EMBEDDING SUSTAINABILITY IN UNDERGRADUATE CIVIL ENGINEERING COURSES

A PRACTICAL GUIDE

think up

CONTENTS

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EXECUTIVE SUMMARY

Universities in the UK are obliged to embed sustainability as a key theme in undergraduate civil engineering courses, but consultations with lecturers suggest that this is an area of the undergraduate teaching curriculum that many universities find difficult to define, deliver or assess. The work of civil engineers is inseparable from the complex world of environmental, economic, political and social factors, and civil engineers must now consider sustainable development as an important driver for design decisions.

In this report we identify three challenges that engineers must overcome in order to make progress in the field of sustainable design: complexity; values-based decision making; and interdisciplinary working. We have made the overcoming of these challenges the basis of nine principles for how sustainability can be enhanced in the curriculum, and provide tools, free online resources and suggestions for implementation in the classroom.

ACKNOWLEDGEMENTS

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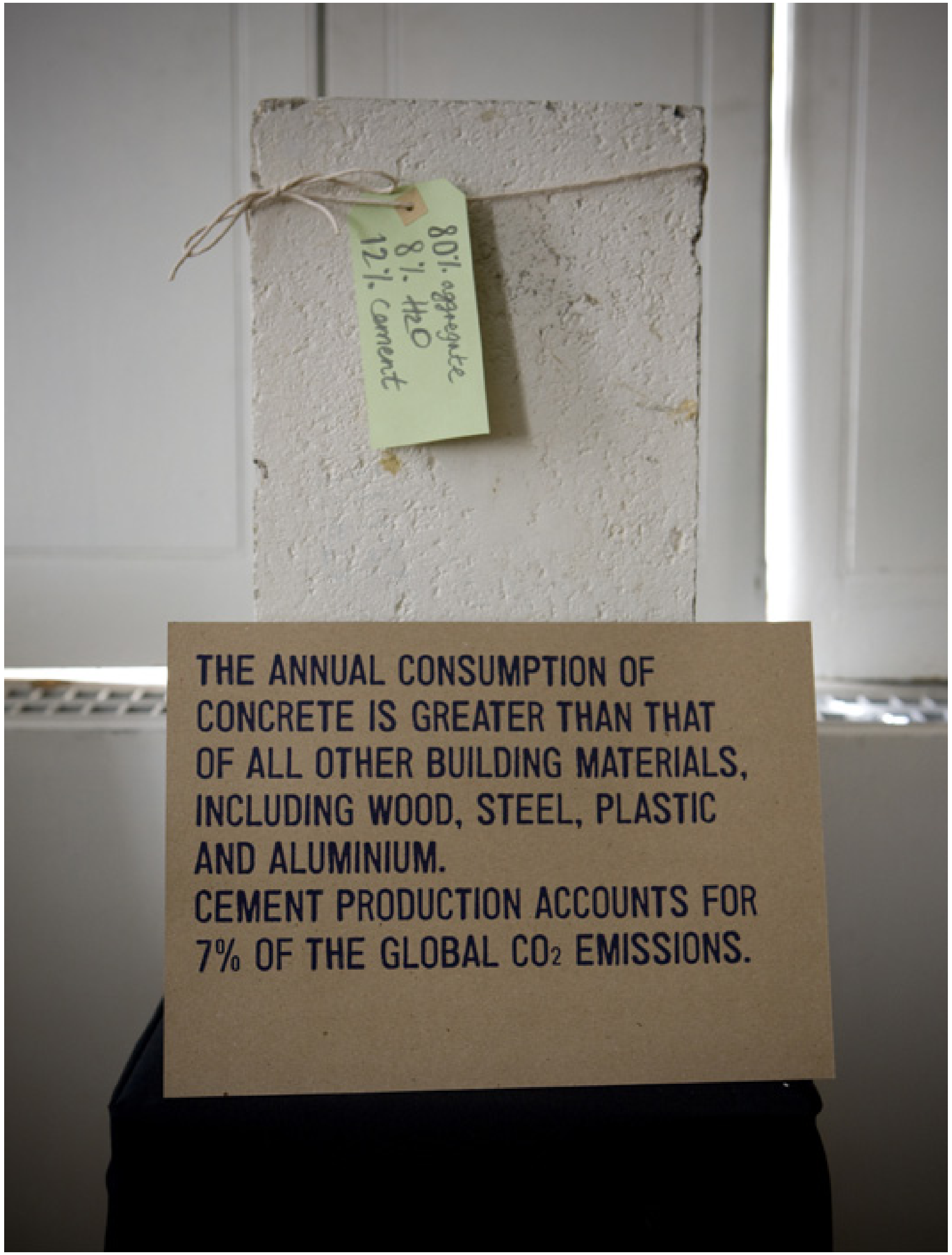
MANY OF THE IMAGES IN THIS REPORT SHOW INSTALLATIONS CREATED TO PROMPT THINKING ABOUT RESOURCE SCARCITY. THEY WERE USED AS VISUAL STIMULI AT THE JBM EXCELLENCE IN ENGINEERING CONFERENCE HELD AT THE ISTRUCTE IN SEPTEMBER 2011*

* Image references are provided at the end of this report


RECYCLING 1 TONNE OF STEEL:
• SAVES 1.5 TONNES OF IRON ORE
• SAVES 0.5 TONNES OF COKE
• SAVES 1.28 TONNES OF SOLID WASTE
• REDUCES AIR POLLUTION BY 86%
• REDUCES WATER POLLUTION BY 76%
• REDUCES THE ENERGY NEED BY 74%
1.987 tonnes Co2 per tonne



INTRODUCTION

The Royal Charter of the Institution of Civil Engineers (ICE) defines the profession of civil engineering as "the art of directing the great sources of power in Nature for the use and convenience of man"[1].

As Paul Jowitt, former President of the ICE has argued[2], the start of the 21st Century marks the end of a technological rationalist phase in technological innovation and economic development, and the start of a new 'systems phase' which demands "sustainable development, and with it the balancing of economic, environmental and social issues at all scales - political (local, regional, national, supranational) and spatial (urban, peri-urban, suburban/rural and land/coastal/marine-based)". Jowitt goes on to say that in order to adapt to this new operating phase engineers need to change their operating paradigm to, "the art of working with the great sources of power in nature for the use and benefit of society".

Further emphasising the important role that engineers will play in sustainable development, in the report 'Engineering for Sustainable Development: Guiding Principles' the Royal Academy of Engineering says that, "often it will be and should be engineers who lead processes of making decisions about the use of materials, energy and water resources, the development of infrastructure and the design of new products. One implication is that engineers must recognise and exercise their responsibility to society as a whole, which may sometimes conflict with their responsibility to the immediate client or customer [3]".

The Engineering Council UK, the body with regulatory responsibility for the engineering professions, requires engineers to undertake their activity in a way that contributes to sustainable development[4]. Reflecting the central role that sustainable development will take in practice, there is a requirement for sustainable development to be embedded in undergraduate teaching: 'pervasive throughout the engineering education programme'[5] in the undergraduate courses that are accredited by the Joint Board of Moderators (JBM). However, the JBM has also identified that sustainability is an area of teaching that some staff find difficult, and that there is a need for further teaching guidance for educators[6].

This report has been compiled to provide practical suggestions to help educators embed sustainability in the undergraduate engineering curriculum, and is based on the findings of desk research, conversations with educational institutions that are recognised as demonstrating best practice in this field, and on the findings of a half-day conference for representatives from the HE sector on embedding sustainability in the undergraduate curriculum, held at the Institution of Structural Engineers in September 2011. Our approach was to start with the concept of sustainable development itself and to ask what makes it different from more traditional areas of engineering practice and to characterise the challenges that engineers need to overcome in order to make progress in this area. In this report we identify three challenges and go on to define nine principles that can applied in undergraduate teaching to help engineers overcome these challenges, accompanied by practical suggestions for classroom implementation.

WHAT MAKES SUSTAINABILITY DIFFERENT?

The development of the London 2012 Olympic Park demonstrates how we can expect to see the principles of sustainability embedded into project briefs in future. It illustrates the context in which the engineers of the future will find themselves working and also the challenges that engineers face working in this domain.

The vision of the Olympic Develivery Authority (ODA) vision was to create a sustainable legacy for the Games (socially, economically and environmentally) and for excellent performance of the buildings in the Olympic Park. The ODA sought to set new standards for sustainable design and construction, which were enshrined in a set of 12 headline objectives embedded in all projects being delivered in the Olympic Park[7] (see box below).

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The twelve objectives for embedding sustainability into construction projects in the Olympic Park

Carbon: To minimise the carbon emissions associated with the Olympic Park and venues.

Water: To optimise the opportunities for efficient water use, reuse and recycling.

Waste: To optimise the reduction of waste through design, and to maximise the reuse and recycling of material arising during demolition, remediation and construction.

Materials: To identify, source, and use environmentally and socially responsible materials.

Biodiversity and ecology: To protect and enhance the biodiversity and ecology of the Lower Lea Valley.

Land, water, noise, air: To optimise positive and minimise adverse impacts on land, water, noise, and air quality.

Supporting communities: To create new, safe mixed-use public space, housing and facilities appropriate to the demographics and character of the Lower Lea Valley, adaptable to future climates.

Transport and mobility: To prioritise walking, cycling and the use of public transport to and within the Olympic Park and venues.

Access: To create a highly-accessible Olympic Park and venues by meeting the principles of inclusive design.

Employment and business: To create new employment and business opportunities locally, regionally and nationally.

Health and well-being: To provide for healthy lifestyle opportunities during the construction of, and in the design of the Olympic Park and venues.

Inclusion: To involve, communicate, and consult effectively with stakeholders and the diverse communities surrounding the Olympic Park and venues.

Challenge 1 - Coping with Complexity

Designers and planners faced with a set of sustainable development objectives such as these run into three difficulties[8]:

- ***Incompleteness***, or the difficulty of fully defining the problem. Development of any sort impacts so many different systems that it is not possible to take into account every factor. Arguably the twelve objectives above all contain sub-objectives, and so on, causing the scope of the problem to expand greatly.
- ***Aggregation***, or the difficulty of bringing factors together. There is no adequate single axis for optimistaion and decision-making.
- ***Specificity***, or in other words, what's important in one location may be unimportant in the next. "All projects these days claim to be sustainable, but none of them define sustainability in the same way"[9].

These difficulties characterise the complex problems that engineers must resolve when designing sustainably. The first challenge therefore that engineers must overcome in order to act with certainty in this domain is to develop the knowledge and skills to cope with complexity.

Challenge 2 - Values-based decision making

The second challenge that this case study illustrates is that unlike, for example, the simple optimisation of a structural system for weight, the consideration of so many different factors means that there can be no single right answer. Of the potentailly unlimited range of solutions, the question of which is the right answer is subjective, and the choice requires the application of judgement. Engineers must become comfortable with applying judgement to subjective decision making. What's more, they need to be aware that there is a professional expectation that the decisions they make adhere to the principles of sustainable development[10].

Challenge 3 - Interdisciplinary working

As such a long list of sustainable development objectives demonstates, the process of sustainable design requires engagement with a wide range of stakeholders and collaboration with professionals from a wide range of disciplines. And yet there are many reasons why learners may be uncomfortable with interdisciplinary working[11]: they may have concerns about finding a common language of working, or simply appearing stupid in front of someone with a different field of expertise; they may be required to consider viewpoints from individuals whom they don't respect; and the practical barriers to incorporating interdisciplinary learning may simply mean that learners get little experience of working in this way. Therefore the third challenge that engineers must meet is to be comfortable with interdisciplinary working.

PRINCIPLES

In this section we define nine principles that can be applied in undergraduate teaching to help engineers overcome the challenges identified above. Here you will find many references to online materials. If you are reading this document on-screen then you can follow the hyperlinks directly from the text; if you are reading a printed version of this document then you can find the web addresses in the table of resources on page 16.

PRINCIPLE ONE: SUSTAINABILITY IS MINDSET, NOT A SUBJECT

Like any of the other professional values that are developed in undergraduate degree courses, sustainability is a way of thinking rather than a subject. It should feature in all subject areas where appropriate.

Where specific knowledge and skills are required for sustainable design (such as those described under Principle Two), their development should be spread throughout the course modules rather than in a specific course called something akin to 'sustsinability'. This approach helps avoid sustainable development as being considered as a bolt-on: by students; or by staff. Over time, the consideration of sustainability in design should be an implied part of tackling engineering projects, rather than an explicit requirement.

In practice

In the undergraduate teaching courses at both Brunel and Bath, sustainability is a feature in most teaching modules where appropriate, rather than drawn out into a single bolt-on course. While some units only have minimal sustainability content - for example, briefly discussing the embodied energy of different retaining wall options in the Geotechnical Engineering course at Bath - these elements are deliberately included to demonstrate how sustainability should influence civil engineering decisions and designs[12].

PRINCIPLE TWO: ESTABLISH THE BASIC BUILDING BLOCKS

Basic (cognitive) learning theory dictates that before we can expect students to master the more advanced skills of assimilation, evaluation and judgement, we must provide basic knowledge and teach basic skills that will form the foundation for the more advanced abilities[13].

In the field of sustainable design this body of basic information is broad. The JBM's guidance note on sustainability in the curriculum requires students to develop knowledge and awareness of a wide range of considerations, including[14]:

- The impacts of sustainability on civil engineering
- Definitions of sustainability
- International protocols
- Environmental management systems
- Tools for environmental assessment and management
- Concepts such as life-cycle assessment.

This list is not exhaustive. Seeking to include all this additional material into the curriculum would be a considerable challenge. Fortunately, the internet is a rich source of up-to-date information on sustainable development and these topics lend themselves well to student-led web research.

In practice

Develop internet research skills - basic internet research skills are a pre-requisite to successful use of the web as a learning resource. In order to navigate the vast quantities of online material related to sustainable development, students should learn how to refine their searches. Many students know the basics of how to search, but this infographic 'How to Use Google Search More Effectively' is designed to help students become much more sophisticated searchers.

Use cascade learning - covering a wide range of relatively simple material in class is not necessarily a good use of class time. A good way to help students cover a lot of ground is to put students in groups in which each member of the group is assigned a single area of research which they then share with the rest of their group.

Work out the embodied energy of a building - at the University of Bath, students are asked to calculate the embodied energy of a building[15]. Using a real number, however crudely estimated, can help students understand the impacts of concepts such as embodied energy and life-cycle assessment. Using the Engineer's Toolbox, hosted in the Tools area of the Expedition Workshed website, students can estimate the volume of materials in an existing or proposed structure. The Tools area also links to calculators that can be used to estimate embodied carbon and energy. Using the carbon valuation resources on the DECC website students can calculate the carbon cost for projects.

Investigate the local impacts of climate change - the UKCIP website hosts a set of case studies detailing how local authorities in the UK predict climate change will have an impact in their area. Studying these examples will reveal to students just how wide-ranging the physical impacts of climate change are expected to be. A similarly rich seam for student-led research into the impacts of climate change comes from the Met Office. Since 2011 the Met Office has been compiling scientifically robust and impartial information on the physical impacts of climate change for more than 20 countries. Detailed reports are available from their website.

Olympic Park Case Study - the development of the London 2012 Olympic Park represents one of the best documented examples of the implementation of a sustainable development plan in the UK. The learning legacy reports, available from the London 2012 website, are ideally suited to forming the basis of a student group study.

What the Government does - the HM Treasury Green Book sets out the framework that Central Government uses to appraise projects. It provides concise descriptions of various economic appraisal methods and concepts, such as Net Present Value and Discounting. Students at Imperial College use the figures in the Green Book to help them apply the principle of discounting future year impacts as part of their coursework.

Demonstrate material life-cycle assessment - ask students to choose a specific material and to research all stages in its life-cycle. The Granta website provides a range of tools to help learners understand the life-cycle of a wide range of materials. Note that these teaching materials are not free-to-use.

Explore project life-cycle cost analysis - students could also be asked to consider the economic life-cycle of a project. While detailed numbers are difficult to calculate, it is relatively straight forward for students to roughly estimate construction costs and operation costs. The American Whole Building Design Guide (WBDG) provides a concise summary of the stages to consider in life-cycle cost analysis for a building. Students could be asked to carry out a crude life cycle cost analysis using the steps in the WBDG guide in conjunction with the figures from Green Book, mentioned above, and the construction costs provided in the Engineer's Toolbox hosted on Workshed.

Introduction to cost benefit analysis - large-scale civil engineering projects, both historic and current, provide good case studies for investigating the conclusions of cost benefit analysis (CBA) studies. Possible projects for investigation could include the M1 Motorway, High Speed 2, the Jubilee Line Extension (JLE), Crossrail and the Thames Tideway Tunnel. Hansard provides a summary of the CBA for the JLE while the Bartlett has produced a detailed report setting out the economic arguments for the line. Two resources provide contrasting perspectives on the CBA for the Thames Tideway Tunnel: the first is from Defra, which provides a CBA supporting the case for the project; the second is a report which criticises Defra's methodology, and proposes an alternative CBA which shows the Thames Tideway Tunnel to be unfavourable.

Flood and coastal erosion risk: CBA in-depth - this area of civil engineering is rich with examples of the application of CBA to appraise options for managing flood and coastal erosion risk. Defra has produced guidance notes for assessing and valuing the risk to life for use in appraisal of risk management measures. The resource includes data for use in calculations and a worked example that could form the basis of a set of problems for students. The Environment Agency has produced a comprehensive guide to carrying out flood and erosion risk management appraisal, which contains detailed case studies. This guidance document may be too detailed for most students, but again the information within can provide the basis of worked examples.

Use real environmental assessment tools - students at Heriot-Watt University use a version of CEEQUAL (an assessment scheme for improving sustainability in civil engineering) to assess the sustainability credentials of real engineering case studies. Students determine an initial project score based on evidence provided, and a potential score based on improvements that could be made to the project, allowing students to engage with a case study in a structured, systematic way[16].

Further resources

The DirectGov website gives a brief history of climate change, a summary of international protocols and links to wide range of further resources.

The Defra website has details of the UK Climate Change Risk Assessment (CCRA), the first assessment of its kind in the UK, providing students with useful examples of how government assesses risk with respect to climate change.

PRINCIPLE THREE: SEE THE WHOLE PICTURE (SYSTEMS THINKING)

In his paper 'Systems and Sustainability: Sustainable Development, Civil Engineering and the Formation of the Civil Engineer' Paul Jowitt usefully differentiates sustainability from technical disciplines, such as hydraulics or mechanics, by defining it as the context in which technical and other disciplines are applied and the emergent properties that arise from their application[17]. He argues that the way to bring rigour to sustainability is to adopt a systems approach.

Systems thinking has many applications in engineering and so the principles can be taught at any time in the undergraduate course and not necessarily specifically in the context of an environmental design project. What is important is that systems tools appear to the learner to offer a way of making sense of the many factors to consider as part of sustainable development. Students should be shown that by defining a project as a system, all the interactions between the elements of that system can be described, bridging the gap between the less technical requirements of some stakeholders and the more technical requirements of others.

In practice

Map the system for building design - taking a building with which they are familiar and ask students to map the system of the building's stakeholders and their interactions.

Use a simple multi-constraint analysis - leading learners through a simple systems analysis such as a multi-constraint analysis (MCA) can demonstrate to students that it is possible to consider quite different variables systematically. The Department for Communities and Local Government has produced a manual for multi-criteria analysis which uses an MCA of buying a toaster to illustrate the process, before going on to show how it has been used on much larger projects.

Incorporate MCA into a design project - requiring learners to carry out MCA or other types of analysis as part their design projects may prompt potentially lively discussions about the factors to include in the analysis and their relative weighting.

Stakeholder mapping - As well as helping engineers make decisions, systems descriptions can be a useful tool for representing complex problems to stakeholders. As part of a project working with real stakeholders, students should be encouraged to take the opportunity to use a systems approach to present the problem to the stakeholders, and show how the stakeholders' perspectives have been incorporated.

For example, students taking the 'Systems Thinking and Practice' module at the Open University are required to carry to use systems mapping techniques to communicate sustainability issues to stakeholders when working on community design projects[18].

PRINCIPLE FOUR: DEVELOP CRITICAL THINKING TO HELP UNDERSTAND DIFFERENT PERSPECTIVES

Understanding and valuing different personal perspectives is important for working with multiple stakeholders and for interdisciplinary collaboration. Developing a critical view of personal perspectives can be a starting point for understanding other people's views and beliefs. There are lots of potential starting points for learner self reflection (several are suggested below). All of these factors and many more help shape personal perspectives, and so students should feel it is legitimate to bring these perspectives into the classroom.

Based on a foundation of self-knowledge, students can then develop critical thinking skills through a range of activities applied in a peer-to-peer learning environment. Where this approach is employed, it must be done so in an atmosphere of trust and respect, with the aims of the exercise made clear[19]. Some students may find this process particularly difficult if they have not experienced this sort of learning before, for example if they have been taught exclusively in traditional learning environments. Poor language ability and cultural differences may also present learners with barriers in this context[20]. Importantly the educator should themselves be engaged in self-critique, and be seen to be actively evaluating their own life-choices as a result of self-reflection[21].

In practice

Fresher's Week - self-awareness development work lends itself well to start-of-term get-to-know-you activities. They also work well to help develop communication skills. Below are three themes for self-reflection; the outcomes could be in any manor of formats including group discussions, presentations, posters, web profiles or video clips.

***My environment* -** ask learners to think about the physical environment in which they grew up, including what their home is like, the local landscape, what they like and dislike about it, what would improve their home environment.

***My motivations* -** ask learners: why they want to be engineers; who they believe have been great engineers; how did they get to where they are now.

***My intentions* -** ask learners: what they want to achieve as professional engineers; what practical changes they could make to the environment around them; what impact they want to have.

Peer-to-peer evaluation of student work - this method of evaluation is increasingly common in undergraduate teaching, and is important for developing skills for constructive criticism. For example, second year civil engineering students at the University of Edinburgh are asked to critically evaluate each other's contribution to the team twice during a group design project. This peer-to-peer evaluation encourages students to think critically about their own attitudes and those of their peers.

Role play - another activity that encourages critical thinking is play. Combining role play with debate asks learners to assume and critique perspectives which may be quite different from their own. For example, at the pilot of the Nuclear Island Constructionarium project, in which a group of undergraduate engineers built a miniature reactor containment building in a week, participants were asked to take part in a mock town hall meeting. This role play exercise required different students to take on the role of concerned members of the public, and to debate issues with other students taking on the role of engineers tasked with defending the project.

Blogging - another method for self- and peer-to-peer critique, blogging can be used to encourage students to set out their thoughts in writing, and opening these thoughts to scrutiny. The IDeX project (described at the end of this report) uses blogging throughout the design course to encourage students to share their thoughts with stakeholders.

PRINCIPLE FIVE: LEARN FROM OTHER STAKEHOLDERS

Sustainable development usually requires engineers to consider the needs of a wide range of stakeholders. It is already common place in undergraduate teaching for students to consider the perspectives of a range of hypothetical stakeholders as part of project work. Where possible, however, students should be given the opportunity to meet and learn from real stakeholders on real projects.

In practice

Stakeholder consideration a basic requirement - ensure that stakeholder consideration is always a part of design projects.

Stakeholder survey - ask students to conduct interviews with people in connection to a real engineering project under development in their area. Working with real stakeholders in this way not only exposes students to real perspectives but it also helps students develop their communications skills.

Run your own enquiry on a real project - invite a number of stakeholders to take part in a mock enquiry into a local engineering project. Challenge a number of students to take on the role of the engineers who are defending the project

Run Your Own Contingent Valuation Survey - introducing students to Contingent Valuation Method (CVM) surveys provides an opportunity for students to explore stakeholder perspectives in a systematic way. The ecosystem valuation website provides a simple introduction to CVM with a number of case studies that students can use to help create their own small-scale survey to investigate perspectives on a real project, either among the student population, or among the local community.

Get involved locally - local community development projects offer a rich seam of sustainable development learning opportunities for students: they encounter real stakeholder perspectives; they can contribute to decision-making; and develop skills that complement their theoretical knowledge. Importantly real projects such as these can teach students about practical solutions to real problems.

Online news - voxpops videos are a great resource for investigating stakeholder perspectives. Students could be tasked with gathering together and presenting a range of stakeholder viewpoints on real engineering projects.

Everyone is a stakeholder - ask students to consider engineering projects under construction in their environment and to consider their own perspectives as a stakeholder on that project.

PRINCIPLE SIX: LEARN FROM OTHER DISCIPLINES

Overcoming barriers to working with other disciplines is an important part of preparing students to work as part of integrated design teams. The internet is a powerful tool for giving educators and learners insights into other disciplines as well as providing ways of overcoming the structural barriers to working between departments, such as timetable clashes.

In practice

Who's involved? - a good starting point is for learners to identify the other design disciplines with which they will have to work. At the University of Bath, first year students are asked to map out all of the different stages in the design of a building and to identify who is involved.

Bio-diversity 101 - students need basic information about other design disciplines in order to confidently open a dialogue with their colleagues. Learners can carry out their own research into other subject areas and share their findings; alternatively experts from other fields can be brought in to the classroom to give an introduction to their discipline. For example, civil engineering students at Brunel University go to presentations by staff from other departments within the university. Visitors from other departments should be asked to share good examples of their work and what they believe the merits of particular projects are.

Show and tell - as a reciprocal to the above arrangement, learners should be able to describe their own work to students in other disciplines. This process could be established as an exchange, if not in person, then using online video clips.

Interdepartmental working - there is little substitute for experience of working with learners from other disciplines. For some universities this is made easier by the nature of their course structure. At the University of Edinburgh, first year students are required to carry out a group design project in teams made up of students from a range of different engineering departments. Typical student briefs include the design of a hydroelectric dam project or the design of a Passiv House. For an advanced example of interdisciplinary working see the IDeX project described at the end of this report.

Interdisciplinary web collaboration - where in-person collaboration is not possible then interdisciplinary collaboration can be facilitated using web tools, from Skype, to Facebook and even Twitter.

Team build challenges - these are challenges typically run outside the university envrionment that encourage interdisciplinary working in a competition environment. This hits a number of our key principles: collaboration with others, working under pressure outside the comfort zone, and peer-to-peer critical thinking.

PRINCIPLE SEVEN: APPLY JUDGEMENT TO REAL PROBLEMS

Principles Two to Six cover scoping the problem and gathering wide ranging information from lots of different sources. Principle Seven is to require student to apply their judgement to sustainable design problems and to encourage them to feel comfortable with justifying their decisions.

The important thing to emphasise is that judgements are based on values rather than objective factors. It is therefore to be expected that two people may make completely different judgements depending on their value sets. While in this context there can be no right answer, there may be answers that are more or less acceptable to the stakeholders involved. The important skill for students to develop is to be able to justify their decisions.

In practice

Appraise build options in the context of sustainability - students at the University of Bath are required to appraise build options in the context of sustainability wherever they have the opportunity to do design as part of the curriculum. Embedding this process throughout the course helps reinforce the idea that applying judgement to design is as natural as using mathematics.

Apply your judgement to a local project - under Principle 5 we suggest students seek out various stakeholder perspectives on real local construction projects. Choose a contentious issue in relation to that project and ask students to apply their judgement to make a decision regarding this issue.

Review the decisions made on a real project - ask students to choose a real project and challenge them to think about why certain design decisions were made in relation to sustainable development. Challenge students to describe the values of the people who have made the key decisions on that project. Ask them if they would have chosen differently. Many projects may claim to be sustainable in their marketing material, but how much of it is 'green wash'?

Assess and mitigate environmental risk - environmental engineering design projects provide an excellent opportunity to ask students to assess environmental risk and to choose between options to mitigate that risk - in doing so they will have to demonstrate the application of judgement.

For example, second year students at the University Bath are required to consider environmental risks when setting out a flood defence scheme to protect a SSSI against rising sea levels.

Re-visit MCA - an important part of multi-constraint analysis is assessing the relative weighting of factors under consideration. Where students have used MCA as part of a design project, challenge them to justify their decisions for the weightings that they have used. Ask them how systems such as BREEAM weigh various factors against each other.

PRINCIPLE EIGHT: EMPHASISE A COMMITMENT TO PROFESSIONAL VALUES

As professionals engineers are expected to act in accordance with a number of principles or values: honesty; care; fairness; respect; a commitment to health and safety; and a commitment to sustainable development. Encouraging students to think of themselves as professionals right from the start of their studies emphasises the importance of judgement in their work, and it emphasises the expectation that as engineers they will adopt a specific set of values. This set of professional values provides a useful framework for critical evaluation, and has the potential to encourage students to think carefully about the judgements that they come to.

In practice

Write a professional development diary - at Brunel University, students are encouraged by staff to keep a professional development log, which can act as a regular prompt for self-evaluation

Meet practicing engineers - students may become motivated to become a professional engineer by meeting people who are already in practice. Encounters can be made either at the university, on a visit to a local company or at a professional institution. Practicing engineers can offer insights into exciting real-life projects as well as offering their own perspectives on the profession, which in turn may prompt students to think about their own attitudes.

Establish a student civil engineering society - doing this requires learners to develop professional behaviours by taking on additional responsibilities. It also offers students the chance to interact with practicing engineers in order to organise events such as site visits.

PRINCIPLE NINE: TAKE LEARNERS OUTSIDE THEIR COMFORT ZONE

It is the expectation that engineers demonstrate among their collection of professional values a commitment to sustainable development. From an educational point of view, changing personal perspectives is a prerequisite to achieving a change in values. Exposing learners to disorientating dilemmas is a crucial step in the development of new perspectives because these dilemas require students to profoundly re-evaluate their own attitudes and beliefs[22].

Such learning experiences may be quite uncomfortable as they are designed to call into question personal perspectives and potentially lifestyle choices as well. Every learner's personal perspective will be different, as will the degree of discomfort they will feel when being asked personally challenging questions.

In practice

Question the ethics of engineering - a crude annual survey of undergraduate civil engineers at Imperial College between 2003 and 2006 would typically show that a third of engineering students claimed to be motivated by doing good[23]. But history yields plenty of examples of when engineers have done more harm than good. Challenging students to confront the harm that engineers may have caused in the past could be used as an opener for discussing the uncomfortable possibility that they may themselves act in a way that causes harm to others.

Personal ecological footprint audit - there are a wide range of online tools for assessing an individual's ecological footprint. Asking students to conduct an audit of their own ecological footprint and to share the results with peers offers the opportunity to hold in-depth conversations about personal lifestyle choices. The discussion can be further widened by asking students to compare their ecological footprints with average results from other parts of the world. Discomfort - and therefore interesting debate - may arise where an individual's beliefs do not hold with their actions.

Discussing departmental strategy - opening for discussion the teaching department's strategy for sustainable management of its resources offers the opportunity to:

- see how a sustainable management strategy must be practically implemented and the decisions that need to be made
- show learners the role they personally have to play in delivering the sustainability strategy of the environment that they occupy
- gives students the opportunity to challenge current practice and to understand what the impacts would be of any changes they would like to see

This approach is likely to prove controversial in departments where the management activities do not reflect the approach to sustainable development taught in the classrooms; however bringing students into the discussion not only offers a great learning opportunity; it may also motivate the student body, whose actions contribute significantly to the department's ecological impact, to behave more responsibly, thus easing the implementation of any sustainable management strategies on the part of the department.

IDeX - Integrated Design Experience - an exemplar project

The integrated design experience - IDeX - led by Washington State University aims to establish a replicable model for student engagement and faculty development in sustainability engineering. The scheme is designed to move the design profession into a new era of sustainable solutions for the built environment by challenging students to develop inspired solutions to challenging and contemporary design projects focused on the tennets of sustainability. These cohorts will be composed of students from relevant design disciplines, construction management, and other subject areas as dictated by the project scope. Allied firms will bring current sustainable design practices challenging students to develop analytical techniques and code justifications related to current practice.

One of the design briefs from 2011/2012 is the improvement of the Friday Harbour Ferry Terminal in Washington State.

Issues looked at by the students include:

- Massing
- Surface run-off and pollution of waterways
- Efficiency of ferry loading and unloading
- Pedestrian safety
- Design of an elevated walkway
- Connecting the community to the ferry.

The IDeX project uses web tools to link students stakeholders of the real Friday Harbour Ferry Terminal regeneration project. For example, students keep a detailed blog tracking the development of their designs and they are using an online survey to gather data from regular users of the ferry terminal.

Combining as it does stakeholder engagement, interdisciplinary working, systems thinking and judgement, the IDex project is a sustainable education initiative that demonstrates many of the pricniples set out in this report for embedding sustainability into undergradaute teaching courses. Find out more at **www.idexstudio.org**

CONCLUSIONS

It will be difficult to identify the point at which sustainability is sufficiently embedded in the undergraduate civil engineering curriculum, since our understanding of sustainable development is evolving, and given the difficulty of assessing students' proficiency in this domain.

Nevertheless, with the challenges of teaching sustainability to undergraduate civil engineers having been raised by the JBM, in this report we have set out a series of principles that course designers can follow to help guide them in improving their educational offer.

We hope that these suggestions will prompt creative and imaginative responses to this educational challenge and we would be delighted to receive any feedback from educators who have implemented these principles in their teaching.

TABLE OF RESOURCES

How to Use Google Search More Effectively	http://on.mash.to/AoJYgy	Really useful tips for how to use Google search effectively - useful for even the most advanced users.
Tools - Expedition Workshed	http://bit.ly/yS16gJ	Contains a 'toolbox' of useful data that students can use to help them calculate the mass of materials in a building.
DECC carbon valuation tools	http://bit.ly/zdkcGN	Figures used by Government for pricing carbon
UKCIP - local authority reports	http://bit.ly/ArkVOY	A set of case studies detailing how local authorities in the UK predict climate change will have an impact in their area.
Met Office data on the physical impacts of climate change	http://bit.ly/AkTCzx	Detailed reports and data on the impacts of climate change in twenty countries around the world.
Sustainability Learning Legacy from the 2012 Olympic Park	http://bit.ly/yXHxdz	The learning legacy reports, available from the London 2012 website, are ideally suited to forming the basis of a student group study.
HM Treasury Green Book	http://bit.ly/yOFVTd	Key information and standard approaches used by Government when carrying out project appraisals
Granta teaching resources on life-cycle assessment of materials	http://bit.ly/wUUH3i	The Granta website provides a range of tools to help learners understand the life-cycle of a wide range of materials. Note that these teaching materials are not free-to-use.
Whole Building Design Guide	http://bit.ly/wf4IJA	A summary of stages to consider during life-cycle cost analysis for a building.
Jubliee Line CBA from Hansard	http://bit.ly/w6JSQH	Useful headline figures for discussing cost benefit analysis for a large civil engineering project.
Jubilee Line project profile	http://bit.ly/yfjfgl	Detailed project profile of the Jubilee Line Extension setting out the economic arguments for the project.
Defra cost benefit analysis for the Thames Tideway Tunnel	http://bit.ly/yiiMw1	Defra's cost benefit analysis that supports the case for the Thames Tideway Tunnel.
Alternative cost benefit analysis for the Thames Tideway Tunnel by Chris Binnie	http://bit.ly/y9AFSf	An alternative cost benefit analysis for the Thames Tideway Tunnel showing the project to be economically unfavourable.
Assessing and Valuing the Risk to Life from Flooding for Use in Appraisal of Risk Management Measures	http://bit.ly/zQSxtt	An example of how risk to life is valued in the appraisal of civil engineering projects.
Environment Agency guide to carrying out flood and erosion risk management appraisals	http://bit.ly/yYjLLr	Provides very detailed examples of the application of cost benefit analysis
A history of climate change on the DirectGov website	http://bit.ly/xl1WBZ	A canter through the history of climate change, international protocols and links to further resources.
UK Climate Change Risk Assessment on the Defra website	http://bit.ly/wlOsri	Students can use this tool to explore how government assesses risk with respect to climate change.
Multi-criteria analysis: a manual	http://bit.ly/xMRkHC	A detailed guide on how MCA is applied in government accompanied by an easy-to-understand example using a toaster.
Introduction to contingent value survey methods	http://bit.ly/yfb7xV	This guide produced by Ecosystem Valuation provides useful examples of how CVM has been applied

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The savings from recyling one tonne of steel	RECAP *Wastewatch*. [Online]. Available at http://www.recap.co.uk/recycling-at-home/materials/cans [Acessed 28-March-2012]
The annual consumption of concrete is greater than that of all other building materials, including wood, steel, plastic and aluminium.	Ashby M.F. 2009 "Materials and the environment" pp17, Butterworth-Heinemann, Canada
Cement production accounts for 7% of CO2 emissions	Mehta P.K, Monteiro P.J.M "Concrete and the Environment", [Online]. Available at http://www.ce.berkeley.edu/~paulmont/CE60New/Concrete%20and%20the%20Environment.pdf [Accessed 8-March-2012]
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