The Centre for
Engineering and Design Education

An Introduction to Sustainable Development in the Engineering Curriculum

a guide by **Roger Penlington**
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Author's biographies

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Foreword

Use of terms – a note from the authors
We believe the engineering discipline has a dominant role to play in sustainable development, in both the provision of sustainable technologies and also in fostering responsible use of technology through societal change. With this in mind we have employed the term Engineering for Sustainable Development (EngSD) throughout this guide to distinguish it from Education for Sustainable Development (ESD).

The origins of our need to consider sustainable development

Engineers' and scientists' concern for the future has a long history, for example William Armstrong calculated the limited life of the coalfields of North East England and predicted the move to solar energy in the mid 19th Century (Heald, 2012) and Svante Arrhenius, at the end of the 19th Century, promoted hydroelectricity and spent the best part of a year calculating the impact on Global temperatures of the rise of CO_2 in the atmosphere (Arrhenius, Caldwell and Wold, 2008).

For many the study of the topic of sustainable development originates from a concept introduced at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992. This conference first identified that sustainable development should comprise three pillars: economic development, social equity and environmental protection (UNESCO, 1992).

Although this concept had been preceded by the United Nations Conference Declaration on the Human Environment held in Stockholm in 1972 (UN, 1972) and before this the publication of the Brundtland Report in 1987 (WCED, 1987), it was the Rio conference in 1992 that established the "Rio Declaration" (of 27 principles) and "Agenda 21", as a set of developmental objectives in achieving sustainable development for the 21st century.

The topic of sustainable development is put into context (IISD, 2013) and summarised by a timeline given by

the International Institution of Sustainable Development (IISD) in their publication (IISD, 2006).

Engineers directly contribute to the meeting of some of the United Nations Millennium Development Goals and facilitate the ability of scientists to deliver their contributions (http://www.un.org/millennium/declaration/ares552e.pdf).

"We must spare no effort to free all of humanity, and above all our children and grandchildren, from the threat of living on a planet irredeemably spoilt by human activities, and whose resources would no longer be sufficient for their needs"

High level aims require lower level initiatives to support their objectives and the Sustainable Development Solutions Network is a component of the United Nations engagement with academia through Solution Initiatives (http://unsdsn.org/what-we-do/solutions-initiatives/).

Education for Sustainable Development (ESD)

It took 20 years following the Rio Summit in 1992 for world leaders to come together, once again in Rio, at the Rio+20 Summit, to produce a document entitled "The Future We Want" (UN, 2012) and establish the SD21 project (UN, 2012a) and to re-focus on the significance of education as the means by which we can work toward a sustainable future (UN, 2012b). This outcomes report re-states sustainable development as an overarching goal, and more importantly:

"…. that we have a responsibility to ensure that the students we teach and train, who will be the leaders of tomorrow, have the skills necessary to create not just the future we want, but the future we need." (IISD, 2012).

It is widely accepted, however, that the concept of attaining a sustainable future continues to be elusive, with critical issues such as economic crisis, environmental degradation and social inequalities combining to lead to instability, unrest and fragility into the 21st century (Nguyen, 2014). Global warming continues, CO_2 emissions rise and resources on the land, in the air and in the sea continue to be depleted without any enduring practices being defined or implemented that can halt this.

There are examples of successful, localised implementations around the world as reported in the media which are primarily based on raised awareness through actions taken as part of the UN Decade of

Education for Sustainable Development (DESD) 2005 to 2015 (UN, 2014), where education is seen as the key, and as advocated by UNESCO:

"Education not only informs people, it can change them. As a means for personal enlightenment and for cultural renewal, education is not only central to sustainable development, it is humanity's best hope and most effective means in the quest to achieve sustainable development." (UNESCO, 2002, p8)

Many initiatives have been through curricula reform, recognition awards and university movements which are included in the teaching and learning resources as part of this guide, http://eden-share.lboro.ac.uk/id/item/100, hopefully to better inform and to encourage the ongoing formation and development of a community of practice across higher education that can become better known, recognised and adopted as ESD.

Engineering for Sustainable Development (EngSD)

The engineering discipline continues to provide a strong basis for educational approaches toward implementing sustainability and sustainable development into our world.

This guide is intended to stimulate thought and consideration amongst those who:

- as members of teaching staff, may wish to introduce EngSD into their teaching
- as leaders of engineering programmes, may wish to consider the broader ethos of their curriculum.

The guide looks at why and how EngSD is included in the engineering curriculum and considers embedded versus discrete approaches. It discusses approaches to teaching and learning for EngSD, including examples of EngSD within the curriculum and a 'what next?' section, which points the reader towards further areas of study and practice.

As an introduction to EngSD within engineering programmes, this guide does not seek to prescribe courses of action but rather aims to outline the main opportunities, sources of guidance and educational resources which may enable informed debate and decision making.

Both personal action and leadership are required in equal measure if graduate engineers are to meet the needs of society, even when society itself may not be taking action (Blincoe, 2009).

Readers of this guide should, therefore, feel empowered toward personal action and leadership in the encouragement of their future graduates in becoming effective global engineers.

Defining Engineering for Sustainable Development

Engineering for Sustainable Development is a wide ranging topic and, as such, may be considered to mean different things to different people.

For this reason broad definitions of sustainable development provide a good starting point, such as "Our Common Future, the Brundtland Report of the World Commission on Environment and Development" (United Nations, 1987):

"…meeting the needs of the present without compromising the ability of future generations to meet their own needs."

Why is Engineering for Sustainable Development in the engineering curriculum?

Brundtland's broad definition can be readily applied to an engineering context, satisfying the personal responsibility felt by the student and enabling us as teaching staff to identify what future employers' expectations of engineering graduates will be in terms of sustainability.

The Engineering Council has defined the role of professional engineers in sustainability using the following six principles (Engineering Council, 2009):

1. Contribute to building a sustainable society, present and future.
2. Apply professional and responsible judgement and take a leadership role.
3. Do more than just comply with legislation and codes.
4. Use resources efficiently and effectively.
5. Seek multiple views to solve sustainability challenges.
6. Manage risk to minimise adverse impact on people or environment.

In keeping with these principles, a primary objective of higher education engineering curricula is to produce graduates who will seek membership of one of the engineering institutions and, subsequently, professional registration.

This requires programme learning outcomes that are aligned with UK-SPEC (Engineering Council, 2014), which states that a Chartered Engineer is expected to be able to:

- demonstrate a personal commitment to professional standards, recognising obligations to society, the profession and the environment
- undertake engineering activities in a way that contributes to sustainable development.

The teaching of EngSD is not new, and present-day academics have the benefit of a solid foundation which has already been laid by prior guides and reports, such as the guiding principles of EngSD as developed by the Royal Academy of Engineering's Visiting Professor Scheme (Royal Academy of Engineering, 2005) and the outcomes of a three year initiative of the Higher Education Partnership for Sustainability (HEPS) programme in 'Learning and Skills for Sustainable Development, Developing a sustainability literate society' (Forum for the Future, 2004).

A case has been made for broadening the undergraduate engineering curriculum (Beder, 1989) for the benefit of a wider intake of students, their gender balance and the professional competence of graduates expected by employers. Despite the overcrowded curriculum, a key component is the addressing of social concerns and environmental awareness (Beder, 1989/90) which illustrates the wider consequences of engineering activity. Sustainability may also attract university applicants to engineering, especially female applicants (Male, Bush and Murry, 2009; Pelly, 2007).

How does Engineering for Sustainable Development fit within the curriculum?

EngSD has a motivational value, which means that it may be used to broaden the learner's perspective. The linking of learning with professional formation and the recognised need for graduates to be self-reflective

has led Mitchell, Carew and Clift (2004) to propose the following principles:

- Help the learner appreciate why consideration of sustainability is in their interest
- Use appropriate pedagogies for active engagement with issues
- Help learners gain plural perspectives
- Encourage learners to continue thinking about issues beyond their formal education.

Alternatives: embedding versus discrete

A first step towards the introduction of EngSD into the existing engineering curriculum could be through a discrete, often optional, module with a clear discipline focus. This may stimulate student demand for a broader curriculum and offer attendant opportunities for stimulating, collaborative and interdisciplinary learning. This can make a strong contribution to reinforcing the curricula in meeting graduate competencies required for professional registration.

An in-depth example of such an approach may be found in the Engineering Subject Centre Mini-Project Report, 'Education for Sustainable Development in Engineering: Report of a Delphi Consultation' (Tomkinson et al., 2008). This study sought consensus from a panel of experts to derive guidance in designing practices that could lead from a discrete module to the embedding of sustainable development within the curriculum.

Another example of the progression from the discrete to the embedded comes from the Centre for Sustainable Development at Cambridge (Fenner et al., 2005), where the initial introduction of an elective at the end of a programme led to the recognition that students

were coming from their pre-university system with an increasing awareness of environmental and societal issues which they then expected to further during their higher education and professional careers. This approach is supportive of the further integration of EngSD thinking into HE at levels 4 and 5.

A wider study (Holmberg et al., 2008) examined the outcomes of differing strategies of integrating sustainable development into the curriculum over a number of years and recognised that institutional commitment is absolutely necessary for the transition from discrete to embedded approaches. The autonomy of individual academics within their discipline requires management commitment if a long term strategy of cultural shift and deep curriculum renewal is to be gainfully employed.

Alternative approaches to the incorporation of EngSD into the curriculum have been considered in more depth and illustrated through examples in Steiner and Penlington (2010) and Steiner (2010).

Approaches to teaching and learning for Engineering for Sustainable Development (EngSD)

This guide sets out to articulate opportunities for good educational practice which support a learner-centred approach to EngSD, establishing it within the core competencies of a graduate embarking upon a career as a practising engineer. It also aims to illustrate that integration of sustainable development within a course offers much in terms of a student's understanding and a wider appreciation of their role as a professional engineer and the place of the profession within wider society.

Integration versus depth of ability has been investigated by both Humphries-Smith (2007) and by Tomkinson et al. (2008). The latter gives an example of developing EngSD through an inter-disciplinary problem-based approach, where it was found that more aspects of EngSD could be incorporated into a module than had previously been expected.

A wider study (Dawe et al., 2005) of education for sustainable development (ESD) identified that skills and attributes which support teaching and learning in ESD are, however, not easy to teach by traditional means. Their research identified three orientations in the teaching of sustainable development:

- The educator as a role model
- Experiential learning by focusing on real and practical life issues
- Holistic thinking.

Having identified that EngSD may not be suited to traditional delivery approaches, the academic embarking upon programme development, for example through a module attainment audit, may find that a course wide reappraisal of the learning process, the balance of knowledge and application skills, must be reassessed for an information-rich future.

Two examples of curriculum audit may inform this process; Desha (2010) considers an EngSD curriculum renewal, with a specific interest in the velocity of change processes, and Male (2012) considers a programme wide approach to curriculum renewal based around the concepts of Threshold Concepts and Threshold Capabilities. This second example provides a comprehensive resource supporting a three stage progression through a course of:

- 'learning to become an engineer',
- 'thinking and understanding like an engineer' and
- 'shaping the world as an engineer'.

This latter stage involves solving complex problems with multiple possible solutions, identifying the troublesome features of sustainability as including:

- the concept of sustainability is vague, complicated, and has multiple meanings
- the concept is influenced by and requires an understanding of culture and students to think about engineering alongside topics such as spirituality, love and social context
- the idea of a sustainable way of dealing with waste.

The application of alternative delivery strategies needs to consider how students' approaches may be classified, for example Hasse (2014) identifies three groups:

- Math/science focused
- All round focused and confident; and
- Professionally focused.

This may then be viewed through a capability theory lens (Bowden, 2004) to consider how learning and assessment activities are constructed to achieve the desired outcomes, the students' ability to apply their knowledge in unforeseen circumstances whilst avoiding a "content-focused curriculum" (Baillie, Bowden, Meyer 2013).

Many approaches to learning encompassed by Enquiry Based Learning (EBL), such as problem based learning, project based learning and modes of self-directed learning, are reported by Khan and O'Rourke (2005) as

being especially suited to the achievement of EngSD derived learning outcomes. These approaches employ the extrinsic motivation of a real world problem where often the identified goals may include the sociological as well as the technological aspects of the problem. This can present opportunities for students to practise higher skills such as dealing with uncertainty or incomplete data in complex situations.

In addition to the suitability of EBL approaches (http://www.ceebl.manchester.ac.uk/ebl/), there is also a strong case for applying EngSD to approaches that consider the linking of research and teaching. As a continuously developing topic, EngSD is especially suited to a learning approach where students are taught to learn in research-like ways. This approach nurtures students' transferable and confidence-building skills (Fasli et al., 2007), where students report outcomes such as:

"understanding how my study impacts on the real world and you don't just take [sic] what other people say".

By being based at the interface between technology and society, these approaches also develop valuable workplace skills of judgement and reasoning. Technology based and analytical subjects must relate and contribute to social policy based topics. These may also have an analytical content, such as energy use audits, and may explore policy and emissions trading issues (Hill, 2005).

Whatever approach is employed, a web resource 'Sustainability Improves Student Learning' (http://serc.carleton.edu/sisl/index.html), which includes a Beginners Toolkit and links to a comprehensive resource

list (US based), identifies the key components of ESD teaching as:

- promote understanding without doom and gloom
- focus on solutions
- empower students to make positive changes, moving from analysis to systemic action.

It is widely accepted that students are motivated by participating in 'real world' or authentic learning experiences; it may be suggested that this is even more apparent where there is an added social benefit. Using appropriate technology as the basis for design projects in the developing world has been outlined by Clifford (2005) through the constructive linking of fundamental knowledge and the engineering skills of its application:

"By undertaking projects based around difficulties encountered in developing world contexts, students are encouraged to reflect on the technological challenges involved as well as the availability of materials, workshop resources etc."

Valuable practical assistance to engineering academics wishing to give a window on the world is provided by the organisation Engineers without Borders, in particular through their annual design challenge (http://www.ewb-uk.org/ewbchallenge) which seeks to give:

"an opportunity to learn about design, teamwork and communication through real, inspiring, sustainable and cross-cultural development projects".

Embedding the 'real world' within the curriculum is also an approach which demonstrates an engineer's need to develop broader skills such as information literacy and the ability to work with other disciplines.

Information sources such as the Crown Estate (http://www.thecrownestate.co.uk/media/5408/ei-a-guide-to-an-offshore-wind-farm.pdf) or Scottish Natural Heritage (http://www.snh.gov.uk/planning-and-development/renewable-energy/) provide a wider perspective of the interface between technology and society making qualitative and quantitative data available for student exercises.

Examples of Engineering for Sustainable Development within the curriculum

There are a wide range of published examples of EngSD teaching and classroom resources. The HEA UK Centre for Bioscience's Sustainable Development webpage (http://www.bioscience.heacademy.ac.uk/resources/esd/) provides a comprehensive introductory selection to complement this guide, including links to both resources and wider networks. A small selection of examples have been given here, drawn in part from Sustainability Education: Perspectives and Practice across Higher Education (Jones et al., 2010).

1. Royal Academy of Engineering Visiting Professors' Scheme

(http://rpd-mohesr.com/uploads/custompages/Engineering_for_Sustainable_Development.pdf)

Engineering for Sustainable Design: Guiding Principles (Royal Academy of Engineering, 2005) provides a summary of the Royal Academy of Engineering (RAEng) Visiting Professors in Engineering Design for Sustainable Development Scheme, with case study illustrations of how EngSD has been included in the curriculum. The RAEng scheme illustrates how stimulating student activity may be derived from real issues within EngSD, such as socially responsible water use or the chemical and manufacturing engineering issues of laundry cleaning products, as well as through scenario activities, such as mock planning enquiries.

Many of the questions raised by EngSD may be interpreted across a broad range of engineering disciplines, for example design, manufacture, use or disposal. All branches of engineering education need to seek solutions to the question raised by Richard Dodds, Visiting Professor at the University of Liverpool, in '*Extending product life – the forgotten challenge*' (Dodds, 2004).

2. Toolbox for Sustainable Design Education
(http://www.lboro.ac.uk/research/susdesign/LTSN/introduction/Introduction.htm)

This provides a structured series of guidance, teaching materials and reading lists. A particularly helpful feature for those new to EngSD is a glossary of terms.

3. The Natural Edge Project
(http://www.naturaledgeproject.net/default.aspx)

This Australian organisation seeks to contribute to and succinctly communicate leading research, case studies, tools, policy and strategies for achieving sustainable development. As a web resource it provides fully prepared teaching materials, books, notes, podcasts and video, that are technically detailed and fully contextualised in terms of the wider social benefits of ESD.

Breadth of coverage is of particular value, with coverage of electronic waste, carbon footprint and waste in the IT sector, sustainable water solutions and whole system design.

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4. Design-Behaviour
(www.design-behaviour.co.uk)

Although it does not include prepared teaching materials, this resource in 'design-behaviour' provides examples of how ESD issues have been interpreted by students and practitioners considering the impact of design upon user behaviour, (see also Lofthouse and Lilley, 2009).

5. Embedding Sustainability in undergraduate Civil Engineering Courses - A Practical Guide
(http://thinkup.org/wp-content/uploads/2014/08/Embedding_Sustainability_in_Undergraduate_Civil_Engineering_Courses.pdf)

This report identifies three challenges that engineers must consider when undertaking sustainable design; complexity, values-based decision making and interdisiplinary working.

Nine principles that may be applied to undergraduate teaching are outlined and supported by reference to any online support materials.

6. SORTED, Sustainability On-line Resource and Toolkit for Education

(http://www.eauc.org.uk/sorted/embedding_sustainable_development_in_the_curric1) and (http://www.eauc.org.uk/sorted/creating_the_conditions_for_embedding_sustainab1)

From the Environmental Association for Universities and Colleges (EAUC), this provides guides for curriculum development and also outlines the conditions and leadership required for successfully embedding ESD within the curriculum.

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7. Developments in ESD at the University of Nottingham

Work at the University of Nottingham has focused on the development of open access materials for use within the formal curriculum and also for those outside of the University. A number of e-books have been produced by authors from across the campus to provide a multiplicity of viewpoints on the impact that sustainability has on academic disciplines and vice versa.

For example: “Sustainability and Engineering Part I”:

https://itunes.apple.com/gb/book/sustainability-engineering/id572912964?mt=11

and “Sustainability and Engineering Part II”:

https://itunes.apple.com/gb/book/sustainability-engineering/id573166431?mt=11

Extra-curricular activities such as the development of a Massive Online Open Course, “Sustainability, Society and You” hosted by Futurelearn, attracted over 8,000 learners (2013/14) willing to engage and discuss issues surrounding sustainability online. Webinars and peer-assessed activities complemented the taught material, which made comprehensive use of the open educational resources.

8. Developments in ESD at the University of Manchester

Building on the earlier RAEng-supported pilot module, the University of Manchester developed its activities in ESD in a number of directions. This included a unit at Masters level in Managing Humanitarian Aid Projects, which was identified as over lapping with the sustainability agenda. The pilot module had been based on a problem-based approach; the challenge was the 'scaling –up' to accommodate larger student numbers. The School of Electrical Engineering and Electronics opted to make a third-year module on sustainability a mandatory element and this posed considerable strain on the inter-disciplinary unit. This subsequently led to a mandatory mono-disciplinary unit, initially based on the problem-based approach but increasingly with more didactic input. A different approach was taken with an NTFS-funded study, led by the University of Keele (Bailey et al; 2013) and also involving Staffordshire University, which looked at using blended learning to meet the problem of larger numbers. The e-learning element in Manchester involved the MSc module and evidence (Hutt and Tomkinson; 2012) has suggested that problem-based approaches can be undertaken online, but students do prefer a face-to-face approach.

Bailey P., Bessant S., Bostock S., Ormerod, M., Robinson, Z., Tomkinson, B., and Tomkinson, R. (2013). *Hybrid PBL: a scalable approach to 'sustainability education'?.* Available online http://www.keele.ac.uk/media/keeleuniversity/group/hybridpbl/PBL_ESD_Case%20Study_Bessant,%20et%20al.%202013.pdf

Tomkinson, B., & Hutt, I. (2012). *Online PBL: a route to sustainability education?*. Campus-Wide Information Systems, 29(4), 291-303.

9. Developments in ESD at the University of Plymouth

(http://www1.plymouth.ac.uk/sustainability/)

The Centre for Sustainable Futures (CSF) was established with CETL funding in 2005, to provide sustainability teaching and learning across the University by providing curriculum and pedagogic support and coordinating cross-institutional research related to ESD.

The Centre offers resources, training and events, and student experience as work-based learning projects, as well as advice and access to its archive of resources:

https://www.plymouth.ac.uk/your-university/sustainability/sustainability-education/resources

10. (Engineering) student perspectives on ESD

Studies have specifically explored the views of engineering students, how they perceive EngSD and the global dimension of engineering encompassing both technology, energy and materials use, assessment methodologies etc. and also ethical and social responsibility of engineering practice. Due to the importance of considering the broader aspects of sustainable development and global societal change an appreciation of the views of students from across the discipline spectrum is also relevant.

Stuart J.A., and Hua I., (2004). Designing and Teaching a Sustainable Design Course at Perdue University. In *Design and Manufacture for Sustainable Development 2004*. Eds. Bhamra, T., Hon, B. Trowbridge: Professional Engineering Publishing, 135-141.

Penlington R., (2007) The wider teaching of sustainability based upon student perceptions and the expectations of professional bodies. Higher Education Academy Engineering Subject Centre. Available online; http://exchange.ac.uk/downloads/scholarart/penlington-sustainability-report.pdf

Drayson R., Bone E. and Agomber J,. (2012) Student attitudes towards and skills for sustainable development. Higher Education Academy Available online; https://www.heacademy.ac.uk/node/10189

Penlington R., Tudor J,. and Perera N. (2013) Staff and student perspectives on embedding sustainability into the engineering curriculum. EESD13 Sixth International Conference Engineering Education for Sustainable Development, Available online; http://www-eesd13.eng.cam.ac.uk/proceedings/papers/74-staff-and-student-perspectives-on-embedding.pdf/at_download/file

Drayson R., Bone E., Agomber J. and Kemp S. A longitudinal study (2010 to 2013) into student attitudes towards, and skills for, sustainable development. https://www.heacademy.ac.uk/sites/default/files/resources/Student%20attitudes%20towards%20and%20skills%20for%20sustainable%20development.pdf

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11. EWB-UK – active student engagement in SD → globalisation; the EWB-UK Challenge

(http://www.ewb-uk.org/ and http://www.ewb-uk.org/ewbchallenge)

Engineers Without Borders – UK is a development organisation with a focus on students and young professionals, putting them at the centre of its operations and providing them with resources and contact to help them become development professionals in engineering scenarios across the world.

The EWB Challenge embodies design activity at levels 4 and 5 with opportunities for students to learn about design, teamwork and communication through real sustainable and cross cultural projects supporting communities in areas such as Vietnam, Cambodia, India and Nepal. http://www.ewb-uk.org/ewbchallenge

12. Institution-led initiatives in sustainability
– HEFCE-funded project in Leadership, Governance and Management - LGM [Gloucestershire, Exeter, Brighton, Aston, Oxford-Brookes]

(http://www.hefce.ac.uk/whatwedo/lgm/lgmprojects/sustainabledevelopment/leadingcurriculumchangeforsustainabilitystrategicapproachestoqualityenhancement/

and http://efsandquality.glos.ac.uk/)

13. HEFCE and other HE-funders – strategy
(http://www.hefce.ac.uk/whatwedo/lgm/sd/ ; http://www.hefce.ac.uk/whatwedo/lgm/sd/sdstrategy/ and http://www.hefce.ac.uk/whatwedo/lgm/lgmprojects/sustainabledevelopment/)

HEFCE funded a number of projects between 2010 and 2102 across UK HEI partnerships that were based on leadership, governance and management across the institutions. The projects included initiatives in sustainable development – for example "Leading curriculum change for sustainability: strategic approaches to quality enhancement", led by the University of Gloucestershire in partnership with Exeter, Oxford Brookes, Brighton, and Aston (see http://www.hefce.ac.uk/whatwedo/lgm/lgmprojects/sustainabledevelopment/leadingcurriculumchangeforsustainabilitystrategicapproachestoqualityenhancement/).

14. The Higher Education Academy - Policy and Strategy; Green Academy Initiative
(https://www.heacademy.ac.uk/workstreams-research/themes/education-sustainable-development
and
https://www.heacademy.ac.uk/workstreams-research/themes/education-sustainable-development/framework-and-hea-guidance)

The HEA supports HE providers in the development of sustainability-literate graduates who have the skills, knowledge and experience to contribute to an environmentally and ethically responsible society. It does this by commissioning research and producing reports to help shape ESD in the HE sector, working with the Quality Assurance Agency (QAA) to develop sector guidance on embedding ESD into the curriculum.

The HEA worked with 18 HE providers on leading institutional change for sustainable development. The work focused on the curriculum and student experience through its Green Academy change programme (see http://www.heacademy.ac.uk/resources/detail/sustainability/ESD_2014/Green_Academy

and

https://www.heacademy.ac.uk/resources/detail/sustainability/green-academy

15. The Ellen MacArthur Foundation: The Circular Economy
(http://www.ellenmacarthurfoundation.org/)

The Ellen MacArthur Foundation works in education, business innovation and analysis to accelerate the transition to a circular economy (see http://www.ellenmacarthurfoundation.org/circular-economy).

Its initiatives include publications and workshops:

- Cradle to Cradle - see http://www.mcdonough.com/speaking-writing/cradle-to-cradle/#.U5bd6vldWwU
- Workshop series - see http://www.heacademy.ac.uk/events/detail/2011/academyevents/23_May_Circular_economy_series_Edinburgh

16. The Royal Academy of Engineering; Engineers for Africa
(http://www.raeng.org.uk/international/activities/pdf/RAEng_Africa_Summary_Report.pdf)

The RAEng commissioned a report in 2012 that identified the need for enhanced engineering skills in Africa. It has established an initiative that looks into building capacity for the formation of engineers who can address and work on projects in sub-Saharan Africa. This is through its Enhancing Engineering Education Programme (EEEP), which aims to bring engineering curricula in universities in line with current industrial practice and to improve teaching practices in engineering through a structured and strong partnership between universities and local industry.

What next?

Having established that EngSD provides a substantial opportunity for the education of engineers, placing knowledge and analytical skills within motivational contexts, developing professional competencies and essential skills, it becomes clear that EngSD is only one step on the path to "improving the world through engineering" (IMechE, undated).

Many of the challenges facing the world are not constrained by traditional boundaries, be they technological, disciplinary, geographical or cultural; rather they are global challenges.
The 2012 Rio+20 UN Conference on Sustainable Development adopted 'The Future We Want' (United Nations, 2012) outcome document:

"We recognize that the younger generations are the custodians of the future…. We therefore resolve to improve the capacity of our education systems to prepare people to pursue sustainable development, including through enhanced teacher training, the development of curricula around sustainability, the development of training programmes that prepare students for careers in fields related to sustainability, and more effective use of information and communication technologies to enhance learning outcomes….."

Also confirming the global scope in that sustainable development activities should be:

"…action-oriented, concise and easy to communicate, limited in number, aspirational, global in nature and universally applicable to all countries while taking into account different national realities, capacities and levels of development and respecting national policies and priorities."

There are many opportunities for classroom activities which bring together the application of technology to real-world problems with a social dimension. A consideration of items as important and familiar as water (Clark and King, 2004) or food (IMechE, 2013) may provide numerous stimulating topic areas for solutions from all the engineering disciplines.

The global dimension brings a deeper meaning to student learning, with problems being characterised by having no pre-defined solutions, incorporated contested knowledge and having to meet the needs of diverse users. But this does pose a potential difficulty for students in the earlier years of their programme, where exposure to complexity needs to be managed to avoid overwhelming more challenged students. Male (2012) identifies globalisation as a threshold concept due to issues related to complexity, requiring foreign knowledge and challenging existing assumptions.

To illustrate the opportunities EngSD can provide in supporting high value learning through complex situations, Tomkinson (2009) describes how problem-based learning across engineering disciplines can approach problems for which there are no 'right' answers. Examples given include: water, shelter, energy and problem spaces. Each is characterised by being set in a situation which is realistic to the future professional interests of the learner but which will only have an outcome with a qualitative value of 'good or bad', rather than 'right or wrong'.

As described in the Royal Academy of Engineering's Guiding Principles (2005), EngSD will be considered to have been achieved when the three spheres of Techno-centric, Eco-centric and Socio-centric concerns

coalesce into one unified activity within the global dimension of engineering education with the openly recognised aim of protecting future generations from the impact of the actions of this generation.
As the teaching of EngSD moves beyond the application of technology or technological tools and towards environmental and eventually social issues, the understanding and skills needed by graduates will evolve and become more interdisciplinary in nature. This will require further evolution of teaching and learning through the integration of EngSD into the fundamental core of engineering programme learning outcomes.
This evolution of teaching may require a re-evaluation of the balance of the acquisition of knowledge and the development of skills within the curriculum, although this in itself requires a clarification of our understanding of the skills required by a graduate engineer beyond those of communication, numeracy, the use of information technology and learning how to learn, as identified by Dearing (1997).

Higher level cognitive skills have been identified by the Henley Report (Spinks et al., 2006) such as those which lead to systems solutions to problems of increasing complexity and which require both specialist and non-specialist knowledge.

The complementary nature of approaches employed in the teaching of professional ethics to those used in EngSD supports the rationale for integrating the global dimension of engineering into the engineering curriculum. Engineering academics have identified the global dimension as including (Bourn and Neal, 2008):

- the ability to take a broader perspective – application of curriculum across countries

- an appreciation that what we do in developing countries impacts upon ourselves
- understanding that our culture doesn't have all the answers and there is more than one perspective and approach
- understanding the local context of development
- coping with uncertainty
- dealing with global issues doesn't necessarily mean going to developing countries
- challenging stereotypes
- recognition of finite resources in the world and the impact of globalisation
- potential role of different technologies
- mitigating and adapting to climate change.

The global role for the sustainable engineer

When engineering curricula have incorporated the global dimension and the challenge of a holistic view of sustainable development, such as questions of economic growth (Goodhew, 2013) then they may be considered as containing the learning experiences necessary to meeting the six principles defining the role of professional engineers (Engineering Council, 2009), the first of which encompasses the societal requirement for engineers to contribute to building a sustainable society, present and future.

Our future engineers will be equipped to contribute to the United Nations Millennium Development Goals including the skills necessary to develop a Global partnership for development.

References

Arrhenius, G., Caldwell, K. and Wold, S. (2008) A tribute to the memory of Svante Arrhenius (1859-1927) *A scientist ahead of his time*. Royal Swedish Academy of Engineering Sciences.

Baillie, C., Bowden, JA. and Meyer, JHF. (2013) Threshold capabilities: threshold concepts and knowledge capability linked through variation theory. *Higher Education*. 65 pp227-246

Beder, S. (1989) Towards a More Representative Engineering Education. *International Journal of Applied Engineering Education*, 5 (2), 173-182.

Beder, S. (1989/90) Educating Ecologically Sustainable Engineers. *Education Links*, 37, 24-25.

Blincoe, K. (2009) Re-educating the Person. In Stibbe, A. (Ed) *The Handbook of Sustainability Literacy Skills for a Changing World*. Totnes: Green Books.

Bourn, D. and Neal, I. (2008) *The Global Engineer: Incorporating global skills within UK higher education of engineers*. Available from: http://eprints.ioe.ac.uk/839/1/Bourn2008Engineers.pdf [accessed 21.01.14].

Bowden, JA. (2004) Capabilities-driven curriculum design. *In Effective learning & teaching in engineering*. Baillie, C. and Moore, I. (Eds). RoutledgeFalmer

Clark, R. and King, J. (2004) *The Atlas of Water: Mapping the world's most critical resource*. London: Earthscan.

Clifford, M.J. (2005) Appropriate Technology: The Poetry of Science. *In Engineering Subject Centre Briefing Papers: Education for Sustainable Development*. Higher Education Academy Engineering Subject Centre.

Dawe, G., Jucker, R. and Martin, S. (2005) *Sustainable Development in Higher Education: Current Practice and Future Developments. A report for the Higher Education Academy*. Available from: http://www.thesite.eu/sustdevinHEfinalreport.pdf [accessed 27.11.14].

Dearing, R. (1997) *Report of the National Committee of Enquiry into Higher Education*. Available from: https://bei.leeds.ac.uk/Partners/NCIHE/ [accessed 15.07.13].

Desha, C. (2010) *An investigation into the strategic application and acceleration of curriculum renewal in engineering education for sustainable development.* PhD Thesis, Griffith University Australia. Available from: https://www120.secure.griffith.edu.au/rch/file/c723a9b3-8869-a011-c036-c80468264c1c/1/Desha_2010_02Thesis.pdf [accessed 30.06.14].

Dodds, R. (2004) Extending product life – the forgotten challenge. In *Design and Manufacture for Sustainable Development 2004*. Eds. Bhamra, T., Hon, B. Trowbridge: Professional Engineering Publishing, 135-141.

Engineering Council (2009) *Guidance on Sustainability for the Engineering Profession*. Available from: http://www.engc.org.uk/sustainability [accessed 15.07.13].

Engineering Council (2014) *UK Standard for Professional Engineering Competence Engineering Technician, Incorporated Engineer and Chartered Engineer Standard*. Available from: http://www.engc.org.uk/professional-registration/standards/uk-spec [accessed 07.07.14].

Fasli, M., Andrews, J. and Billam, N. (2007) *An investigation into the relationship between research and teaching in science and engineering departments: staff and student perspectives*.

Available from: http://www.heacademy.ac.uk/assets/documents/resources/publications/Andrews_Final_Report.pdf [accessed 15.07.13].

Fenner, R.A., Ainger, C.M., Cruickshank, H.J. and Guthrie, P.M. (2005) Embedding sustainable development at Cambridge University Engineering Department. *International Journal of Sustainability in Higher Education*, 6 (3), 229-41.

Forum for the Future (2004) *Learning and Skills for Sustainable Development: Developing a sustainability literate society*. Available from: http://rltperformingarts.org/rltpa-study-area3/files/2011/08/Sustainable_learningandskills.pdf [accessed 14.08.13].

Goodhew, P. (2013) Growth of what: GDP or quality of life, Letter to the Editor, *European Journal of Engineering Education*. 38. 2. pp119-120

Haase, S. (2014) Engineering students' sustainability approaches. *European Journal of Engineering Education*. 39 (3) 247-271

Heald, H. (2012) *William Armstrong: Magician of the North*. McNidder & Grace.

Hill, M. (2005) Emissions Trading and Sustainable Design. In *Engineering Subject Centre Briefing Papers: Education for Sustainable Development. Energy and Energy Systems*.

Holmberg, J., Svanström, M., Peet, D.J., Mulder, K., Ferrer-Balas, D. and Segalàs, J. (2008) Embedding sustainability in higher education through interaction with lecturers: studies from three European technical universities. *European Journal of Engineering Education*. 33 (3), 271-282.

Humphries-Smith, T. (2007) To Embed or not to Embed (Sustainability in the Curriculum) That is the Question – and do we have a choice? *International Conference on Engineering and Product Design Education*, 13-14 September 2007, Northumbria University, Newcastle upon Tyne, UK, 27-32.

Humphries-Smith, T. (2010) *Socio-centric sustainable design : the development of a learning resource: Engineering Subject Centre mini project report.* Available at: http://www-new1.heacademy.ac.uk/assets/Documents/subjects/engineering/sociocentric-sustainable-design.pdf [accessed 17.12.14]

IISD (2006). *The Sustainable Development Timeline – 2006*. Heather Creech. Available at: http://www.iisd.org/sites/default/files/pdf/2006/sd_timeline_2006.pdf [accessed 10.04.14].

IISD (2010). *Sustainable Development: From Brundtland to Rio 2012*. United Nations, New York. Available at: http://www.un.org/wcm/webdav/site/climatechange/shared/gsp/docs/GSP1-6_Background%20on%20Sustainable%20Devt.pdf [accessed 10.04.14].

IISD (2012). *Beyond Rio+20: What It Means for Global Higher Education*. Pamela Chesek in TDK Publication: The Chronicle of Higher Education. http://www.iisd.org/tkn/research/pub.aspx?pno=1630 [accessed 10.04.14]

IISD (2013). *What is sustainable development?* Available at: http://www.iisd.org/sd/ [accessed 10.04.14].

IMechE (undated) *Improving the world through engineering, a vision*, Institution of Mechanical Engineers, London. Available from: http://www.imeche.org/docs/default-source/about-us/IMechE_Vision_Book_2012.pdf?sfvrsn=0 [accessed 22.07.14]

IMechE (2013) *Global Food, waste not, want not*. Institution of Mechanical Engineers, London. Available from: http://www.imeche.org/docs/default-source/reports/Global_Food_Report.pdf [accessed 22.07.14]

Jones, P., Selby, D. and Sterling, S. (Eds) (2010) *Sustainability Education: Perspectives and Practice across Higher Education*. London: Earthscan.

Khan, P. and O'Rourke, K. (2005) Understanding Enquiry-Based Learning. In: Barrett, T., MacLabhrainn, I. and Fallon, H. (Eds) *Handbook of Enquiry and Problem Based Learning*. Galway: CELT. http://www.nuigalway.ie/celt/pblbook/chapter1.pdf [accessed 15.07.13].

Lilley. D and Lofthouse. V. A (2009) Sustainable design education – considering design for behavioural change, *Engineering Education: Journal of the Higher Education Academy Engineering Subject Centre*, 4 (1), 29-41

Male, S.A., Bush, M.B. and Murry, K. (2009) Think engineer, think male? *European Journal of Engineering Education*, 34 (5), 455-464.

Male, S. (2012) *Engineering Thresholds: an approach to curriculum renewal*. The University of Western Australia. Available at: http://www.ecm.uwa.edu.au/research/engineering-threshold-concepts [accessed 30/06/14]

Mitchell, C.A., Carew, A.L. and Clift, R. (2004) The Role of the Professional Engineer and Scientist in Sustainable Development. In: Azapagic, A., Perdan, S. and Clift, R. (Eds), *Sustainable Development in Practice Case Studies for Engineers and Scientists*. Chippenham: Wiley.

Nguyen, P. (2014). *Engineering Education for Sustainable Development in Vietnamese Universities*. PhD thesis, University of Gloucestershire, 2014.

Pelly, L. (2007) *Challenges to Engineering Education for Sustainable Development*. Available from: http://epc.ac.uk/wp-content/uploads/2012/10/Pelly-EPC-Congress-27-28-March.pdf [accessed 15.07.13].

Royal Academy of Engineering (2005) *Engineering for Sustainable Development: Guiding Principles*. Available from: http://www.raeng.org.uk/events/pdf/Engineering_for_Sustainable_Development.pdf [accessed 15.17.13].

Spinks, N., Silburn, N. and Birchall, D. (2006) *Educating Engineers for the 21st century: the industry view*. Available from: http://www.raeng.org.uk/news/releases/henley/pdf/henley_report.pdf [accessed 15.07.13].

Steiner, S.J. (2010) Engineering our world toward a sustainable future. In: Jones, P., Selby, D. and Sterling, S. (Eds) *Sustainability Education: Perspectives and Practice across Higher Education*. London: Earthscan.

Steiner, S.J. and Penlington, R. (2010) Approaches to the embedding of sustainability in the engineering curriculum – where are we now, and how do our graduates become global engineers? *Engineering Education 2010: Inspiring the next generation of engineers*, 6-8 July 2010, Aston, UK.

Sustainable Development Solutions Network (2014) *Solutions Initiatives*. Available at; http://unsdsn.org/what-we-do/solutions-initiatives/ [accessed 23.10.14].

Tomkinson, B. (2009) Coping with Complexity. In: Stibbe, A. (Ed) *The Handbook of Sustainability Literacy Skills for a Changing World*. Totnes: Green Books.

Tomkinson, R., Engel, C., Tomkinson, B. and Lawson, A. (2008) *Engineering Subject Centre Mini-Project Report: Education for Sustainable Development in Engineering Report of a Delphi Consultation*. Loughborough: Higher Education Academy Engineering Subject Centre

UN (1972). *Declaration of the United Nations Conference on the Human Environment*. Stockholm. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?documentid=97&articleid=1503 [accessed 10.04.14]

UN (1987) *Our Common Future: Report of the World Commission on Environment and Development*. Available from: http://www.un-documents.net/wced-ocf.htm [accessed 15.07.13].

UN (2012). *Back to our common future. Sustainable Development in the 21st Century (SD21). Summary of policy makers*. New York, Department of Economic and Social Affairs. Available at: http://sustainabledevelopment.un.org/content/documents/UN-DESA_Back_Common_Future_En.pdf [accessed 10.04.14]

UN (2012a). *Sustainable Development in the 21st century (SD21). SD21 project*. Available at: http://sustainabledevelopment.un.org/sd21.html [accessed 10.04.14]

UN (2012b). *The future we want*. Outcome document adopted at Rio+20. Available at: http://www.uncsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf [accessed 10.04.14].

UN (2014). *UN Decade of Education for Sustainable Development*. Available at: http://www.desd.org/ [accessed 10.04.14]

UNESCO (1992). *The United Nations Conference on Environment and Development*, Rio de Janiero. Available at: http://www.unesco.org/education/nfsunesco/pdf/RIO_E.PDF [accessed 10.04.14].

UNESCO (2002). *Education for sustainability, From Rio to Johannesburg: lessons learnt from a decade of commitment*. Paris 2002. Available at: http://unesdoc.unesco.org/images/0012/001271/127100e.pdf [accessed 10.04.14]

UNESCO (2010) *Engineering Report: Issues, Challenges and Opportunities for Development.* Available at: http://unesdoc.unesco.org/images/0018/001897/189753e.pdf [accessed 01.07.14].

WCED (1987). *The Brundtland Report: Our common future*. Oxford: Oxford University Press, 1987 p. 43.

Further reading

Teaching and learning resources
http://eden-share.lboro.ac.uk/id/item/100

The purpose of the resources document is to provide access to materials in curricula reform, recognition awards and university movements that this guide recommends to readers.

It is organised into sections giving information on organisations and publishers in the field of SD/ESD and journals, books, papers and reports. The entries include references and urls where appropriate as a basis for further reading.

About this guide:

The updated version of this guide has been written in three parts – a foreward that introduces sustainable development, the guide itself with newly-structured content and a new repository of teaching and learning resources as further reading and reference material.

About the series:

This is one of a series of peer reviewed booklets looking at various aspects of teaching and learning aimed at all those involved in engineering education. Originally published by the HEA Engineering Subject Centre in 2008 and reproduced by CEDE as an online resource in 2014.

About the centre:

The Centre for Engineering and Design Education's team of specialists work closely with the engineering and design schools at Loughborough University to encourage effective and efficient practice and innovation in teaching.

The Centre builds on the achievements of the engCETL and the HEA Engineering Subject Centre, to further enhance Loughborough's reputation for excellence in engineering education.

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