a website, http://www.world-nuclear.org/, rich of information and statistics about nuclear energy. Similarly, the European Wind Energy Association (i.e. the association of industries involved in the wind power business) has a website, http://www.ewea.org/, rich of information and statistics about wind power. Both associations have a vested interest and therefore provide biased information. There is nothing wrong with that, but students need to understand it and carefully keep in mind (Owens, Sadler, &

Friedrichsen, 2019). Indeed, even the direct collaboration between industry and academia can bring advantages for the development of curricula and the learning process (Klimova et al., 2016).

The bias principles apply for an academic paper: if an academic is an expert on solar power is usually because he/she works on it, he/she is a consultant for the solar industries and gets his/her research funds from the solar grants. There is nothing malicious in that; he/she is probably convinced that solar power is a great technology. Students need to learn and own two key ideas. Firstly, there is a bias in high-quality technical information. Secondly, if someone is an expert/professional in the engineering field (even not energy), he/she has his/her interest and belief. Developing critical thinking (and experts) is exactly a key point of (Lidgren, Rodhe, & Huisingh, 2006). Another set of skills fundamental for engineers and often disregarded in engineering course are the "soft skills", including teamwork, presentation and summary and writing of a technical report. Being Energy System a field where "soft skills" (i.e. communications, group work) are fundamental, the module also allows the development of these skills (McPherson et al., 2016).

3 Original module delivery and assessment

3.1 *Rationale*

As engineers, students should deeply learn about the implications of world energy use in current and future scenarios as well as estimation and evaluation of energy resources. Students do not need to memorise statistics; rather they need to understand the applicability of energy systems and sustainability metrics, as well as the implications of using unconventional energy sources such as shale gas and oil sands, where there is a strong debate particularly in the UK (Boudet et al., 2014). With this background, students can explore the various “modern technologies”, for instance starting from nuclear power plants: history, technologies, accidents and fuel cycle, Economic, Social and Environmental (ESE) aspects, influence on the energy system. Nuclear power is an important topic in the UK national energy strategy, and the students need to develop what the (QAA, 2008) defines as “systematic understanding of knowledge” and “critical awareness”. After nuclear power, students deeply learn about solar power, geothermal power, wind power, hydropower, ocean wave, tide, and biomasses. Students might evaluate critically current researchers in these technologies from the ESE aspects, and their impact on the energy system perspective. Key aspects such as the Life Cycle Analysis (Mälkki & Alanne, 2017) are used to make the different options comparable and avoid the simplistic ideas such as “nuclear and solar does not produce greenhouse gasses”. (Lund, 2007) is a great example of this critical awareness: students need to deal with multifaceted issues both creatively and systematically in the area of system energy management. In particular, students need to critically discuss energy storage, transportation, and distribution, energy security, and energy markets. Finally, in the last section of the course, a case study is useful to demonstrate self-direction and creativity in attempting and resolving problems in the case of eco-efficiency and energy efficiency, in particular regarding barriers to adoptions and the investment analysis. A fundamental aspect of energy systems teaching is the individual development of a large “feasibility study”. Therefore, students initially develop deep learning by understanding the theory and then applying it to a small project; later, in the development of a “feasibility study” by applying the constructivist philosophy.

3.2 *Module structure*

To foster deep learning and constructivism, the module is structured as follows:

1. The lecturer provides the “toolbox”: an introduction to sustainability (basic concepts) and focuses on the social dimension (because it is more qualitative and in general engineers struggle with qualitative analysis) alogn with the economics and environmental metrics.

2. The lecturer shows the application of tools to the first type of technology (e.g. nuclear power).
3. Students apply the same framework to a certain technology. The students, following the lecturer example on nuclear power, have to make a comparative analysis for another type of power plant of their choice (e.g. tidal or biomasses). This is a group work with a final presentation and feedback from the lecturer and other students. This is the first step toward constructivism as in (J. Biggs, 1996).
4. Other more advanced tools and methodologies are presented.
5. The students use the knowledge and skills gained to analyse another technology. This is the second step toward constructivism.
6. Enlargement to the systemic view (i.e. grid implication, electrical market, energy storage,)

Along with the development of the module, the students have to work on their final individual coursework, i.e. the full "feasibility study".

As discussed in (F Marton & Säljö, 1976), students learn differently from the same teaching material. Their familiarity with scientific principles, ideas and methods vary as regards to what is learned instead of simply differing as regard to how much is learned. With this in mind, the suggested readings include two key textbooks. (Tester & al, 2013) provide a rigorous, thorough and comprehensive view of the energy systems,. (MacKay, 2009) is more succinct than (Tester & al, 2013) and has fewer details, but it is based on UK data. The book is legally-free to download in several languages. This book and papers from scientific journals can represent a reading list. Yet, there is an issue of having a suitable textbook tailored for engineering students to study energy system, as discussed in (Nowotny et al., 2017). Other recommended websites with databases and reports freely available for students are from the US Department of Energy, the Organisation for Economic Co-operation and Development, the International Atomic Energy Agency, and the International Energy Agency. The students appreciated the idea of having updated and freely available information.

3.3 Case study

3.3.1 Sustainability case study – Dam case

Regarding the case study, the goal is to make engineering students (with an edge on quantitative/numerical skills) develop "qualitative analysis" tools and a deep understanding of the social aspects of the deployment and management of energy systems. 4th year engineering students are very talented with mathematical approaches. Throughout their studies, they learned several equations (i.e. static, dynamic, thermodynamics): therefore, learning a new equation in another field (e.g. economics) is relatively easy. However, the goal here is to overcome the barrier of "strong disciplinarian" presented in (Mulder, 2017). The goal of the case study is building upon the lectures on social aspects and take the students out of the "mathematical comfort zone"; by taking away calculations, the aim is to enhance their qualitative thinking empowering them to use techniques usually associated with social sciences. A capstone project is ideal for this scope (Dancz et al., 2017). The long case study employed for this purpose concerns a hydropower dam projects in a developing country. From one perspective, the dam might promote economic development in the country, providing a large amount of electricity with a small production of greenhouse gasses and generating a cash-flow that might be used to finance programs aimed at poverty reduction. From another perspective, the dams impacts on the environment and the lives of thousands of people living in small villages. Furthermore, in large projects, corruptions and misguided incentives are also a threat (Locatelli, Mariani, Sainati, & Greco, 2017). The students need to read the case, do a thorough literature review and prepare a short presentation (10 slides maximum) to discuss the sustainability implications.

3.3.2 Two small technology feasibility studies

Regarding the analysis of the different technologies, the students choose a certain power plant (e.g. biomass, wind farm, tidal power plant) and analyse its sustainability aspects. They work in small groups and the opportunity to present their analysis, receiving useful feedback from the lecturer and other students, that they incorporate in a group essay. The suggested structure for the presentation and the essay starts with the state of the art of the technology: what is existing today and what will be available in the next 10-20 years: break-through technologies, proved technologies (lower risks). Students review the worst and best practices: unsuccessful and successful cases and lessons learned (negative and positive). The next step is to analyse the environmental dimension (per MWh o GWe): adverse impacts either during design, construction, operations or decommissioning, direct effect on human health in the UK or overseas, the effect on the environment, benchmarking with existing UK portfolio. The second phase is the social dimension (per MWh or GWe), intended as the job positions created in the UK, the effect on the local residents (besides the environmental one), impact on Gross Domestic Product (GDP), impact on the grid, power security. The last section of the analysis is the economic dimension and risk analysis. In conclusions, the students need to make sound judgments when they present their conclusions to non-specialist and specialist audiences (as recommended in (QAA, 2008)), justifying if the technology is suitable for the UK. This is very much aligned with the view of (Leal Filho, Shiel, & Paço, 2016) about the careful selection of suitable projects. Learning through practise, in real-world situations, support the development of competencies and skills that will not only be appreciated in the workplace (e.g. teamworking) but might be essential to promote sustainable development in the everyday life.

3.4 Assessment strategy

The assessment strategy is entirely based on coursework. 30% of the final mark is on the "students' portfolio" that includes the analysis of the Dam case study and two small "feasibility studies" for power plants aforementioned. These elements constituting the portfolio are the results of group works. The individual coursework, i.e. the final feasibility study of a certain power plant, accounts for 70% of the final mark. This is individual coursework that builds on the skills knowledge, feedback gained from the Dam case study and the two small "feasibility studies". This final summative feasibility study includes the initial selection of a certain type of power plant, the discussion of its sustainability elements and a final summary. Students have the following key recommendations:

- Choose a topic of their interest. *(this is consistent with the constructionist approach)*.
- Be sure that there is enough information and its applicable to the UK setting.
- Be "as much an engineer as possible": you are not writing a novel. Be concise, use bullet points to present advantages and disadvantages, support your sentences with scientific references.
- Make all the necessary analysis, and presents a clear position. It is appropriate to say something like "the concept X is acceptable for the contest Y if the conditions a, b, c are satisfied otherwise is better not invest", "the concept X is ready to be implemented. The pathway is a – b – c", or "the concept X is not acceptable for the UK: the reasons are a, b, c". It Is "not" appropriate concluding the feasibility study with considerations such as "maybe it is good to do X but also Y is not bad", "probably is better to invest another semester in evaluating X and Y", and "I get X because X is the right choice."
- The aim is to produce a technical report written for engineers. If the reader (an engineer) is unable to understand, it is the writer's fault".

4 Improved delivery and assessment

4.1 Proposal of an improved syllabus

As presented in (Mälkki & Paatero, 2015), the development of a curriculum should start from establishing learning outcomes. At module level, an interesting reflection paving the way to a new syllabus is from (Ference Marton et al., 1997). The authors are talking about "learning as understanding (phenomenon)" and explaining what the student is trying to read through the text. The holistic, open deep understanding of sustainable energy systems should be the true outcome achieved through trough the syllabus. Table 1 shows an improved syllabus designed around those ideas, ideas from section 1 and 2 as well as students' feedback (see appendix). Considering the broad number of sectors where engineers can work, the lecturer needs to explain tools and techniques which are transferrable. A key message in the first lecture might be: *"Energy is a critical aspect of engineering: some of you are going to work in the energy industry. Others will work in other sectors, e.g. the food industry or transportation. This module needs to provide you with a mindset useful to cope with all kinds of large and complex engineering systems".*

Main areas	Actual Syllabus	Future Syllabus
Introduction to sustainability	• Introduction to sustainability in the energy field • World energy use in actual and future scenarios • Estimation and evaluation of energy resources	• Introduction to sustainability in the power and energy sectors • World energy use in actual and future scenarios • Estimation and evaluation of energy resources
Methods and tools	• Energy system and sustainability metrics • Unconventional energy sources: oil sands, shale gas, others • Project economic evaluation in the energy field: theory and application	• Energy system and sustainability metrics including Life-Cycle Analysis • Holistic project appraisal in the energy field: theory and application
Energy Production	• Nuclear power plants: history, technologies, accidents and fuel cycle, ESE aspects, impact on the energy system • Geothermal energy: Technologies, ESE aspects, impact on the energy system • Hydropower: Technologies, ESE aspects, impact on the energy system • Solar Energy: Technologies, ESE aspects, impact on the energy system • Wind energy: Technologies, ESE aspects, impact on the energy system • Ocean Wave, Tide: Technologies, ESE aspects, impact on the energy system • Biomasses: Technologies, ESE aspects, impact on the energy system • New, not commercial renewable technologies	• Unconventional energy sources: oil sands, shale gas, others • Nuclear power plants: history, technologies, accidents and fuel cycle, ESE aspects, impact on the energy system • Renewable technologies: Technologies, ESE aspects, impact on the energy system. Focus on geothermal, hydropower, solar, wind, ocean and Biomasses • New, not commercial technologies • Impact of renewable sources on the power system
Ancillary services, distributions and marketing	• Energy storage, transportation and distribution • Energy security - centralised vs local production of electrical energy • Energy markets and the influence that might have on the energy consumption behaviour; demand-side management. • Smart grids: advantages, cost and social implications • Impact of renewable sources on the power system	• Energy storage, transportation and distribution • Energy security - centralised vs local production of electrical energy • Energy markets and the influence that might have on the energy consumer behaviour; demand-side management. • Smart grids: advantages, cost and social implications
Other topics	• Eco-efficiency and energy efficiency: barriers to adoptions, investment analysis, best practices and state of the art • The environmental dimension as a competitive advantage for companies	• Eco-efficiency and energy efficiency: barriers to adoptions, investment analysis, best practices and state of the art

Table 1 Improved Syllabus

4.2 New ways of delivery

4.2.1 Fostering constructivism

(J. Biggs, 1996) is probably the key reference for constructivism. Aiming to be specific within the engineering field, constructivism can be an extremely valid pedagogical approach since the profession of engineers increasingly requires that the individual take ownership of their training (focused on deep knowledge). Therefore, the university needs to "equip" the students with a methodology that develops the critical thinking necessary for the future (Cavenett, 2017). According to the constructivist theory, it is necessary to shift from a perspective focused on teaching (training from the educator/trainer perspective) to one focused on learning (training from the perspective of the learner). Knowledge can no longer be reducible to a simple transmission of traditional knowledge related to rote learning (Chowdary, Singh, & Reddy, 2018; Indraganti, 2018).

The lecturer should inspire students to adopt active techniques (e.g. problem-solving, experiments) to develop knowledge, and then critically reflect and discuss their actions and how their understanding is improving. With a well-organised classroom setting, students *learn how to learn*. This has paramount importance for engineering students since the technologies, tools, techniques and markets evolve extremely rapidly. Engineers need to learn throughout their lives to do their work. Therefore, the lecturer helps students to develop knowledge rather than to rota-learn information. The key benefits of this approach are (EBC, 2004):

- Students might feel that they are learning more and faster when they are dynamically involved, rather than inactive spectators.
- Teaching works better when it focusses on reflecting and understanding, instead of on rote memorisation. This is extremely important in general and for engineering in particular.
- Constructivism gives learners possession of what they study because the learning process is based on students' enquiries and investigations.
- By basis learning actions in a genuine, real-world setting, constructivism encourages and engages students.
- Constructivism stimulates soft-skills by generating a classroom atmosphere, promoting teamwork and discussions. Teamwork is a fundamental skill for engineers.

4.2.2 Making things personal

(Cotton, Miller, Winter, Bailey, & Sterling, 2015) present the relatively low state of energy knowledge in a UK university, and suggest techniques to enhance it through a behaviour change model. This idea of delivery, very much aligned with the concept of constructivism, can be fully implemented as described in the work of (Savageau, 2013). These actions can be taken at the "university level" (Hugé, Block, Waas, Wright, & Dahdouh-Guebas, 2016) or "student-level". For instance, students will create and adopt a personal "Energy Resource Consumption" making their resource consumption tangible (during a three-day audit), providing the background for self-reflection during the module. A similar experience in Cambridge (Fenner, Ainger, Cruickshank, & Guthrie, 2005) and Manchester (Gallego-Schmid, Schmidt Rivera, & Stamford, 2018) also demonstrated the validity of "first-hand experience". To have a truly sustainable energy system, engineers need to design elements (such as cars or power plants) able to make the best use of our energy resource (Weiszer, Chen, & Locatelli, 2015). However, engineers need to understand and critically reflect on their use of energy as citizens. Only from this, they can truly appreciate the holistic approach required by engineering/energy solutions. Most students are not aware of the amount of their energy consumption. (Savageau, 2013) explains that one of the most outstanding outcomes of this audit is that almost everybody expressed surprise and consternation for their consumption. They had dramatically misjudged their consumption. The audit empowers students to assess more precisely their waste and consumption. Most of the students who performed the audit described by (Savageau, 2013) thinks that it is the most useful and life-changing experience regarding sustainability. The traditional teaching of the course, while valued and thought to provoke, have not produced equal personal engagement and passion among the participants. This indicates that students are keen to learn in ways that can change their consumption behaviours. Mechanical engineers are very focused on solving abstract equations, really need this fresh view, and this is truly constructivism.

A step forward of this approach would be to escalate the experience to "university level", for instance, promoting actions to foster initiatives with a wider range of participants (Rusinko, 2010). This is a more long-term commitment because of the number of barriers to overcome (Maiorano & Savan, 2015).

4.2.3 Transdisciplinary case study

Another constructivism action is the usage of transdisciplinary case studies. As presented in section 3.3, case studies are already part of the program, but it is possible to improve in this area. A learning approach that is extensively adopted in sustainability research and education is the Transdisciplinary Case (TDC) study approach, as presented in (Scholz, Lang, Wiek, Walter, & Stauffacher, 2006). TDC has three key advantages:

1. It is built on three rigorous paradigms that are focused on diverse, significant characteristics of multifaceted and environment-human systems: case studies, transdisciplinary, and sustainable development.
2. It is precisely prepared considering an elaborate and reliable theoretical framework including ontological, methodological, epistemological, and organisational considerations.
3. It is itself topic of an ongoing investigation and adaptation process.

(Stauffacher, Walter, Lang, Wiek, & Scholz, 2006) claim that this perspective of TDC is grounded on functional socio-cultural constructivist and project-based learning; learners become better able to address complex real-world cases. According to (Shephard, 2008), it remains to be proved that behaviours established by learners during TDC events are replicated in real-world instances, but this disclaimer almost definitely applies to all methods of teaching.

4.3 Revisit/fine-tune learning outcomes

(Shephard, 2008) is clear when he says that the essential element of teaching sustainability is a commitment for real learning outcomes of attitudes, values and behaviours. As explained by (Warburton, 2003), deep learning is fundamental for sustainability in education, where the all-inclusive view and capability to structure and organise different types of evidence into a coherent whole is essential for the entire exercise. Deep learning requires paying attention to the underlying meaning. It is related to the use of cross-referencing, analytic skills, independent thinking and imaginative reconstruction. This might be reflected in the learning outcomes. (Chalkley, 2006) says that lecturers teaching sustainability must pursue outcomes involving not only skills and knowledge but also the values underpinning sustainable behaviour by government, businesses, and society. Educating for sustainability pursues three primary outcomes:

- Students might know their sustainability issues,
- Students might have the skills to act sustainably,
- Students might have individual and emotional traits to behave sustainably.

The learning outcomes, Table 2, have been reviewed considering also (QAA, 2008, 2010; Segalàs, Ferrer-Balas, & Mulder, 2010). (QAA, 2008) provides the descriptors for higher education qualification at Level 7: Master's degree.

4.4 Revisit assessment

According to (QAA, 2010), effective and appropriate assessment enables students to demonstrate the outcomes of learning intended for the program. Suitable assessment methods are essay assignments, dissertations, reports, portfolios or other deliverables from research/project work, which might include performances, artefacts, compositions, written or oral examinations, presentations, problem-solving exercises, placement reports, posters. The new assessment method introduces the framework for peer group assessment and transdisciplinary Engineering Design project presented in (Moore & Esley, 1994). This paves the way to the peer assessment and self-assessment of students. Other key recommendations from the students will be:

- Provide a word limit for the feasibility study (8,000 words ideally, 10,000 absolute maximum)
- Provide written feedback after the first assignment

Table 2 summarises the links between learning outcomes and the assessment strategy.

Original learning outcomes	New learning outcome	Dam case study	Small technology feasibility study	Peer group assessment	Individual technology feasibility study
LO1 Critically discuss the significance of sustainability in the field of energy systems	LO1 Develop a Systematic understanding of the dimensions of sustainability with a focus on energy systems	V	V		V
LO2 Systematically assess the consequences of resource usage on the environment in terms of pollution, resource depletion, security of energy and waste management	LO2 Mature a critical awareness to assess the consequences of resource use on the environment in terms of resource depletion, pollution, waste management and security of energy		V		V
LO3 Analyse advantages and disadvantages of novel or unconventional energy sources	LO3 Develop a comprehensive understanding of appropriated techniques to analyse the disadvantages and advantages of novel or unconventional sources of energy		V		V
LO4 Develop a comprehensive knowledge of technologies applicable to clean energy systems to make knowledgeable judgments on present and future energy policy	LO4 Evaluate methodologies and develop critiques applicable to clean energy systems to make knowledgeable judgments on present and future energy policy	V		V	V
LO5 Investigate complex energy systems starting from fundamental scientific principles, considering efficiency and environmental impacts, identifying the importance of assumptions formulated in evaluating energy systems	LO5 Analyse multifaceted energy systems starting from first scientific principles, concerning efficiency and environmental impacts and identify the importance of assumptions formulated in assessing energy systems. Make sound judgments in communicating the conclusions clearly to non-specialist and specialist audiences		V		V
LO6 Learn independently, exercise independent thinking, and comprehensive technical judgments	LO6 Demonstrate self-direction and originality, ability to learn independently, independent exercise thought, and sound technical judgments	V		V	V

Table 2 New Learning outcomes and Assessment strategy

5 Discussions and conclusions

As presented by (O'Byrne, Dripps, & Nicholas, 2015; Shephard, 2008), universities are involved in numerous ways in promoting and teaching sustainability. The choice of universities-based activities accomplished in the name of sustainability is extraordinary. This is true from a broad sense since universities have a specific function, to form citizens who value their environment and understand that they have an obligation to help to sustain it (Wam*sler et al*, 2018). However, as aforementioned in the previous sections, this is even more relevant for engineering students that will influence sustainability with their profession. The journey towards the development of appropriate curricula in "sustainable energy system" to be delivered all over the world is still long, especially for countries that have just started this journey in recent years (Alawin et al., 2016; Jaber et al., 2017). This paper provides a toolbox to support this journey.

According to (Toohey, 1999), higher education amounts to more than the sum of the knowledge and skills which people acquire through studying different topics. Learning can transform the understanding of the way the world functions and the way that engineers operate within it. Therefore, lecturers need to consider the larger goals of teaching their modules. Although the importance of sustainability is largely recognised within universities, transdisciplinary activities could be regarded as secondary to traditional discipline-based modules. (as explained by (Warburton, 2003)), the topic of sustainability is too extensive and as such unsuited to fit current disciplinary "boxes": this has been a long standing objection that will require to be addressed with university administrators The poor implementation of transdisciplinary accounts is one of the main obstacles to the United Nations agenda for promoting and teaching sustainability (Bina *et al*, 2016). Sustainability is an ongoing process. Lectures should be presented as an experience that builds individual awareness, rather than a set of pre-packaged information to memorise. Leveraging more problem-based teaching, students can be stimulated to critically analyses assumptions, choose investigative techniques and scrutinise values.

Effective teaching for sustainability stimulates students to reflect on their learning and promotes changes in attitudes, values, and ultimately behaviours (Jensen, 2016). The lecturer can ask the student to think about their personal impact on sustainability in everyday life. It might be suitable to introduce some form or "personal impact awareness" measures and see how it changes over the development of this course (see also (Savageau, 2013)). In this case, the lecturer would act as a "role model"; as demonstrated in (Brahm & Kühner, 2019; Gagné, 1985)his/her behaviour (positive and negative) will influence and inspire students. This is a key since regardless of the quality of the curriculum and the teaching materials, lecturing will not be fruitful without effective teaching delivered by motivated educators (Ciriminna, Meneguzzo, Pecoraino, & Pagliaro, 2016). Making things personal and transdisciplinary would be essential in particular for part-time and mature students, bringing together education, technology, business and entrepreneurship (Grega & Pikoń, 2018).

As recommended by (Ashford, 2004), one of the ideas for improving this module is that engineering should concentrate on changing, rather than simply assessing technology and science. If an engineer has a narrow focus, he/she might produce designs or making decisions with major flaws. For example, during energy crises, buildings were designed and built focusing only on energy efficiency, later leading to serious indoor air quality problems. Regarding the buildings, (Alanne, 2016) shows that game-based learning has a vastly untapped pedagogical potential for engineering students. A further step might be expanding the analysis to consider the circular economy (Mignacca, Locatelli, & Velenturf, 2020; Nunes et al., 2018). In summary, the coupling of transdisciplinary and constructivist is the way forward for teaching "Sustainable energy systems". The literature presented in section 2, the principles presented in this section, and the student feedback collected in the semi-structured interview (transcript in Appendix A) have been the basis for the improvements described in section 4.

In conclusion, energy is a fundamental dimension of sustainability and the teaching of "Sustainable energy systems" is becoming common in the master engineering program. Master of engineering students have a good technical/quantitative background but often struggle in demonstrating skills common in social science. Therefore, "Sustainable energy systems" is a "bridge module" that develops and complements students background from both a knowledge and skills point of view. This paper reviewed the module of "Sustainable energy systems", suggesting several practical actions useful for other lecturers delivering comparable modules. In particular, the paper discussed and leverage two key concepts: "deep learning" and "constructivism" and how to apply them in the delivery of this module.

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Appendix A - Focus Group Interviews

The methodology for these interviews is inspired by (Kishita *et al*, 2018). The students already had the final mark for this module and, being 4th-year students, there are no further assessments for them from the lecturer. This is the basis of honest feedback from their side. 20 students were involved in the interview in 5 groups of 4 persons. The lecturer firstly presented the scope of this interview, and then he started asking the questions.

Q1 “If a future student would ask you “what the module is about / what the aim is” what would you say to him?”

- Critical thinking in the term of sustainable systems.
- This is the only modules about soft skills, referencing, thinking about people opinion (can we trust them?) and quality of the information.
- Try to see the way forward for energy security and power plant: nuclear, renewable such as wind, tide, etc… about build knowledge.
- How different technologies applies to different areas, like “base-load vs. peak load”.

Q2 “What is the most useful thing that you learned for your professional career?”

- From doing the feasibility study (*i.e. The final individual assignment*): how our real career could be like, how we plan for building something like a wind farm… project management.
- Soft skills, including how to write a technical report that is different from a dissertation.
- How to tie all together: economic and environmental and social aspects together.
- To add numerical content to the decision-making process.
- Presenting skills.

Q3 “What is the most useful thing that you learned about your personal development?”

- We learned from case study because we had to work as a group. Working together checking that the section was finished.
- Try to speak about to technical topics to not technical people.
- Look also at sustainable impact: social and environmental.
- Public speaking, building your confidence.
- We don’t do many presentations in other modules.

Q3 “As I told you my key expertise is on nuclear energy, SMR in particular. Do you believe that I had been biased toward nuclear? Do you feel that I tried to “sell nuclear”?”

- The was a focus on nuclear/SMR but was more a demonstration of how to do things for our project.
- It was helpful because we saw an analyses of a technology.
- Not biased, you did not try to sell nuclear.
- Nuclear is very relevant for the UK, so it is important to have knowledge about it. There is a lot of misinformation around.

Q4 “Do you believe that the assessment was taking too much of your time/to light?”

- Depends, I really enjoyed doing the feasibility study, I found it very interesting, maybe I did too much of that.
- It took a lot of time, but I didn’t feel.
- Maybe would have been useful to have a constraint in terms of words.
- I felt that the feasibility study took me more time than the dissertation.
- I felt that the was no limitations and I tried to improve it over and over to make it better.
- A lot of people wrote 10.000 words… too much… would be better to have more focus.

Q5 “Would be useful to introduce a written test?”

- The feasibility study was a very useful assignment. It pushed me to learn a lot about many different things. That would be difficult to do with a written test.
- In addition, the small case studies was useful.
- It would be better to have the deadlines for the small case studies along the course. That’s would be more useful for the time management.
- Courseworks are better than the exam for this type of topics. It allow to deep you knowledge and understanding.

Q6 “What you think about the “big case studies” (e.g. The Dam case study) vs. “conventional tutorials (e.g. calculate the NPV)?”

- The Dam case study was interesting, I got the idea of social dimension. Analyse it during the lecture was good. I thought about dams operations. It is more real life than calculate the Net Present Value.
- Introduce new domains for understanding real life. There is more than financial.

- It add an extra perspective at what we are used to “this add up” (i.e. doing numerical exercises).
- As engineers, we are not used to deal with social aspect, so it is nice to look in to that.

Q7 “If you could change one thing for next year, what would you change?”

- Smaller groups, with more technologies analysed. 5 students maximum in the group, otherwise the group management becomes difficult,
- We would like to have hand in dates early and have early formal feedback (not just at the end),
- Oral feedback was good, but we forgot it when we had to apply it for the final submission,
- Constraints the feasibility study. It would “take the pressure off”,

Q8 “How do you think that you could continue to learn about this topic?”

- Media, but it could be a misrepresentation.
- Reading documents from energy companies, regulators, utilities.
- Reading scientific literature and reports.