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Practical Competences as Learning Outcomes Using CES EduPack

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The quality of modern engineering education is measured in terms of learning outcomes. This holds true for, e.g., the ABET accreditation system and the CDIO Syllabus. This paper demonstrates how a computer-based teaching resource, CES EduPack, could be used by Universities towards learning outcomes necessary for accreditation of engineering programmes.

Key words: *learning outcomes, engineering education, assessment criteria, accreditation.*

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Introduction

Quality assurance is an essential aspect of modern engineering education. In this context, learning outcomes are important. Learning could be defined as what the student can demonstrate that they know; desired learning outcomes can be used to specify and evaluate courses and programmes. This is central to the Bologna process of the European Higher Education Area and also to major accreditation systems for higher education. In this paper we examine how a computer-based teaching resource, CES EduPack [1], can contribute to the CDIO Syllabus 2.0 [2, 3], which offers a set of learning outcomes with particular emphasis on practical competences. Many of the findings can be extended to accreditation systems, such as ABET or EUR-ACE.

This paper addresses five areas of CDIO Syllabus 2.0. These are, at the second level of detail: 1.3 Advanced Engineering Fundamental Knowledge, Methods and Tools; 2.1 Analytical Reasoning and Problem Solving; 2.3 System Thinking; 4.1 External, Societal and Environmental Context and 4.4 Designing. The authors give three examples of how CES EduPack and associated teaching resources can support educators in achieving learning outcomes in these areas.

Learning Outcomes

Within an outcome-based educational framework, teaching/learning activities (content, methods etc.) should be aligned with the intended learning outcomes and with the assessment of these, see Fig. 1 [2, 4].

It is helpful to group learning outcomes into three categories: (I) Knowledge and understanding, (II) Skills and abilities, and (III) Values and attitudes. We interpret learning outcomes associated with knowledge as the capability to use information correctly. Understanding requires the ability to use this knowledge in new and unfamiliar situations and the ability to create new knowledge. Skills and abilities are sometimes referred to as practical knowledge. Finally, Values and attitudes reflect the ability to use knowledge and understanding responsibly.

Teaching resources to support outcome-based teaching can be designed to contribute to all three of these categories. CES EduPack has been developed with this in mind. It supports

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a methodology that links the selection of materials with the design process. In this paper, the outcomes discussed are mainly associated with practical competences (such as skills), which are primarily acquired with adequate interaction between the students, the teacher, and the software/resources.

CES EduPack is a high-quality source of information for materials and processes. CES EduPack introduces students to ideas of eco-design and of eco-audits (fast, approximate life cycle inventories). Moreover, it supports the teaching of sustainable development, providing access to information about the economies, environmental behaviour, social provision and governance of the nations of the world – the nations from which materials are sourced.

It must be emphasized, however, that the information contained in databases, such as those of CES EduPack, cannot alone generate learning outcomes in higher education. It is how the teacher and students use information (in a critical manner) – that is important. This aspect is supported by a number of additional teaching resources, within the software as well as in several textbooks to provide a detailed explanation and depth in the topics of mechanical design [5, 6] and environment/sustainability [7]. Furthermore, a range of White Papers and exercises are available to the teachers on specialized topics [8], such as: Teaching Engineering Materials, Materials and Product Design, Eco Design, or Materials and Sustainable Development. Users [9, 10] have found CES EduPack to be helpful in gaining ABET accreditation of programmes and have written about their experiences in using CES EduPack and how it supports various learning outcomes. These examples are outlined further.

Examples in teaching

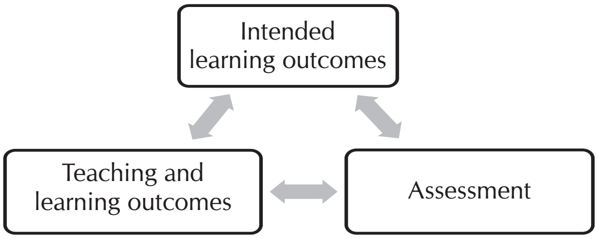
The software is particularly well adapted for use in applied engineering projects, such as product development or capstone courses. Since CES EduPack is an advanced engineering teaching tool, implementing sophisticated methods for materials selection, most courses using the software adequately would be able to contribute to learning outcome 1.3 Advanced Engineering Fundamental Knowledge, Methods and Tools. Therefore the examples below focus on other four learning outcomes (see Fig. 2).

Example 1: Mechanical Design

CES EduPack enables the selection of materials and manufacturing processes during engineering design. This approach, developed at the Engineering Department of Cambridge University [1, 6, 7], uses a rational, systematic approach that starts with the design objectives (minimizing weight, for example, or minimizing cost) and design constraints (the mechanical, thermal, electrical or durability requirements set by the design brief). The methodology is clearly laid out with numerous worked examples and suggestions for projects provided.

A specific example is provided by Professor Eason of the University of North Florida [9] where CES EduPack has been used in Senior Capstone design projects (EML 4551&2) for some

Fig. 1. The Concept of Constructive Alignment Used by Biggs [4]



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years. Students, working in pairs, were tasked with re-designing and building a mountain bike. They needed to understand the requirements and translate these in to constraints and objectives in order to use the selection tools available in CES EduPack to select frame-materials that meet real-life specifications for the bike. They could easily factor in different design priorities and review how that changed the selection, while playing out different scenarios in the software, including consideration of conflicting objectives and trade-offs decisions in a design process.

The criteria of high strength, low density, acceptable cost and low carbon footprint, was straightforwardly implemented with the graphical selection facility of the software (Fig. 3). This led to a number of possible choices, among them the possibility of a bamboo-framed bike, which the students successfully built and tested. This example of a Design-Build course, including elements of testing, modelling and a teamwork shows how CES EduPack can contribute to CDIO outcomes point 4.4 Designing, 2.1 Analytical Reasoning and Problem Solving and 2.3. System Thinking.

Example 2: Eco Audit Tool

Responsible engineering design, today, should include an analysis of the environmental impact of the proposed design. The eco audit tool of CES EduPack allows rapid, approximate, life cycle assessments. The model used in the Eco Audit Tool is purposefully simple and explicitly explained in the help menu, so that students can engage with, discuss and disagree with the model, as well as its output. Data used on life-cycle assessment projects is notoriously weaker than the mechanical property data that engineering students are used to.

Therefore, this is highlighted, both in the help menu and the suggested exercises, so that students can learn to deal with uncertainty. This means that projects where students use the Eco Audit Tool are particularly useful in supporting learning outcomes 2.1 Analytical Reasoning and Problem Solving and 2.3. System Thinking.

A course on Materials Selection for Mechanical Design (EMA 4507), also from the University of North Florida [9, 12], uses this tool to reverse engineer a Smartphone. The structures and materials of the phone were analysed by two teams one tasked with maximizing mechanical robustness, the other tasked with minimizing embodied energy and carbon footprint. Eco Audit was mandatory for both teams.

Further, a general graphical output of CES EduPack (Fig. 4) illustrates a comparison of the embodied energy of two alternative designs. The "What if..." facility allows immediate feedback on the consequences of any change of material in the product.

Fig. 2. Learning Outcomes Aided by EduPack, in Relation to CDIO 2.0

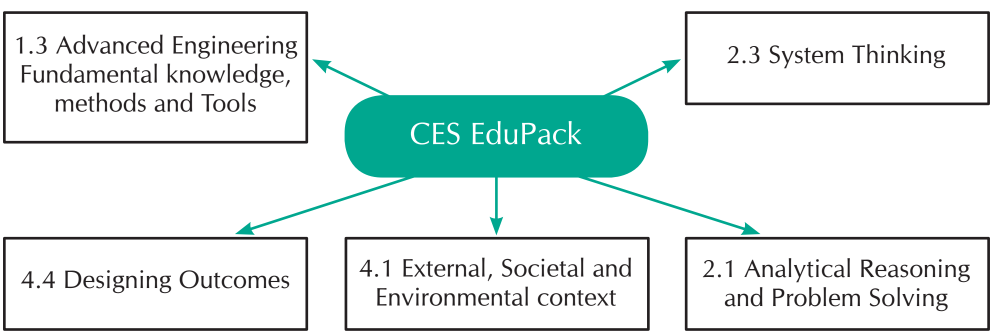

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Fig. 3. Materials Chart Comparing Bamboo with Other Frame Materials [9]

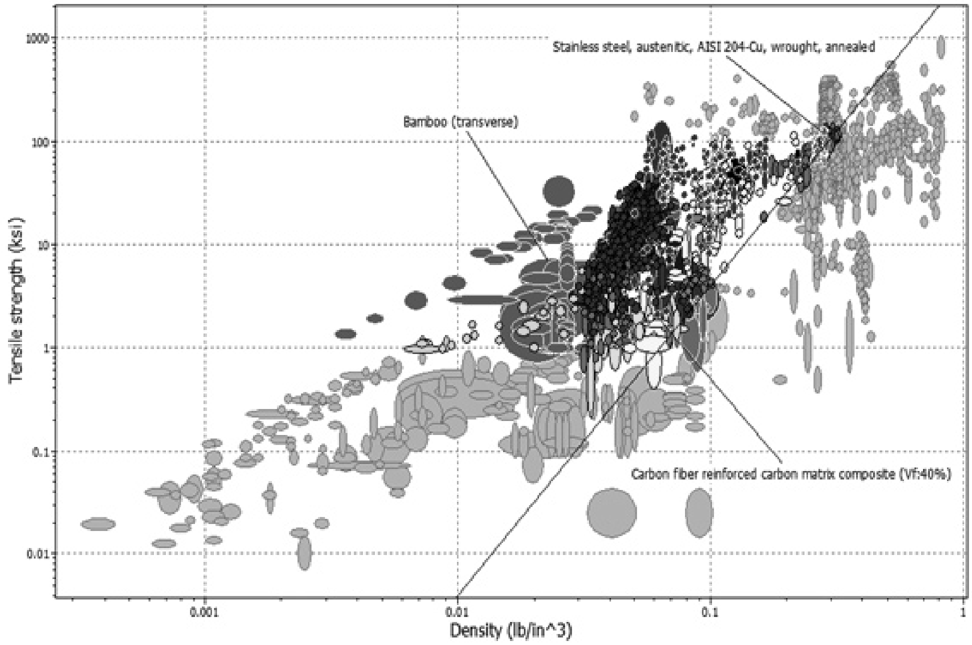


Fig. 4. Eco Audit tool can be used for re-engineering and exploration

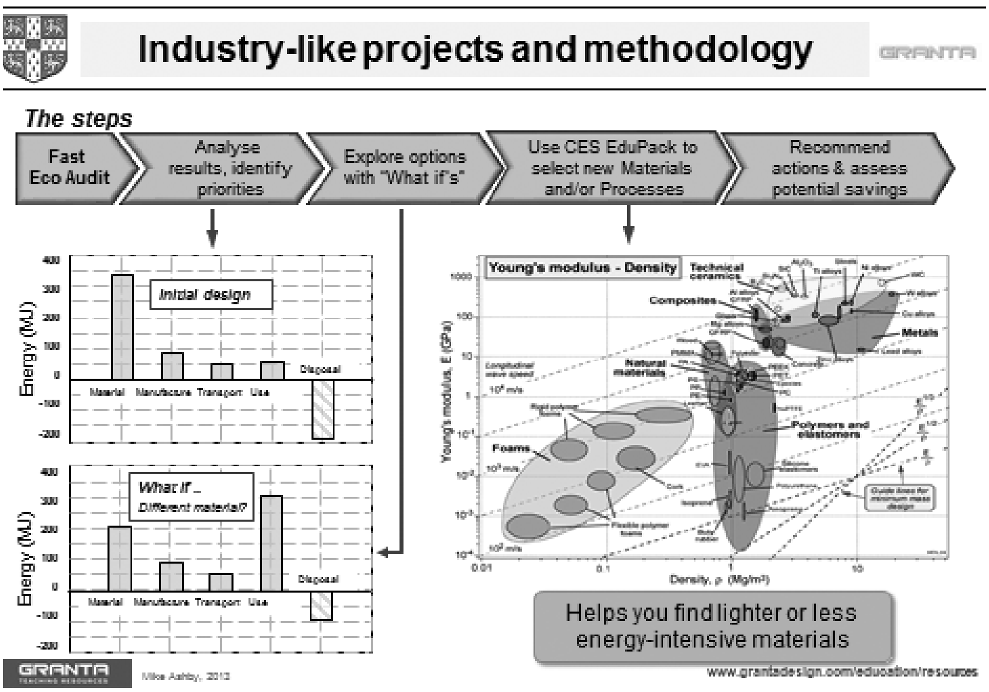
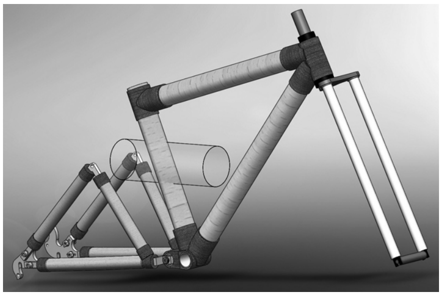
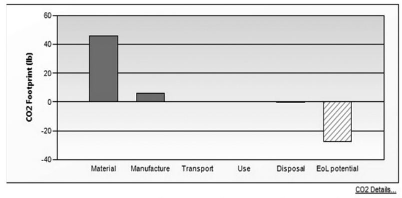


Fig. 5. CAD Image and Eco Audit for Bamboo Mountain bike [9]





Phase	Energy (kcal)	Energy (%)	CO2 (lb)	CO2 (%)
Material	8.63e+04	90.6	45.6	88.1
Manufacture	8.38e+03	8.8	5.8	11.2
Transport	0	0.0	0	0.0
Use	0	0.0	0	0.0
Disposal	548	0.6	0.354	0.7
Total (for first life)	9.52e+04	100	51.8	100
End of life potential	-5.23e+04		-27.7	

The case of the Bamboo bicycle, mentioned in the previous example, was also subject to an Eco Audit (Fig. 5) and compared to a traditional metal bike.

Example 3: Sustainability Analysis

The Sustainability Database and supporting methods of CES EduPack guide students through a broad study of the supply-chain of engineering materials, background information on ethical sourcing and manufacture, and awareness of business risks, associated with materials and with the legislation that now controls materials' use and their disposal. The Sustainability Database includes access to data on economic, social and environmental performance of 210 nations. The method was tested in Universities from Cambridge (UK), Urbana (USA) and Barcelona (Spain). The five-step methodology (see Fig. 6) includes: setting-up objectives, identification of stakeholders, fact-finding, integration and reflection. A case from Professor Ferrer-Balas of Universitat politecnica de Catalunya in Barcelona [11] provided feedback on use of the Sustainability Database and CES EduPack (The main outcomes of the project have been presented elsewhere [11]). The aim of the exercise was to analyse bamboo as a construction material in Mexico. Students improved their understanding of the case, concluding that just two dimensions – natural and recyclable were too simplistic. The concepts of Human, Natural and Manufactured Capitals were used to represent diverse contributions of materials/technology to environmental and social aspects.

The intended learning outcomes for students of the course using CES EduPack sustainability database and the described method are summarized and classified, according to the CDIO syllabus, in Table 1.

Wider issues, such as market availability, regulations, capacity, social acceptance, costs, were analysed while having access to reliable traceable and coherent data sets in the database. The debate about sustainable creden-

Fig. 6. Five-step methodology for analysis of sustainable development

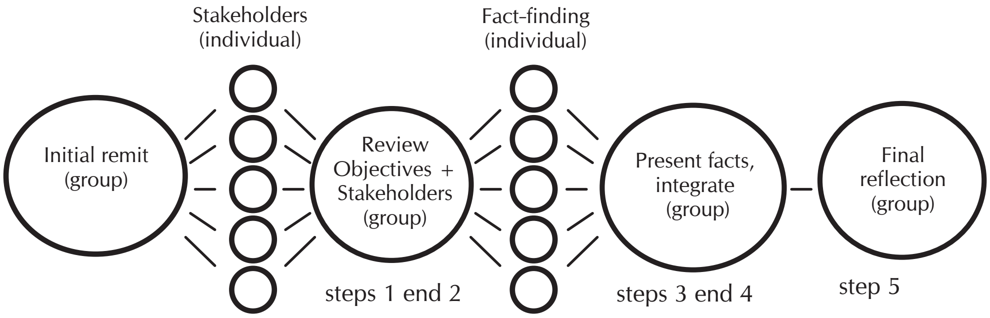


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Table 1. Sustainability Design Course Learning Outcomes (self-assessed) [11]

	Learning Outcomes (LO)	LO vs the levels of Knowledge, Skills and Attitudes [Based on Bloom's and Krathwohl's taxonomy]						LO vs the most frequent accreditation standards		
	By the time the students finish the course, they should be able to ...	Knowledge	Comprehension	Application & analysis	Synthesis, creativity and evaluation	Receiving, responding and valuing	Compare, relate and synthesis	Standard		
		Knowledge		Skills		Attitudes & values		EUR-ACE	ABET	CDIO
1	Know and understand the basic dimensions of the sustainability concept through the capitals approach	●	●			●		1.2 1.4	a, j	1.2
2	Understand the complexity of sustainable technology development due the different cometing articulations and be development due the different cometing articulations and be capable of explaining it with examples	●	●			●		1.5 5.5 5.7	f, h	2.3 4.1
3	Conduct a systemic sustainability analysis in a four step methodology			●		●	●	2.2 2.4	b, k	2.2 2.3
4	Integrate multidisciplinary information regarding one problem			●	●	●	●	5.5	e	2.1
5	Identify stakeholders regarding a controversial socio-technical issue and identify their perspectives on a specific issue			●		●	●	5.4	J	4.1
6	Find contrasted information in databases (in particular SUSTAIN), internet, etc., about materials, technology, states, legislation related to a project.			●		●		4.1 4.4 4.6	b	2.2
7	Plot diagrams with the SUSTAIN database and present information to a specific audience.					●		6.2	g	3.2
8	Work in teams in a specific project			●	●	●	●	6.1	d	3.1
9	Evaluate options for sustainable technology developments					●	●	6.4	h	2.3 2.4

tials of materials prepares students for industry-related questions, challenges and opportunities, including the roles of stakeholder analysis and relevant legislation. This example demonstrates facilitation of outcomes 4.1 External, Societal and Environmental context and 2.3. System Thinking.

Conclusions

Used appropriately in relevant activities, CES EduPack is well aligned with learning outcomes under 1.3, 2.1, 2.3, 4.1 and 4.4 of CDIO Syllabus 2.0.

Since CES EduPack is an advanced engineering tool, one used both by industry and in research, it is able to contribute to learning outcome 1.3 Advanced Engineering Fundamental Knowledge, Methods and Tools. Built-in science notes, explicit details about models used and data sources, and warnings about uncertainties, facilitate interactive, critical use inside or outside the classroom. This leads to better Analytical Reasoning and Problem solving, 2.1.

CES EduPack is predominately used in a system context (e.g. a product, a production system or the world). Trade-offs within a system with regard to material selection, Eco Audits and Sustainable Development project work, help students to gain skills outlined in 2.3 System Thinking. The Eco Audit Tool and the Sustainability Database of the software provide unique support for the analysis of sustainability of products and technologies, with students encouraged to consider different stakeholder perspectives, as in 4.1 External, Societal and Environmental Context.

CES EduPack was originally created to support teaching related to mechanical design, although it has broadened its remit significantly. The design process and the ways in which material and process selection fits in to that, are described in detail in many books, supporting exercises and white papers, thus contributing to 4.4 Designing.

The CES EduPack supports an active, creative and practical learning approach, helping students in complex multidisciplinary issues. Provided supportive guidance of a teacher, it helps to prepare students for professional challenges in industry.

REFERENCES

1. 1. CES EduPack [Electronic resource]//Granta Design: the official site – Cambridge, 2013 – URL: http://www.grantadesign.com/education/, free.
2. Edward F. Crawley et al., The CDIO Syllabus v2.0 An Updated Statement of Goals for Engineering Education [Electronic resource]//Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20–23, 2011 (usage date: 01.11.2013).
3. The CDIO Initiatiave//CDIO: the official site, Gotthenburg, 2013 – URL: www.cdio.org, free.
4. Biggs J. Teaching for Quality Learning at University, 2:nd ed., The Society for Research into Higher Education and Open University Press, Berkshire: England, 2003.
5. Ashby M. F., Shercliff H. and Cebon D. Materials: Engineering, Science, Processing and Design (3rd edition) Elsevier, 2014.
6. Ashb M.F. Materials Selection in Mechanical Design (4th edition) Butterworth Heinemann, 2011.
7. Ashby M.F. Materials and the Environment: Eco-informed Materials Choice (2:nd ed), 2013.
8. Ashby M.F. The CES Sustainability Database, A White Paper Granta Design, Cambridge, 2013.
9. Eason P. Achieving ABET Outcomes 'h' through 'k' Using CES EduPack Eco Audit, Proceedings of the 4:th North American Materials Education Symposium, URL: http://www.materials-education.com, free, 2013.
10. Sharif Ullah, A. M. M., Significance of Materials Selection Tools in Undergraduate Engineering Education, Proceedings of JSEE Annual Conference, 2011, Sapporo, Sept. 9, 2011.
11. Ferrer D-B. Proceedings of the Rethinking the Engineer EESD Conference, Proceedings, Paper 25, 2013.
12. Eason P. WebSeminar, [Electronic resource], Supporting accreditation criteria for engineering programmes, URL: http://www.grantadesign.com/education/events/2013/us-eason-video.htm, free, 2013.