TAKING STOCK: SUSTAINABILITY IN ENGINEERING TEACHING; CASE OF CES EDUPACK – SOFTWARE FOR TEACHING

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Abstract
The paper presents the results of a survey of academics about teaching sustainable development topics in engineering, design and materials science courses, with particular emphasis on materials aspects of the problem. Over 200 responses were analysed, complemented with the outcome of a multi-national workshop on the subject, and the main findings were summarised. Key findings were the need for well-documented case studies for project-based learning, and the need for a more global perspective in teaching this topic. A recently published ‘5-step methodology’ provides a framework for individual or group student work on a diverse range of problems: from substitution of sustainable materials into products, energy-using devices, to renewable energy and storage technologies. The diversity of potential case studies, and the breadth of knowledge that could be required to address the dominant issues in a given problem, presents a particular educational challenge to help students to navigate with confidence through a meaningful analysis. The paper discusses some refinements to the new methodology that could improve its rigour, and its ease-of-use by undergraduate or graduate students.

1 INTRODUCTION

Engineering students are now expected to understand and demonstrate competencies in wider contemporary global challenges. The UK criteria for accreditation of engineering degrees explicitly specify sustainability and sustainable development under “Design” and “Economic, Social and Environmental Context”. Similar statements are found in the equivalent ABET criteria in the USA. In professional practise these issues are increasingly connected to assessment and reporting of resource, energy and material efficiency, challenges of international trade and global supply chains, environmental policies, and wider stakeholder involvement in decision-making. These issues are complex and multifaceted – in contrast to much of the conventional content of engineering training. Analysis of the sustainability of different design solutions requires traditional engineering skills and knowledge, but broadened in several respects to include: (i) the less familiar metrics of environmental impact and life cycle assessment; (ii) the softer skills of assessing stakeholder engagement and interpreting international regulations; and (iii) managing uncertainty and recognising multiple answers, requiring a degree of subjectivity.

1 The UK Standard for Professional Engineering Competence: (http://www.engc.org.uk/professional-registration/standards/uk-spec)
2 ABET accreditation Website: (http://www.abet.org/)
It is recognised that the best way to involve students with issues of this type is by project-based learning using active learning techniques. Discussions, workshops and presentations on the educational challenge have been increasingly common at international conferences in recent years\(^3\). These confirm the issues identified above, and suggest that it is timely to review current practice, emerging educational solutions, and to analyse future trends.

A survey was therefore conducted by the Education Team at Granta Design, who develop teaching resources for materials-related courses in engineering, design and science, built around the Cambridge Engineering Selector (CES) software tools\(^4\). The aim was to identify academic user needs, and to assess the potential for future development of the Sustainability Edition\(^5\) and case studies, using the methodology recently published by Ashby and co-workers (Ashby et al 2013).

### 2 METHODOLOGY AND DATA

The survey\(^6\) was run for 2 weeks in February 2015 and the data collected and analysed with the online tool: [https://www.smartsurvey.co.uk/](https://www.smartsurvey.co.uk/). The survey was sent to around 4000 academics worldwide involved in teaching Sustainable Development to engineers, including those who had indicated a specific interest in Environmental topics in the internal database of Granta Design.

The number of responses was approx. 5% with 212 respondents from around the world, mostly with engineering, design and materials science background, and teaching a mixture of undergraduate and graduate courses. Additional data was also collected at a workshop at KU Leuven, Belgium (January 2015) on the topic of Materials and Sustainable Development, with 28 participants from 10 universities and colleges from Ukraine, Russia and Israel, involved in education of materials-related disciplines. The format of the workshop was: introduction to the topic and the "5-step methodology" (see section 4), showcase of the methodology via a case study involving group work to conduct stakeholder analysis, and a final discussion.

The workshop identified a lack of global perspective on materials in teaching. Environmental impact is considered from the perspective of how a certain material or process could potentially be harmful and mostly at a local or national level. A global scale assessment was not a common practice in the countries from which the delegates came. The cultural sensitivity and political dimensions thus have to be carefully considered in any global scale debate, as things can look different from each country or regional perspective. The social dimension of sustainable development, too, is often ignored. There was a discussion among academics, in particular, of how and who should consider and introduce the social impact into the debate.

### 3 THE SURVEY: WHAT WE HAVE LEARNED

Selected questions and responses are presented here to draw out the main findings of the survey.

**Question 4 asked about the preferred sources used in teaching Sustainable Development**

85% of the respondents indicated the use of case studies in their teaching (Figure 1). Realistic case studies are the strongly preferred approach among educators in many contexts, whenever there is a need

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\(^6\) The whole survey can be found on-line ([http://www.smartsurvey.co.uk/s/143055ZGMXU/](http://www.smartsurvey.co.uk/s/143055ZGMXU/)).
to bring in strategic and business-related information with a focus on systems thinking and analysis. This is certainly the case in analysis of Sustainable Development.

There was a notable demand for case studies of different lengths – from as short as an example within a single seminar or lecture, to projects running for a full semester. Sample responses of the challenges included: “Finding case studies that are simple enough for the students to get involved and complex enough to challenge their reasoning”; “Finding problems that are simple enough to serve as introductory material and yet are interesting for the students”; “My Materials Selection course serves students with different backgrounds, some strongly quantitative and some not”. Another academic commented that: “In general: “small data” for a teacher can mean “big data” for a student: so there is always a demand for examples that have different levels of complexity”.

<table>
<thead>
<tr>
<th>4. Which of the below are used in your teaching? (choose any that apply)</th>
<th>Response Percent</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Case studies</td>
<td>84.43%</td>
<td>179</td>
</tr>
<tr>
<td>2. Field work</td>
<td>32.55%</td>
<td>69</td>
</tr>
<tr>
<td>3. Text book(s)</td>
<td>80.19%</td>
<td>170</td>
</tr>
<tr>
<td>4. Other (please specify):</td>
<td>35.85%</td>
<td>76</td>
</tr>
</tbody>
</table>

Figure 1: Q4 from the survey: Sources for teaching Sustainable Development

Another point concerning the local context was made: “Most of the examples available are from a developed world environment, and only act as a guideline – ours is a very different environment, where sustainability has to be considered from the point of view of how a family of five can survive on an income of less than one dollar a day”. She continues, “Our students live in an environment where extreme levels of income disparity exist – hence what design should be selected as the best possible alternative, for example, while selecting a bench for a railway station platform: steel, concrete, polymer composite, or a bamboo-based alternative? Similarly, for school furniture, or for infrastructure-related solutions, or the body and interior fittings of a truck or bus – these all demand judicious selection”.

Question 14 asked: “What do you find most challenging in teaching your courses?”

This generated many thought-provoking responses:
“Teaching uncertainty and expert judgement of complex systems. Not black-and-white”.
“To create an awareness that all materials should be treated with respect, care and understanding: there are no bad materials, only bad or wrong applications of materials and processes.”.
“Not frightening the students with sustainability stories that sound like certain doom for humanity. In particular, I steer away from scary stories for first-year students because I don't want them to feel like there's very little they/we can do to improve our future. I want them to get hooked on engineering as a problem-solving tool before hitting them with the really hard problems”.
“Make students understand the concept of environmental impact before designing and producing the product, with reference to energy, water, resources consumption and the pollution caused by the product on ground water, air, land etc. CAD/CAM helps in the quick launch of new product, but we have to consider the environmental impact for a safer tomorrow, so that we cause the least climate change effect”.

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Question 6 asked about themes to introduce Sustainable Development in teaching

Figure 2 shows that the dominant themes were "life cycle assessment" and "environmental impact" with 75% and 78% of respondents selecting those. "Material circularity" and "critical materials" scored above 40%; "resource management" and "materials risks" were above 30%. Both "environmental regulations" and "social impact" were less than 30%.

<table>
<thead>
<tr>
<th>6. Which themes, related to the topic of Sustainable Development, do you cover in your teaching? (choose any that apply)</th>
<th>Response Percent</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 resource management</td>
<td>37.02%</td>
<td>77</td>
</tr>
<tr>
<td>2 material circularity</td>
<td>45.19%</td>
<td>94</td>
</tr>
<tr>
<td>3 critical materials</td>
<td>41.83%</td>
<td>87</td>
</tr>
<tr>
<td>4 materials risks</td>
<td>33.17%</td>
<td>69</td>
</tr>
<tr>
<td>5 life cycle assessment</td>
<td>75.00%</td>
<td>156</td>
</tr>
<tr>
<td>6 environmental impact</td>
<td>77.88%</td>
<td>162</td>
</tr>
<tr>
<td>7 social impact</td>
<td>29.33%</td>
<td>61</td>
</tr>
<tr>
<td>8 environmental regulations</td>
<td>28.37%</td>
<td>59</td>
</tr>
<tr>
<td>9 Other (please specify)</td>
<td>14.42%</td>
<td>30</td>
</tr>
</tbody>
</table>

answered 208
skipped 6

Figure 2: Q6 from the survey: Themes to introduce Sustainable Development in teaching

The question “How do you assess the course?” indicated that course assessment usually includes an examination and/or a report on a project. Considering that themes of sustainable development are introduced normally alongside the core subjects, this was an expected outcome. Around 60% indicated that group working was included in assessing the performance, with 35% using presentations of real case studies, with feedback from key stakeholders.

Other key aspects from the responses included raising student motivation and engagement as a major challenge for educators, and the goal of embedding environmental concepts throughout the whole course, rather than as a separate subject.

Given the strong emphasis on high quality case studies, of varying length and complexity, as central to further development of education in this field, we next summarise the status of Granta Design’s teaching resources for teaching materials and sustainable development, and conclude with a critical discussion of possible future needs.

4 GRANTA DESIGN: SUSTAINABLE DEVELOPMENT TEACHING RESOURCES AND ASSOCIATED METHODOLOGY

The Cambridge Engineering Selector (CES) EduPack software includes multiple databases of material data and information, including environmental metrics such as embodied energy and CO₂ emissions, recycling fraction etc. An Eco Audit tool in the software allows simple life cycle assessments to be made.
of products for which a “bill of materials” is known. The recent Sustainable Development Edition of the software includes data associated with energy generation and storage, critical materials and ‘nations of the world’. The standard user interface enables browsing and searching of all the records, while the graphical interface allows data to be interpreted visually. License holders of the software also have access to extensive supporting resources – papers, lecture slides and project files for worked-out case studies.

For the specific context of materials and sustainable development, a ‘5-step methodology’ has recently been developed and illustrated through multiple case studies – now available as a textbook by Ashby and co-workers (Ashby et al 2015). The ‘5-step methodology’ offers a framework for assessment of so-called ‘articulations’ of sustainable development (proposed (usually policies) projects that claim to contribute to a more sustainable future), concerning materials, products or technologies. The methodology (Figure 3) provides five-stages of analysis, starting with definition of the articulation, its time scale, objective and scale; the second layer include stakeholders’ analysis; and the third layer is fact-finding. The final two layers synthesis the findings in relation to the ‘three capitals’: natural, human and manufacturing, and reflect on the trade-offs between them.

![Figure 3: The 5-step Methodology (Ashby et al 2015)](image)

This methodology has emerged from teaching materials and sustainable development through group project work, primarily with Masters-level students, in a number of universities in Europe and the USA. The approach and supporting resources are now at a stage where they can be thoroughly “road-tested” by academics and students, and feedback is strongly invited on its ease of use, gaps in provision, and

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7 Teaching Resources on-line portal: http://teachingresources.grantadesign.com/Sustainability
suggestions for refinements. Here we offer some of our own initial reflections on teaching challenges and future developments.

5 DISCUSSION

Levels of complexity
The case studies presented (Ashby et al 2015) aim to synthesise all of the relevant aspects of sustainability for the case in hand, but in particular to provide a framework and checklists of things to consider at each step. To date the methodology has been developed through Masters-level project work – though individual students have also succeeded in conducting a complete analysis. Naturally, these full case studies require from the students a minimum level of expertise, sufficient time to gather information and reflect on the data.

The methodology incorporates key elements of sustainability thinking and analysis, so it is straightforward to build up students’ analytical techniques gradually, using self-contained extracts from the full case studies. For example, within a full assessment of large-scale wind farms, there might be evaluations of: (i) the life cycle energy and payback time for a single turbine, comparing the embodied energy of construction of a wind turbine on a particular scale, with the energy generation rate at the typical capacity of the turbine; (ii) assessment of critical materials, such as rare earths for permanent magnets in the generators, considering future growth in demand and the implications for secure supply in the longer term. Teaching of sustainable engineering is likely to start with extracts such as these, and to build up to complete case studies once students have acquired the analytical skills. It might therefore be helpful to develop resources which present a selection of individual elements of the full picture, together with the completed case study which draws them together.

Iteration in applying the methodology
The methodology as currently presented appears as a linear progression from the articulation of a sustainable development, through to an assessment of the balance between the three capitals: natural, manufactured and human. Working through a completed case study may make this appear deceptively easy. In practice, it is likely that the process of working through the steps will be more iterative, particularly in the first 3 steps (Figure 3). For example, fact-finding about the articulation initially proposed is likely to lead to refinement of the statement of the articulation itself, or suggest relevant stakeholders that were initially over-looked. As with design education generally, it would be good practice to encourage students to recognise that they need to go back and re-evaluate the problem being addressed, as their understanding of it evolves.

Guiding students on ‘what they need to know’
A feature of the current completed case studies is that key decisions have already been made about which aspects of the problem should be investigated in the central “fact-finding” step. These decisions are not explicitly documented, so an inexperienced student may again think it is self-evident – until they are confronted with a new problem, and are not confident in ‘knowing what to look for’. This issue is commonly found in the teaching of product design, and the analysis of existing products – it is important to recognise how much prompting students may need to select a line of enquiry, while leaving freedom for making poor choices and learning from them.

A further characteristic that sustainable development analysis has with product design is that students should first be encouraged to think carefully about the function of the product (or technology). Leading questions are: “what does this product/technology do?” and “what are the metrics that quantify its performance in delivering this function?” These need to be understood before a meaningful comparison can be made, in terms of the use of materials or use of energy, between alternative solutions to a problem. As an example, consider a case study comparing different solutions to providing domestic lighting. Consideration of material and energy consumption, or economics, should be done on the basis of provision of equal function – that is, equal useful light output. Metrics for quantifying light output may not be familiar to the students, who may be diverted onto, for example, nominal power. Another simple example would be a comparison of packaging materials for drinks containers. Direct ranking of materials...
by embodied energy per kg is potentially very misleading – comparison should be made incorporating the quantities of material that perform equal function, such as “packaging required per litre of liquid contained”. Consideration might therefore be given to formalising this “pre-fact-finding” step in the methodology, to the extent that instructors may wish to set an intermediate evaluation of a student’s proposal for fact-finding, in which they outline the basis for their investigation in terms of the product function.

**Refinement of guidance for ‘fact-finding’**

There is one feature of the fact-finding step that students may currently find somewhat ambiguous. Three categories of fact-finding are indicated as “materials”, “energy”, and “environment” (Figure 4). A recent student project at Cambridge University has used the 5-step methodology to consider the potential future growth in flax-based biocomposites, for use as lightweight panels in automotive or aerospace applications. What became apparent was that it was not clear cut where to consider the “embodied energy” of the panels, since a case could be made for placing it under any of these three headings. Some re-definition of these headings might provide clearer guidance to students as to what to think about in each case – for example, “material supply”, “energy: production, consumption or storage”, and “environmental impacts”. As is often the case in providing structure to pedagogical methods, a balance needs to be struck between brevity and clarity.

![Figure 4: Fact-finding stage of 5-step Methodology](image)

**Classification of case studies**

One of the most promising characteristics of the 5-step methodology is its apparent breadth of applicability – the case studies documented by Ashby (Ashby et al 2015) span renewable energy technologies, biopolymers and bamboo for specific sectors of application, electric cars and domestic lighting. Students approaching a new problem of their own will often be advised to read up relevant previous case studies for inspiration. As the library of case studies grows however, the very breadth of applicability may become a problem. It is likely that some form of case study categorisation will be needed to guide students to the most relevant sources. “Find relevant case studies” could in due course emerge as a key part of step 1 in the methodology “clarifying the prime objective”. From the case studies conducted to date, a number of headings for classifying case studies could be proposed: “substitution of bio-based materials”, “renewable energy systems”, “domestic energy-using products”, and so on. It is not yet clear whether an exhaustive list could be proposed that covers all eventualities in an unambiguous fashion. What may be more useful is a form of key wording, designed not just to lead students to relevant case studies, but also to guide them to the first-order issues to bear in mind in formulating their articulation, and later when thinking about design and functionality, and approaching materials and energy appropriately. This approach also addresses the issue raised earlier from the survey, relating to the importance of regional context.
A checklist of questions about the problem in hand, linked to keyword lists, could therefore take the following form:

- Is the problem a material, a product, or a whole technology?
- Is it energy producing, or energy consuming, and does it involve energy storage?
- What scale is being considered: domestic, regional, national, global?
- What is the national/international development and economic context: a developed Western economy, the EU, an emerging economy?
- Is material supply limited to local, national, or global scale?

Considerations such as these should be visited up-front: there is little point in evaluating the sustainability of a material, product or technology without having this appreciation of function and context from the start. For example, an assessment of “micro-hydro power generation” will have a number of generic issues to address, regardless of context, but the approach will nonetheless need to be refined for application in Nepal, compared to the contrasting circumstances in the UK.

6 CONCLUSIONS

A survey of academics indicates considerable interest in developing methods and resources for teaching materials and sustainable development in engineering, design and materials science course. A common need is the provision of well-documented case studies, covering a range of levels of complexity, and recognising the variation of local context between countries. A recently published methodology and associated software tool offers promise in this field, but needs testing and feedback from a wide range of users. Our own investigations have suggested a number of refinements that are expected to help to improve the rigour and ease-of-use of this methodology.

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References