LIFELONG LEARNING AND CONTINUING PROFESSIONAL DEVELOPMENT IN STEM – INNOVATION, SUSTAINABILITY, INCLUSION

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Abstract

Innovation, Sustainability and Inclusion are explicit in several of the UN Sustainability Goals but also implicit in goal #4 **Quality education**, highly relevant to this forum. Lifelong learning and continuing professional development need to be part of addressing the skills-gap created by a rapid digital transition as well as the urgent issue of sustainability. "*Rapid technological changes present opportunities and challenges, but the learning environment, the capacities of teachers and the quality of education have not kept pace. Refocused efforts are needed to improve learning outcomes for the full life cycle*" [1].

Engineering education is evolving, which puts demands on educational tools for the purposes described above. Ideally, it requires a platform that (i) is innovative, capturing the interest of learners, (ii) contains information and tools to face the sustainability challenges and (iii) provides adequate flexibility for the inclusion of the diverse group of lifelong learners in continuing professional development.

Materials Science and Engineering represents an area suitable for STEM learning at all levels, not only engineering. Everybody has experience of materials from an early age and the subject comprises all levels of complexity, from the very simple, to Nobel Prize discoveries. Material properties are also very much connected to the real world, *e.g.*, sustainability issues. Materials, in other words, appears to be an ideal topic to exploit and elaborate on in order to integrate innovation and sustainability in teaching, enabling a truly lifelong learning experience including all ages from schools to beyond retirement.

In this paper, we describe best practices from a widely used digital tool for materials-related teaching and learning, consistent with points i-iii above. Whereas only some engineers will make use of very detailed and advanced knowledge of Materials Science, it can be argued that the subject lends itself to both University and out-of-University activities for all ages.

Keywords: Software, Teaching, Innovation, Sustainability, Lifelong learning, Materials.

1 INTRODUCTION

Lifelong Learning (LLL) and Continuing Professional Development (CPD) need to be part of the solution for closing the skills-gap created by the rapid digital transition. There is an increasing need for higher levels of qualifications in knowledge-based industries, particularly in STEM-related areas (IT and AI included) [1]. In addition, the rate of change in industry urgently requires professional development and retraining to deal with this transition. It is challenging, since lifelong learning is not a reality for most people; obstacles include limited learning opportunities that does not adequately accommodate the needs of different target groups, a lack of accessible information and support systems, as well as rigid learning pathways [1-2]. It also puts demands on educational tools for this purpose, both when it comes to methods of delivery and the volumes that can be anticipated.

The concept of lifelong learning can be defined as "a continuous process that can last throughout a person's entire life, from quality early childhood education to post-working age. Moreover, learning also takes place outside formal learning contexts, particularly in the workplace" [1], see overview in Fig. 1. Lifelong learning and continuing professional development are therefore characterized by a need for *flexibility* to accommodate the practical requirements of adult learners with family commitments or workplace demands. Both these categories of learners may also have important roles to fulfil in locations far away from providers of higher education, which creates the need for *distance learning* platforms, online or otherwise. The strategic relevance of LLL and CPD has been known for more than 20 years, as reflected on the international level in European Commission's Working Paper, "Memorandum on Lifelong Learning" [3] and more recently within the UN sustainable development goals, as well as in many national policy documents, *e.g.*, in Scandinavia [4-6].

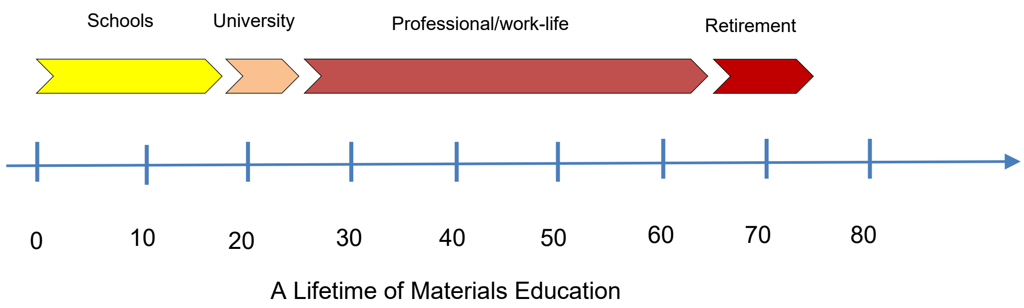


Fig. 1. The phases of lifelong learning, with the software covering the first three.

The EduPack software platform (referred to as the software) [7] was specifically developed to support materials teaching at the Engineering department of Cambridge University in the UK. It has since evolved into a widely used standard tool for several areas of both higher and continued education. This is relevant, since a significant number of engineering jobs for graduated students are concerned with design, manufacturing, maintenance or sales of complex technological products relying on safe high-performance materials. This software is also used pre-University in schools (see Fig. 1) to support STEM teaching. In particular, it is aligned with the national curriculum in France, and used by many Lycées. The professional version of the software, Granta Selector, is similar in operation to EduPack but more powerful in terms of external databases, meaning that training utilizing the educational software is highly relevant to both learners within professions and to employers, see Fig. 2.

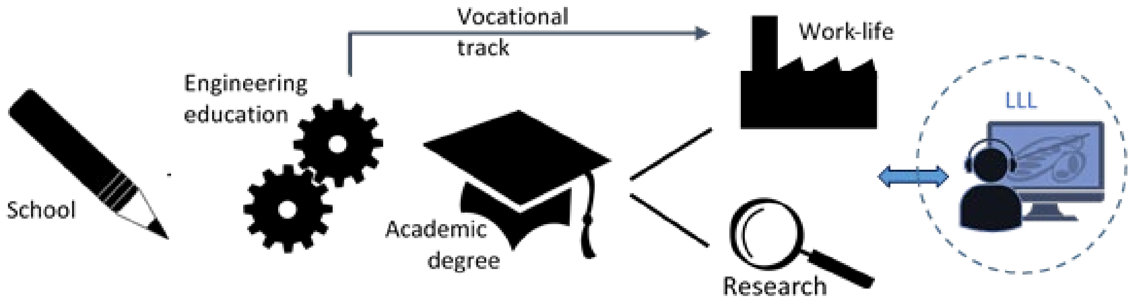


Fig. 2. EduPack used throughout education and suitable for all levels of training [8].

In this paper, we describe three aspects of a software developed for materials-related teaching that can be considered best practise in a field highly relevant for STEM subjects and educational programmes. These are (i) innovative pedagogy, (ii) sustainability data and tools and (iii) how it constitutes a flexible platform for inclusion of LLL and CPD within the comprehensive and self-directed software, see Fig. 3.

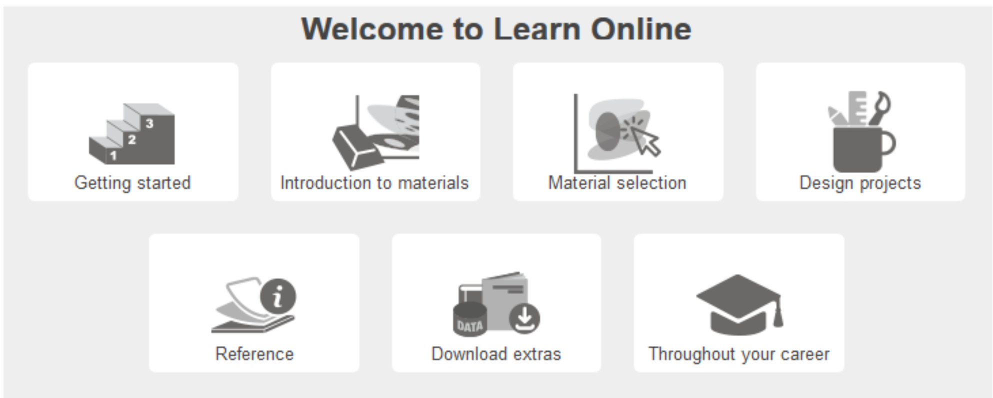


Fig. 3. Screenshot (example) of some embedded resources to enable self-directed learning [7].

2 INNOVATIVE PEDAGOGY

There are at least three fundamental components to the innovative approach embodied in the software and described in detail in a number of textbooks for undergraduate and post-graduate education [9-10].

2.1 Design-driven material approach

The first component of the innovative approach is that you don't need to learn about materials (meaning mechanical engineers, materials scientists *etc*) going through the traditional route, starting from quantum mechanics (atoms) and chemical bonds, which are abstract concepts far from most engineering applications. Instead, you start with the products and the material properties needed to fulfil their required performance, which is more tangible and closer to learners' experiences. It is still necessary to understand all the steps connecting the atoms to material performance, as shown in Fig. 4, but for most learners, it is more engaging to have a concrete product in mind. The link between the performance of the product and the material from which it is made is *material properties*.

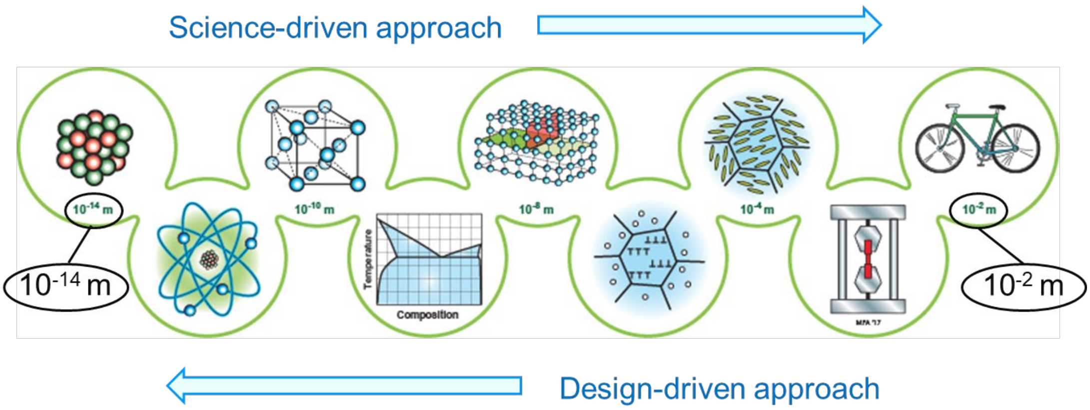


Fig. 4. Traditional science-driven approach to teaching and the innovative design-driven approach.

2.2 Material property charts

The second component of innovation is the visualization of material properties in property charts (so called Ashby charts). These are simple 2-dimensional overviews in diagrams with logarithmic axis scales. Every material is represented by a bubble, where the width and hight of the bubble corresponds to the range of values or uncertainty in each property value. Any relevant property can be chosen for the axes. The charts show relationships between material families (metals, polymers etc. shown as envelopes in Fig. 4) and variations within each type. These have revolutionized the teaching and promoted the understanding of material properties which enables learners to compare and relate different materials to each other. They can also be used in systematic materials selection for specific applications by using a performance index that ranks the relevant material property combination.

Name	Density	Modulus
	kg/m³	GPa
ABS	1.11e3	1.79
Alumina	3.89e3	366
Aluminum alloys	2.69e3	74.7
Aluminum nitride	3.29e3	324
Bamboo	693	17.3
Borosilicate glass	2.25e3	62.5
Brick	1.83e3	21.2
Butyl rubber (IIR)	910	1.41e-3
Cast iron, ductile (nodular)	7.15e3	172
Cast iron, gray	7.15e3	105
Cellulose polymers (CA)	1.13e3	1.79
CFRP, epoxy matrix	1.55e3	102
Concrete	2.45e3	19.4
Copper alloys	8.94e3	129
Cork	170	25.5e-3
Epoxies	1.25e3	2.69
Ethyl vinyl acetate (EVA)	950	20e-3
Flexible Foam (LD)	51.6	1.73e-3
Flexible Foam (MD)	89.7	6.93e-3
Flexible P Foam (VLD)	23.7	500e-6
GFRP, epoxy matrix	1.86e3	20.5
Gold	19.3e3	79
High carbon steel	7.85e3	207

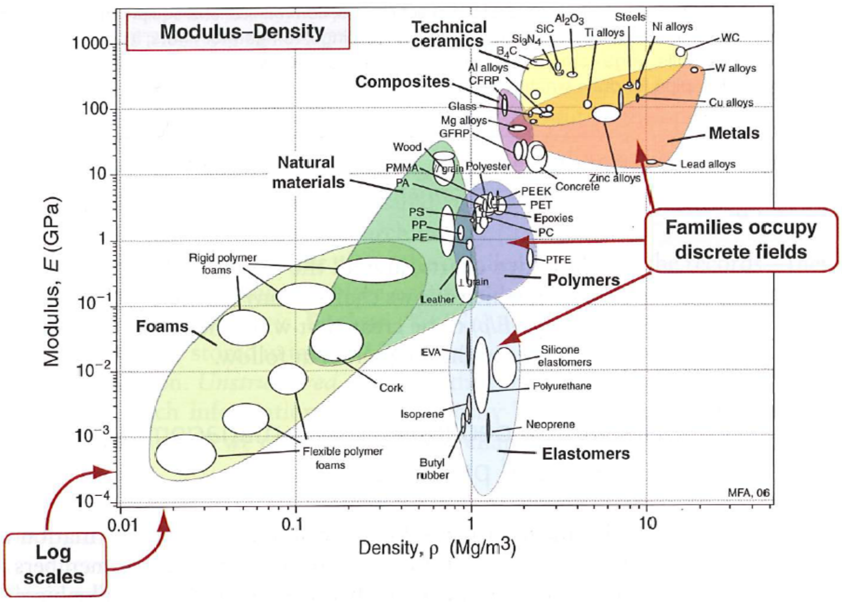


Fig. 5. Contrasting ways to represent materials data; traditional numeric table vs visual property chart.

2.3 Systematic selection and performance indices

The third and final concept in the sequence of this pedagogic innovation is the performance index and how this can be implemented in a property chart to allow a visual and interactive material selection. Selecting materials for product development and design or re-design is a core activity for many engineers and incorporates many aspects in STEM areas, as illustrated in the example below. Consider the blade (enclosed by the chain) of a chainsaw. It is subjected to bending forces in two main directions.

Fig.6. A blade of a chainsaw needs to be stiff and light, sustaining horizontal and vertical bending.

Without going into great detail, the best performance for a stiff and light blade can be derived using basic equations, as indicated below, where m is the blade mass, *L* is its length and *A* its cross section area, given by blade width (*b*) and hight (*h*). *C* is a numeric constant whereas the density ρ and modulus *E* are material properties of the blade. The performance indices of the vertical and horizontal bending, M_v and M_H respectively, can be represented as selection lines of different slopes in a diagram with logarithmic axes, as shown in Fig. 7 for the two cases.

Fig.7. Chainsaw case study, showing performance indices of a stiffness-limited minimum mass blade.

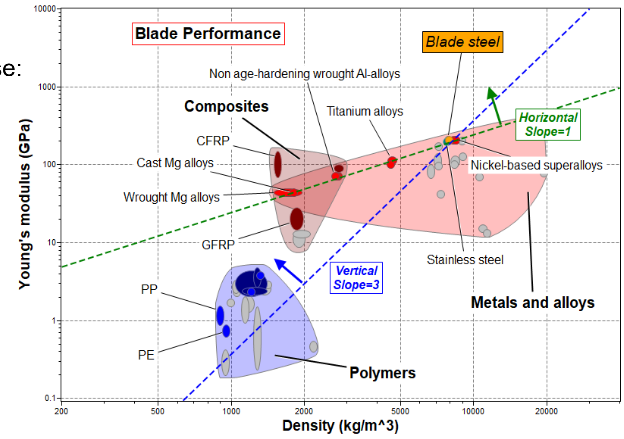
Objective: Minimize mass, $m = A\,L\,\rho = b\,h\,L\,\rho$

This yields two performance indices, one for each case:

Vertical: $$m = L^2\left(\frac{b^2 12S^*}{C}\right)^{1/3}\left(\frac{\rho}{E^{1/3}}\right)$$

Horizontal: $$m = \left(\frac{12S^*L^4}{Cb^2}\right)\left(\frac{\rho}{E}\right)$$

$$\boxed{M_V = \left(\frac{E^{1/3}}{\rho}\right) \qquad M_H = \left(\frac{E}{\rho}\right)}$$



The best materials for each load case can be found using the software and interactively moving these lines upwards/left, indicating progressively better performing material (bubbles) in the diagram [9-10]. Both cases result in the same optimal material; carbon fibre reinforced plastics (CFRP).

3 SUSTAINABILITY DATA AND TOOLS

In addition to traditional material property data, such as strength, stiffness and density, the software has a comprehensive set of other data relating, for example, to *energy use* in material production and associated *CO_2 footprint* (CO_2 emissions). This offers several possibilities to investigate environmental sustainability of products if the materials of their components are known or to select these based on their eco properties. The performance indices described in section 2 can be derived to also find materials that minimize energy use or carbon footprints, enabling eco design or re-design. A database dedicated to sustainability has additional capabilities to explore resource production, sourcing of critical elements, relevant rules and legislation (see Fig. 8) and social sustainability parameters for all nations of the world.

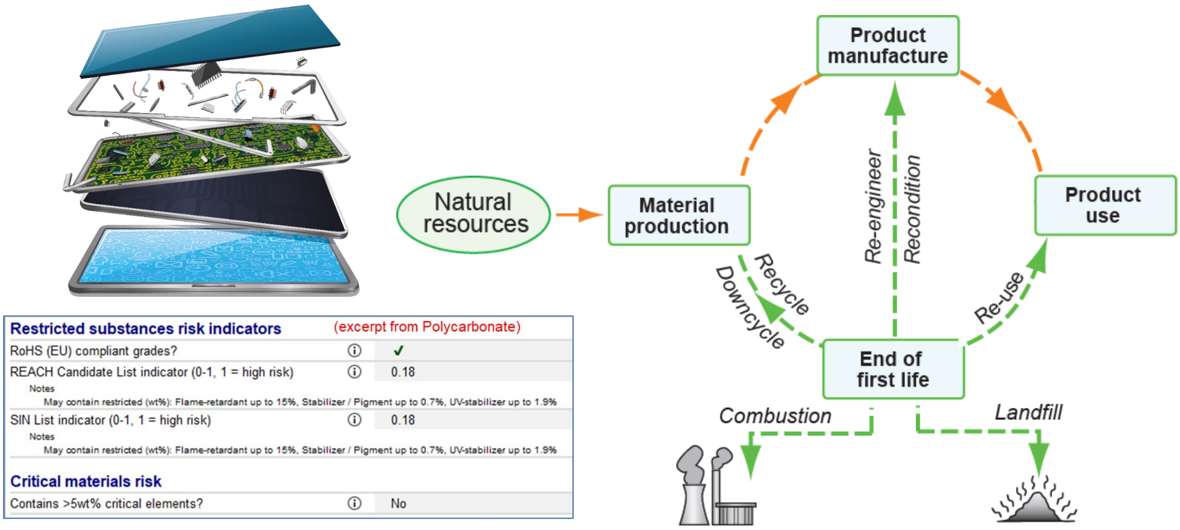


Fig. 8. Tablet device case study, showing material life-cycle phases as well as risks and critical material.

The Eco Audit tool performs a streamlined Life-Cycle Inventory (LCI) of a product to enable designers to assess and compare different scenarios over a whole life-cycle, including recycled feedstock as well as reuse, recycling and incineration at the end-of-life. Alternatives to PET bottles are shown in Fig. 9.

Container:	PET bottle (0.5 l)	PLA (0.5 l)	Al-can (0.33 l)	TetraPak (0.5 l)
Units for 10 litre [#]	20	20	30	20
Material (bottle+cap)	PET+PP	PLA+PP	Wrought Al non-aged	Cardboard+PP
Mass [g] (bottle+cap)	23+3	30+3	12.5	20+3
Mass [kg] (dummy)	0.5	0.5	0.33	0.5
Recycled [%]	21	0.3	42.5	71.9
Transport [km]	405	188	936 (road)+41 (ship)	1082 (road)+41 (ship)
Source	Armathwaite, UK	South Downs, UK	Perrier, France	Fläming, Germany
Energy [MJ]	105	97	108	79
CO2 [kg/kg]	5.53	6.11	6.95	4.22

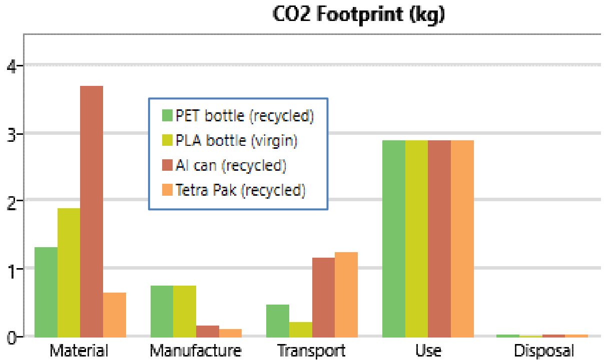


Fig.9. Water bottle case study, showing options to reduce plastic waste for some alternative containers.

4 A FLEXIBLE PLATFORM FOR INCLUSION

Inclusion can mean many things in education. We have taken it to mean including non-traditional students in STEM subjects that are looking to enhance their careers through lifelong learning. The software has been demonstrated to successfully provide opportunities, for example, within the Open University (UK), a global leader in flexible distance education [7]. Success factors are given in Fig. 10:

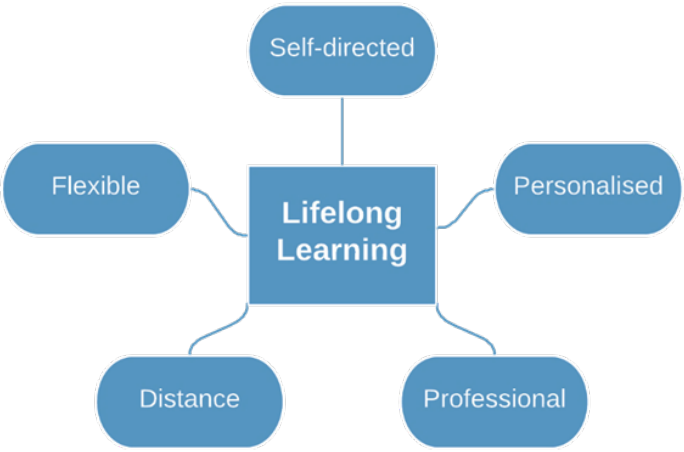


Fig. 10. Critical aspects of software for lifelong learning and continuing professional development [8].

The available databases (Fig. 11) cover a large range of professional areas closely connected to STEM.

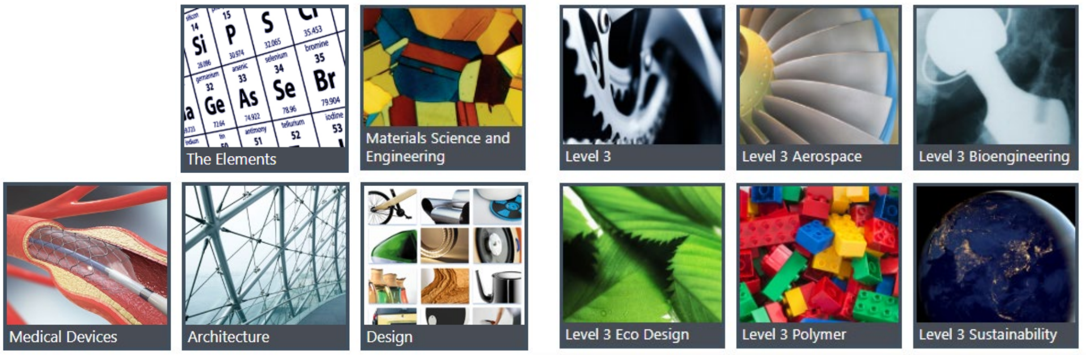


Fig. 11. Pervasive set of databases for lifelong learning and continuing professional development [7].

5 CONCLUSIONS

In the previous sections, we have shown some brief examples of what we consider unique and best practice in the field of materials teaching, an important and relevant contributor to STEM education. Three aspects of the software, promoting innovation, sustainability and inclusion have been described and showcased. For more detailed descriptions we refer to the texts and link below [8-10], which contain extensive and accounts in line with this paper. The best practice claim, in particular, is supported by a reported trend of increasing appreciation for the software, at the expense of a traditional textbook in an undergraduate course on Materials Science and Engineering [11]. The usefulness of the software in distance education and professional development is also supported by results from a survey [7].

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