GRANTA
TEACHING RESOURCES

Teaching Materials with CES EduPack

Hannah Melia, Magda Figuerola,
Claes Fredriksson, Elisabeth Kahlmeyer

Contents

Click on a link

Introduction

Materials Education covers a broad area since all physical objects in this world are made of materials. However, people in different disciplines will need to understand different aspects. An industrial designer may be fascinated by surface properties, a material scientist curious about a beautiful microstructure, and a structural engineer riveted by the strength of an I-beam. Add to this the different ways in which this varied audience is taught, in lectures, through project work, online, self-study, and so on, and you will see that there **cannot possibly be one universal Materials Education Teaching Resource**. We can, however, try and inspire and support as many educators as possible around the world with resources that are varied and flexible. So there is no one way to use CES EduPack. Use it however fits your course, your students, and your teaching style. If you would like some examples of the most common ways in which CES EduPack is used, read on.

CES EduPack is used in many different circumstances; some in well-resourced computer labs, others in self-directed studies using students own laptops. It may be fundamentally integrated in the curricula and an essential tool for students in each year. Figure 1 illustrates the diversity of use of CES EduPack.

The paper *Uses of CES EduPack*[1] documents the results of a survey of CES EduPack users around the world and illustrates how it is used across different disciplines and throughout all years of study. The most common courses on which it is used are at the introductory level, giving an overview of Materials and/or Manufacturing Processes, and Capstone Design Project courses, but it has also been used and valued in many other ways. **This paper does not intend to prescribe how you use CES EduPack.** For that reason, instead of talking about specific courses, it looks at different modes of learning that are supported by CES EduPack and the skills that can be developed by students while using it.

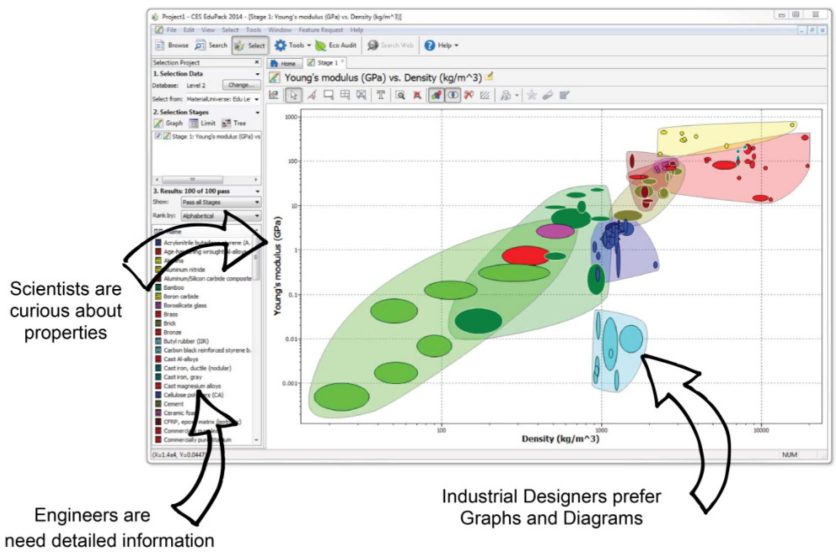

Figure 1. Examples of the need for diversity in teaching

[1] Silva, A.; Ashby, M.F.; Melia, H. "The Use of CES EduPack at all levels of Higher Education" Teaching Resources Granta Design Ltd, 2012 [www.teachingresources.grantadesign.com/Type/Papers/PAPUHEEN12]

Self-learning / Interactive Textbook

A resource than can promote self-learning can help students to work out concepts that were not fully understood in class, aid revision, or explore beyond the syllabus. To do so, it must be engaging and easy to use.

Teaching Materials Not Teaching the Software

Courses are time-constrained and so educators would like to spend as little time as possible teaching students how to use software. CES EduPack is very easy and intuitive to use. Very little time needs to be spent introducing the software. There is a **set of video tutorials**[2] (see Figure 2) that show students how to use all functionalities of CES EduPack and what is in the different databases. There is also a getting started guide[3], with simple exercises to build knowledge of each function.

Figure 2. Embedded Video Tutorials which are also available on YouTube

> Many educators ask students to prepare by watching video tutorials before starting the class

Interactive textbook

Many students bring laptops, tablets, phones, or other devices in to lectures. They might be looking up vocabulary they don't understand in Wikipedia or busy trying to finish that homework you set. With CES EduPack on their computers, they have the possibility to put lecture content in perspective, with quick access to reliable materials property descriptions for example.

---

[2] Teaching Resources "CES EduPack 2014 Video Tutorials" Granta Design Ltd [www.grantadesign.com/education/resources/videotutorials]

[3] Teaching Resources "Getting Started Guides" Granta Design Ltd [www.teachingresources.grantadesign.com/Getting_Started_Guides]

Outside of lectures, students can use CES EduPack to learn about definitions, measurement techniques, and origins of materials properties in more detail, on-demand, using the **science notes**. These effectively act as an interactive textbook within the software. Speakers of Spanish, French, German, or Japanese can learn the English translation for materials terms in the **language glossaries** contained in the Help Menu. In general, the Help Menu has a lot more than just software help, for example *Solutions to Standard Engineering Problems*, *Case Studies*, *Performance Index Tables,* and information on *Selection Methodology* also being available.

All available material properties are nicely compiled in the **Limit stage and their range charts**, where students can immediately see the actual ranges of value for different material properties of all families, the unit used for the property and a basic one or two word description – *e.g.*, Young's Modulus – Stiff or Flexible (see Figure 3).

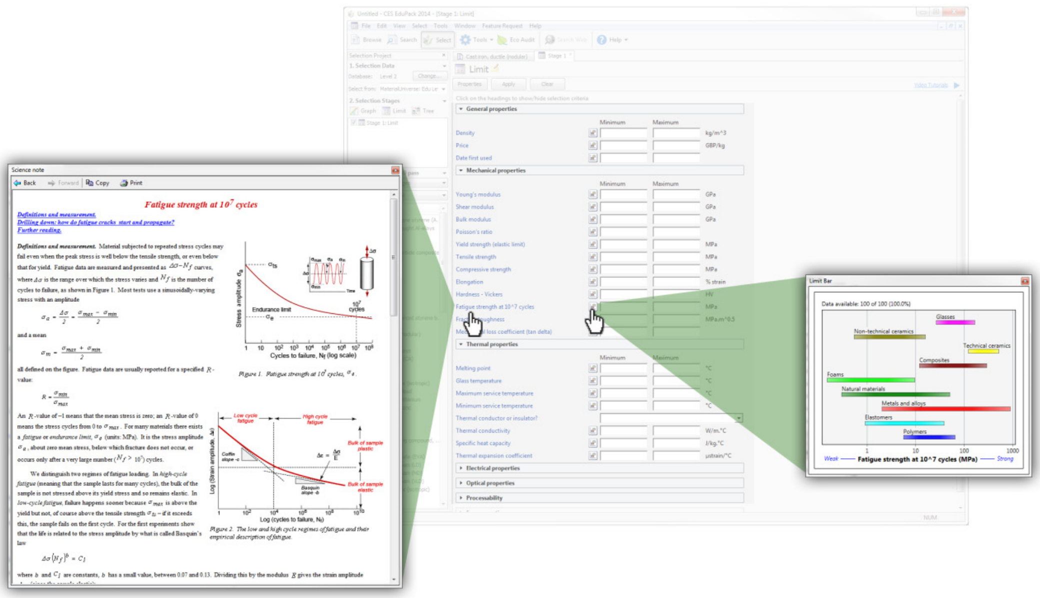

Figure 3. Science Notes and Range Charts in the Limit Stage

Creating charts with CES EduPack is compelling

Explore and understand

By offering the students the ability to access CES EduPack, you can help them satisfy their natural curiosity. They can plot any of the approximately 50 properties against each other and **spot trends and relationships**. This is especially useful in order to prevent misconceptions, such as the difference between stiffness and strength (see Figure 4).

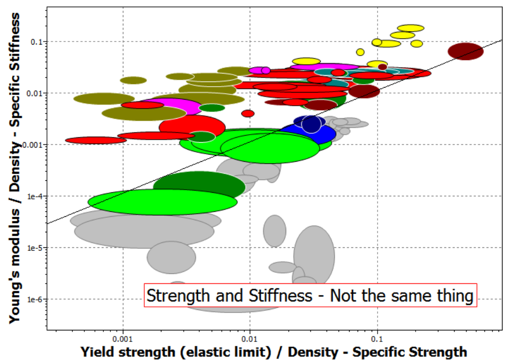

Figure 4. Specific Stiffness vs Specific Strength

Then of course there is the data itself. In Level 1 and Level 2, the records purposely have **engaging pictures** that tell the student something about their use, and if possible, also show a surface finish. The descriptions and supporting information sections have a wealth of information. A student is not likely to start reading datasheets from top to bottom, but using the search function in a full text search brings up interesting answers to many questions. A search for “age-hardening” in Level 2 takes a student to the *Al-alloys* record, where age-hardening is described (see Figure 5). If a student has a particular application in mind, they might also be tempted to find out what something is made of by making use of the typical uses section.

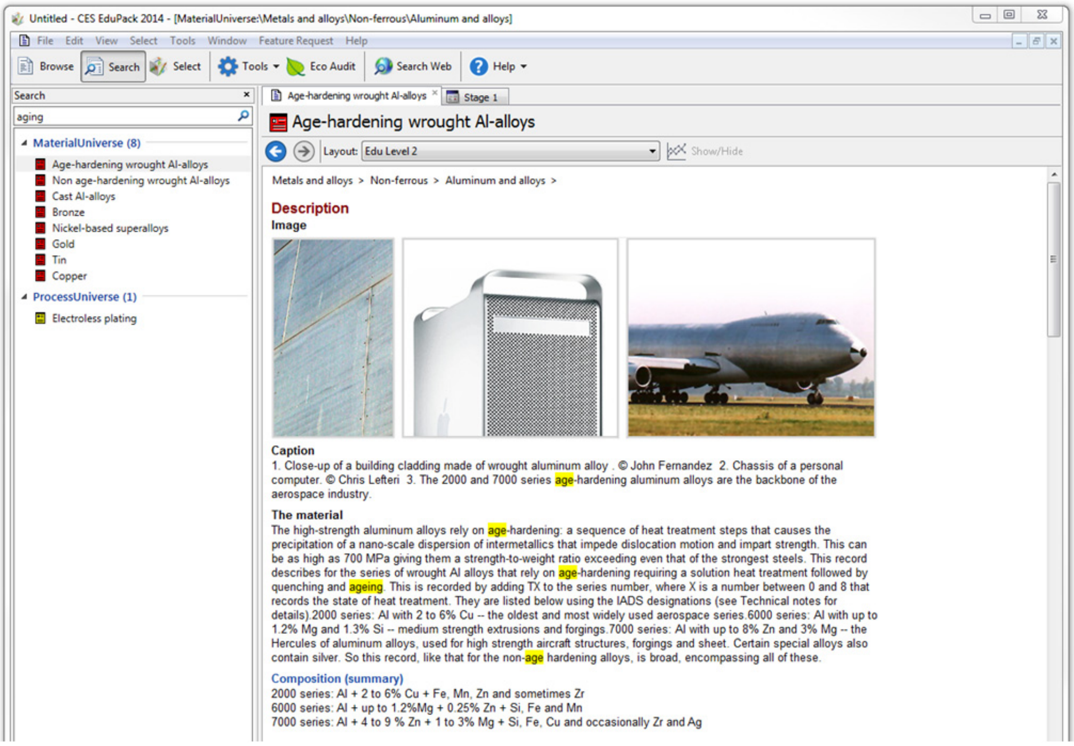

Figure 5. Search for the word Aging

In Level 3, even more text-based explanations and summaries are available and searchable. Most lower-level folders have a “Folder-Level Record” which includes high level information on a group of materials (see Figure 6). This is **similar to what you might get in widely used Materials Science Textbooks** that have chapters on Aluminum Alloys and Carbon Steels, *etc*.

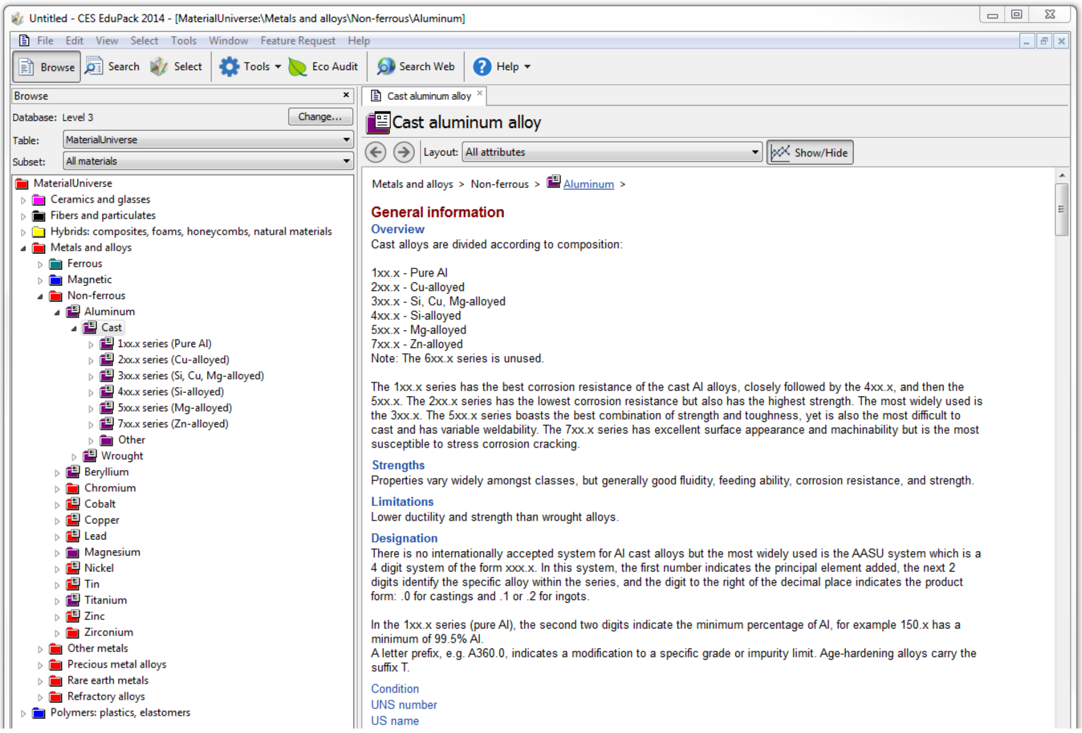

Figure 6. Folder-level records with information on a materials class

There is a set of resources specifically designed for self-learning available via the help menu under the case studies button. The case studies take students through the problem definition, constraints and objectives, the model, the selection, and conclusions, in such a way that the student could follow along with software.

Lectures and Visualization

Students have **different learning styles** [4](auditory, verbal, visual *etc.*). For many people, diagrams, charts, images, and graphics generate meaning that sticks in the mind. Sometimes, when you have large amounts of data to convey, a chart is probably the only way to do it. However, **materials charts are not the only way in which CES EduPack can be used in preparing lectures.**

Charts

CES EduPack can produce bar charts and bubble charts using the data on Materials and Processes with a few clicks of a button. Here are a few typical examples of how this gets used by educators.

[4] Felder, R.M.; Silverman, L.K. "*Learning and Teaching Styles In Engineering Education*" [Engr. Education, 78(7), 674–681 (1988)]

Sometimes, the basics are best shown graphically

Two perspectives on the world of materials

A good starting point for understanding the importance of various materials might be to use data on world production. A simple bar chart compiling key families, for example, could be useful (see Figure 7).

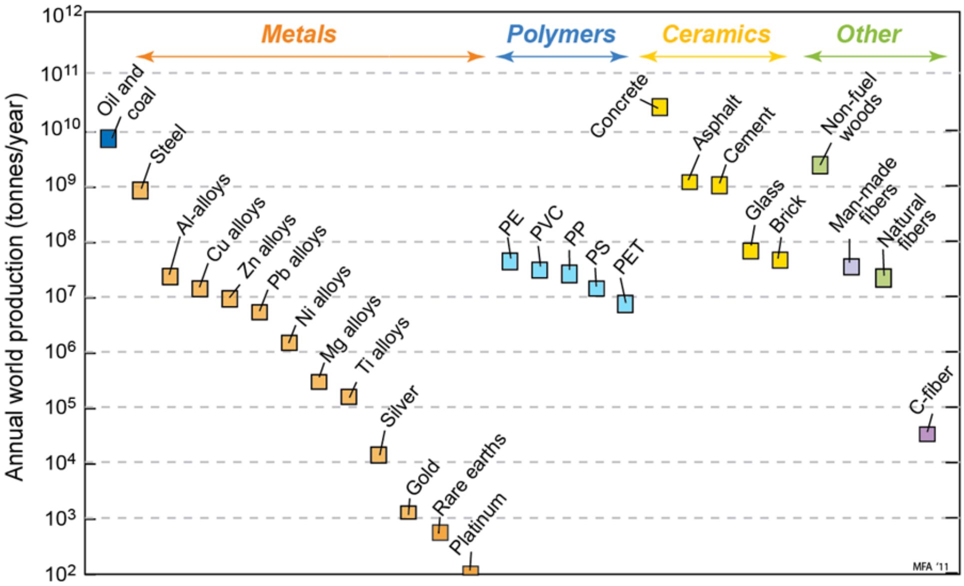

Figure 7. Annual World Production by material family

Different materials classes have strikingly different properties with, sometimes, many orders of magnitude separating the highest and lowest values. Bubble charts, using a log scale and the family envelope feature of the charting tool are a good way to give students a comprehensive overview and start to discuss the topic (see Figure 8).

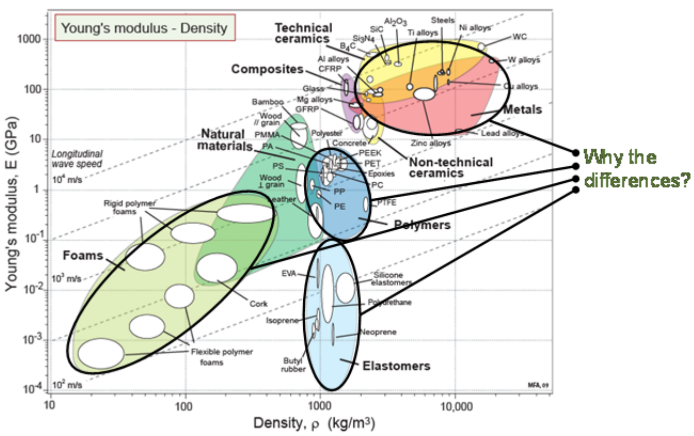

Figure 8. Family Envelopes on Bubble charts show how materials have similar properties within each family

Students also need to understand different materials classes, what defines them, and how their properties compare

Trends and Relationships

Charts can also illustrate relationships between properties. Young's Modulus is a basic Mechanical property, which engineers need to understand. It is fundamentally a measure of how easily you can deform materials elastically. Melting point is a measure how much heat energy you need to put in to a material before its atoms move apart. These two properties are **both linked to the potential energy** curve of the atomic bonds, shown in Figure 9.

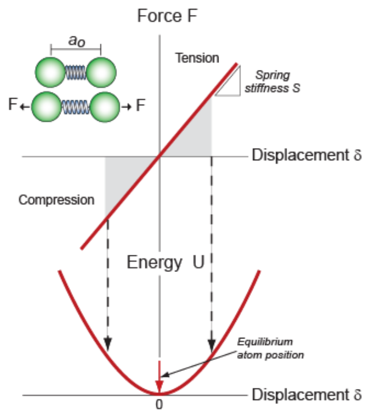

Figure 9. Diagram showing the energy needed to displace atoms

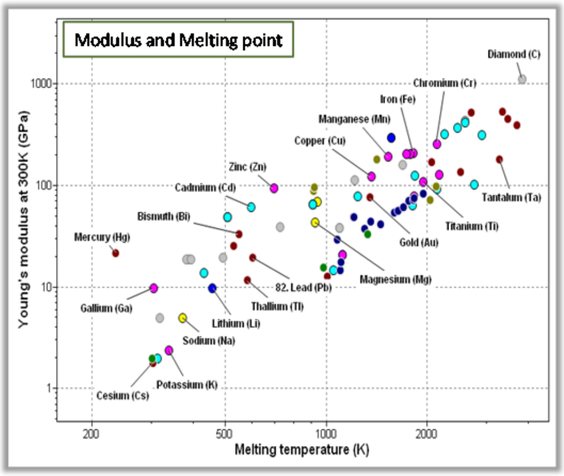

Figure 10. Chart showing the relationship between Young's Modulus and Melting Temperature

You can explore the relationship between Melting Point, Cohesive Energy, or Young's Modulus using the Elements database (see Figure 10). Mark De Guire[5], an Associate Professor at Case Western Reserve University, uses CES EduPack in lectures, then has students check that trends found in the Elements database also hold true in real engineering materials in the Level 2 database.

Multiple Dimensions

Understanding the evolution of materials over time, can help students to realize that there are many different grades of polymers and many metal alloys and that they need to be systematic in approaching selection from 160,000+ materials. Hopefully, it will also inspire them to create their own materials. In the example in Figure 11, below, there are **three dimensions: Strength, Density and Time**.

[5] De Guire, M. "*Exercises: Materials Course Assignments - Mechanical Properties*" Case Western Reserve University 2010 [www.teachingresources.grantadesign.com/Exercises/EXEMECEN10]

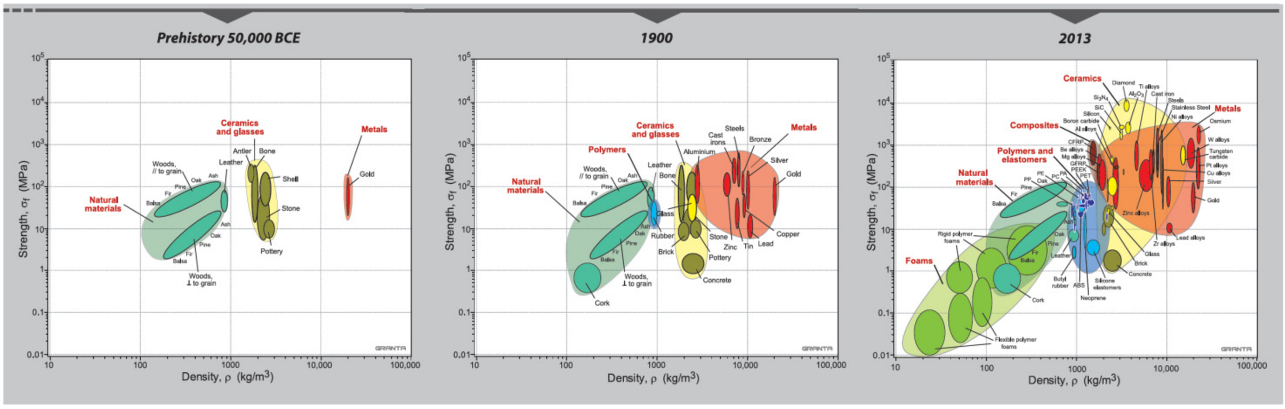

Figure 11. The explosion in the number of materials over time

Another easy way to add a third dimension is to use the Custom Subset feature, to chart only the group of materials that you are currently lecturing about today and colour-code those materials to highlight your point. For example, you could colour Carbon Steels by tempering temperature, adding another dimension to your plot, as shown in Figure 12.

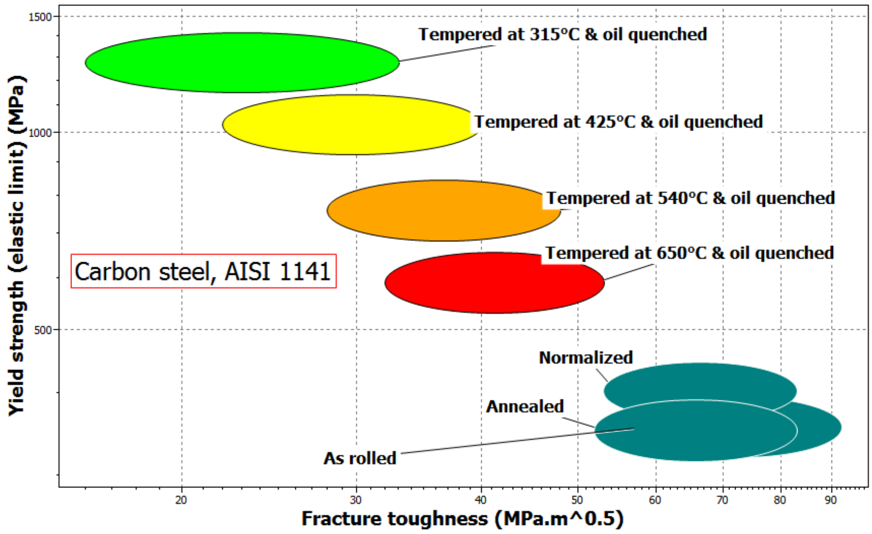

Figure 12. Chart showing just a sub set of materials and using colour to illustrate a point

You can take temperature into account in the Aerospace Database by plotting temperature dependent properties at different temperatures. This is also like having a third dimension, see Figure 13.

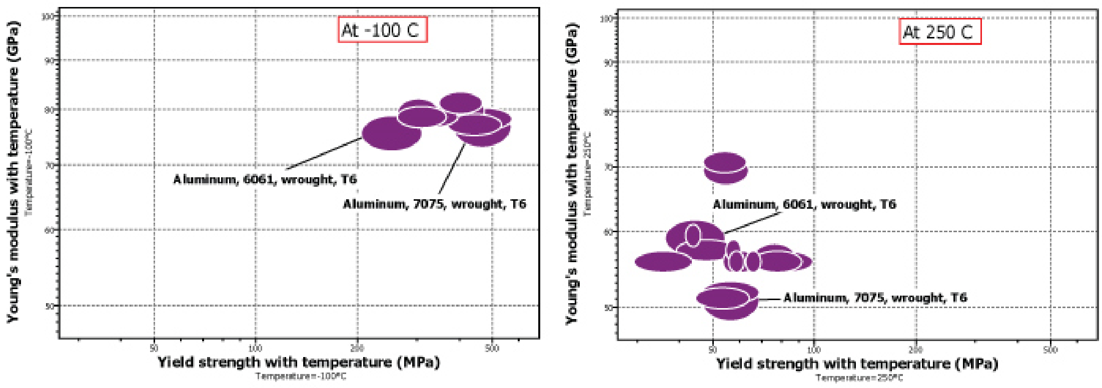

Figure 13. Charts showing the Yield Strength and Young's Modulus of common aerospace alloys at -100 and +250 degrees Centigrade.

A striking feature of many of the bubble charts is the large range of values covered by one material (see Figures 12, 13 and 14). With natural materials, there is variation in how the tree or crop has grown and a huge variety of species; for man-made materials, the variation comes about through the ingenuity of materials engineers.

Researchers have put a lot of effort in to **understanding the microstructure** of alloys and how they can be manipulated by changes in composition and heat treatment. Charts showing how solid solution hardening, precipitate hardening, and work hardening affect changes in mechanical properties help give students an overview of the different levers they can pull in order to tailor properties in new materials. Trajectory charts (see Figure 14) are used by Dr. Hugh Shercliff at the University of Cambridge, to help the Engineering students understand how they can manipulate the properties of materials, and the fact that processing changes the properties of a material.

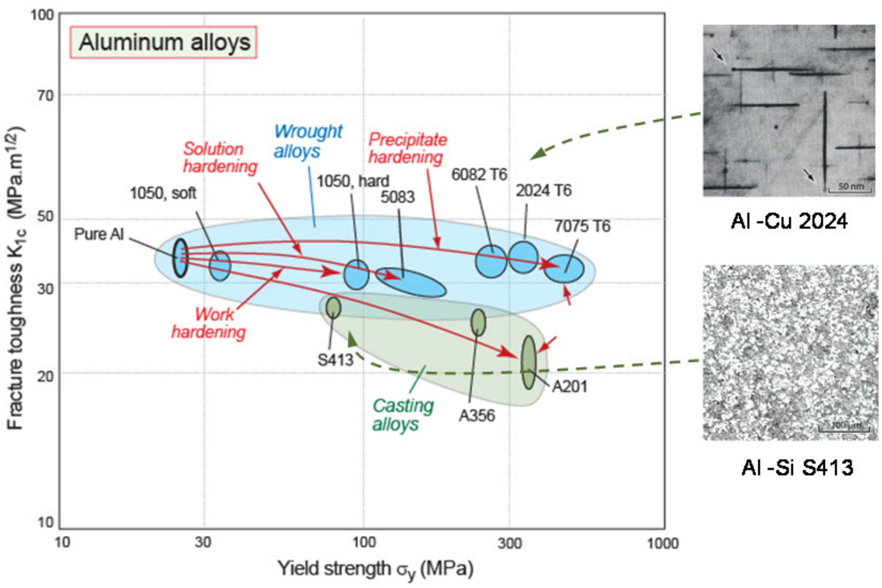

Figure 14. Chart linking microstructure to hardening mechanisms, from Lecture Unit 4

Aluminium Alloys have a range of yield strengths, with the highest being almost ten times the lowest

Images

A picture tells a thousand words. Pictures can help students quickly connect what is being discussed in a lecture with an object they have seen and possibly touched before. It helps them to engage with the lecture and file the new information they are receiving. Each record at levels 1 and 2 has images. Where possible, images are provided of **multiple applications and a surface image** (see Figure 15).

Image

Caption
1. Aluminum foil. © images-of-elements.com - (CC BY 3.0) 2. Block of crushed, recycled aluminum cans. © Lance Cpl. Miranda Blackburn, United States Marine Corps - Public domain 3. Aluminum drinking can. © Thinkstock

Figure 15. Images and caption from the record for Non Age Hardened Aluminum Alloys

The images all have captions that tell you about the copyright of the image. Many are either public domain or have a creative commons license so that lecturers can **copy and paste** them in to their lectures. Right click on datasheets to copy them in to your PowerPoint lecture. As well as Materials images, there are process diagrams, surface finish images in surface processes records, phase diagrams, and crystal structure diagrams (see Figure 16). Not to mention many very helpful diagrams in the science notes created by Professor Ashby.

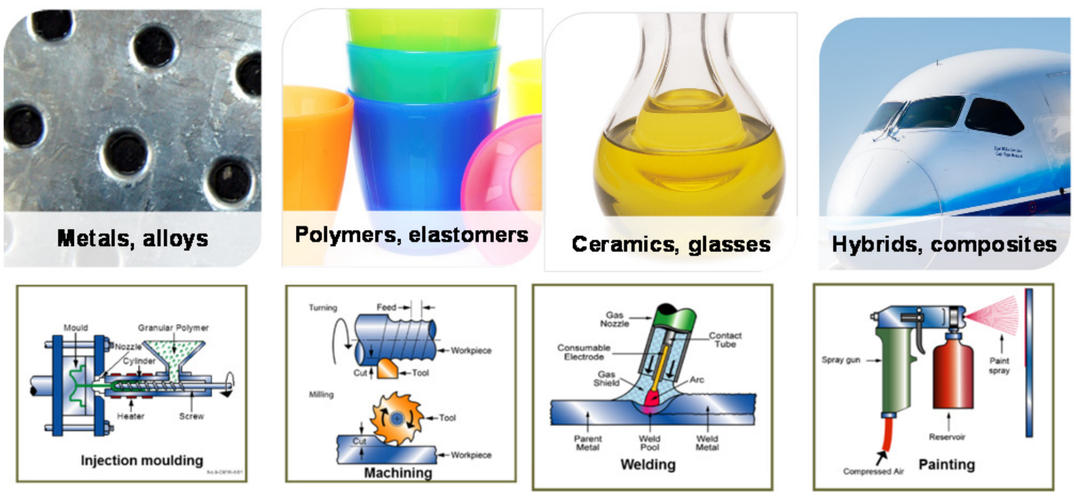

Figure 16. All Materials and Process Classes covered

Mike Ashby's Lecture Units

Professor Mike Ashby, author of many textbooks on materials, and an emeritus Professor at the University of Cambridge, is the co-founder of Granta Design and guides the evolution of CES EduPack. He developed CES EduPack in his teaching in the Engineering Department and produced a comprehensive set of PowerPoint lecture units for his teaching, primarily around Materials and Process Selection. They have since been expanded upon and are shared via Granta's Teaching Resources Website[6] (see Figure 18). These high quality PowerPoint slides have accompanying notes sections for Educators and many **beautifully clear images and diagrams** to illustrate concepts. There are versions with and without animation so as to facilitate printing them out for students. As was articulated earlier, all materials courses are different and these lecture units are provided merely as inspiration and to facilitate the use of diagrams and charts *etc*. Educators using CES EduPack are free to copy and paste slides, charts, and images *etc*. from the lecture units to use them in their teaching, as long as the source is stated.

Finding and Displaying Information	
Unit 1	**The materials of engineering**
Unit 2	**Material property charts:** mapping the materials universe
Unit 3	**The Elements**: property origins, trends and relationships
Material Properties	
Unit 4	**Manipulating properties:** chemistry, microstructure, architecture
Unit 5	**Designing new materials:** filling the boundaries of materials-property space
Selection	
Unit 6	**Material selection:** translation, screening, documentation
Unit 7	**Ranking**: material indices
Unit 8	**Objectives in conflict:** trade off methods and penalty functions
Unit 9	**Material and shape:** materials for efficient structures
Unit 10	**Selecting processes:** shaping, joining and surface treatment
Unit 11	**The Economics:** cost modelling for selection
Unit 12	**Eco selection and the Eco Audit tool**

Sustainability
Eco-informed material selection
What is a Sustainable development? a materials perspective
Materials for low carbon power
Special Topics
Architecture and the built environment: materials for construction
Structural sections: shape in motion
Materials in Industrial design: Why do consumers buy products?
CES EduPack Bio edition: natural and man-made implantable materials
Advanced Teaching and Research
Advanced databases: Level 3 Standard, Aerospace and Polymer
The Aerospace edition
The Polymer edition
Hybrid synthesizer: modelling composites, cellular structures and sandwich panels
Editing and creating new databases: CES Constructor
CES Selector and Constructor in research

Figure 18. A list of the Lecture Units by Mike Ashby available on the Teaching Resources Website

Exercises, case studies, and Lecture Units are available for inspiration

[6] Teaching Resources - Granta Design Ltd [www.teachingresources.grantadesign.com]

Assignments and Assessment

The most basic learning activity one can set with CES EduPack is simply to assign the students to research a topic and report back, for example, exploring the properties of carbon steels, or describing how Young's Modulus varies across material classes and why. There are **many exercise booklets provided** on Granta's Teaching Resource Website and most of the specialist editions of CES EduPack come with an exercise booklet highlighting the specialist materials knowledge needed in their areas. These help students differentiate between constraints and objectives, derive performance indices, perform materials and process selections *etc*. Case studies are also provided in many topic areas (see Figure 19). You can save selection project files, meaning that an Educator can save and distribute a file with questions in the notes section, or Educators can request that students deliver a selection project file as part of their assessment. Ready-made Eco Audit Projects are provided on the Teaching Resources Website, and these can be used as the basis for assignments, exploring different redesign options to reduce the environmental impact of a product. Lastly, **Solution Manuals are also available** on the Teaching Resources Website for three books by Professor Ashby: *Materials Selection for Mechanical Design*; *Materials: Processing, Design and Science*; and *Materials and the Environment*. These books all have exercises that students can do using CES EduPack.

Figure 19. Examples of Case studies in the Teaching Resource Website

Projects within courses

Project-based teaching is very valuable for engineering, design, and scientific degrees. It helps the students to synthesize their knowledge and learn professional skills such as teamwork, communication, and project management. CES EduPack can support many different kinds of project-based activities.

Eco Audit Projects – Modelling, data handling, and sensitivity analysis

The Eco Audit tool aims to help students model a product or component and assess its environmental impact and cost during design. It is suitable in introductory courses on Materials or Manufacturing as well as on Design or Product Development. It is **purposely not a full LCA tool**, but something quick and easy to set up, allowing students to play with different scenarios in a short space of time. The student downloads or builds a model of a product, detailing its size, existing or intended bill of materials, what each component is made of, how it is processed, and how the product is transported and used. All the calculations and sources of Eco data are intended to be **transparent** to the student and the model is well described under the i-button or help function within the software.

> You and your students are free to disagree with how the model is set up; in fact, such discussions are very welcome in this relatively new field

A lot of effort has gone in to making sure that the Eco Data used, such as embodied energy or carbon footprint of materials, is as fully referenced and accurate as possible. However, **Eco Data is not the same as mechanical property data**, where thousands of physical tests have been performed to agreed standards. In the help menu, there is a warning for the students about Eco data and how to use it sensibly (see Figure 20 as an example of data variability). Exercises using Eco Audit projects have been created to highlight that uncertain data can still be used in decision making as long as the difference in the data is larger than that of the uncertainty in the data.

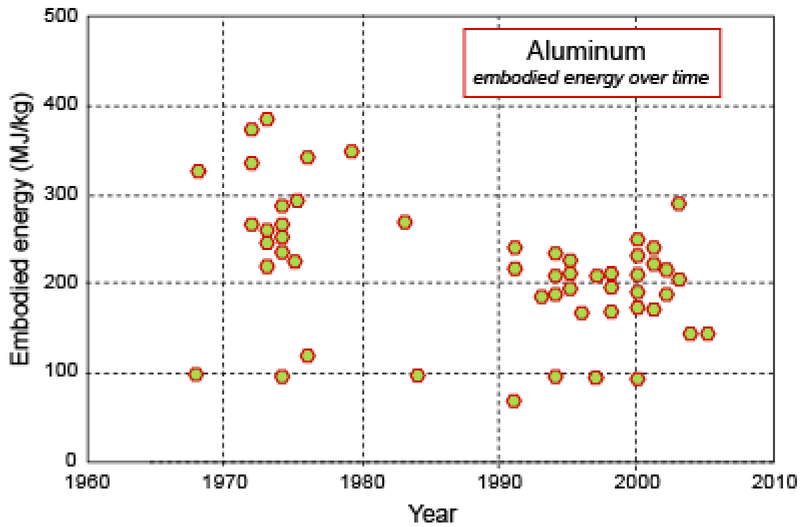

Figure 20. A chart shown in the help menu of the Eco Audit Tool helping students to understand the level of uncertainty in the data they are using

Many Eco Audit Projects are formed around the idea of assessing a product, suggesting redesigns, and making a comparison. You can Bar-chart the design and redesign alongside each other and quickly see the pros and cons of a product from both an environmental and cost perspective. If you click on a column on the comparison chart, you get some hints and tips for ideas on how to reduce the environmental impact in that phase of the product's life. Because the Eco Audit Tool is so easy to use and the comparison chart updates as soon as you change a parameter in the model, you can use these charts (see Figure 21) to get the students to find out which aspects of design make the most impact on the environment and get them to **focus their efforts where they will make the biggest difference**. At the same time they need to be aware of the cost implications so that they can properly argue for their design in a business context. (Note that the cost to the environment isn't included in the model, but is represented by the carbon footprint and embodied energy figures.)

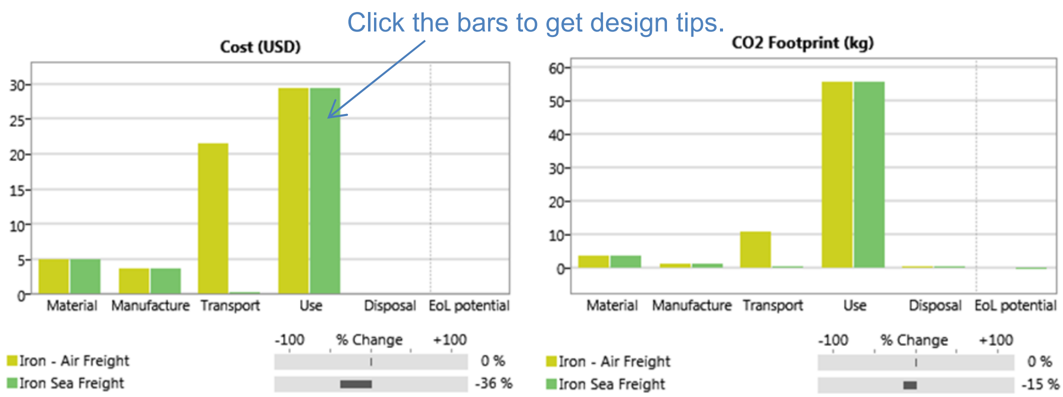

Figure 21. An example where cost and environmental impact can both be reduced by changing the transport method. Notes are provided on how to reduce environmental impact

Materials Selection – Decision making, trade-offs

There are well-known methodologies for selecting materials and processes[7]. CES EduPack supports that methodology by providing data and selection tools (you can read about those tools and the methodology in more detail elsewhere[8].) The software provides students with a **mini textbook on selection methodology**, a guide to performance indices, and varied selection case studies accessible via the Help menu of the software. A series of lecture units on how to select materials and processes are also available on the teaching resources website.[9]

> A material selection course can prepare students for wider **decision making**

Materials Selection in CES EduPack is, however, much more than simply getting the right materials for the job. It involves deciding on your criteria, finding the data you need, prioritising different requirements, and making sure you read the fine print. Students are lead through a process where they decide which design requirements are constraints and which are objectives. They learn how to derive a performance index using common engineering equations and, importantly, they learn how to **handle conflicting objectives** in a systematic manner[10]. Trade-offs (see Figure 22) are one of life's inevitable features and it is important that students learn how to tackle these. The results of most selection projects are a short list of potential materials. It is then important that students read the records in more detail.

[7] Pahl, G.; Beitz, W.; Feldhusen, J.; Grote, K.-H. "*Engineering Design: A Systematic Approach*" Springer 3rd Ed. 2007 and Ashby, M.F. "*Materials Selection in Mechanical Design*" BH 4th Ed. 2010

8 Ashby, M.F.; D. Cebon, D; Silva, A. "*Paper: Teaching Engineering Materials*" Granta Design Ltd 2012 [www.teachingresources.grantadesign.com/Type/Papers/PAPTEMEN12]

9 Ashby, M.F. "*Set of Lecture Units: Presentations*" Granta Design Ltd [www.teachingresources.grantadesign.com/Presentations]

[10] Ashby, M.F. "*Lecture Unit 8. Objectives in conflict*" Granta Design Ltd [www.teachingresources.grantadesign.com/Presentations/PPTOBJEN14]

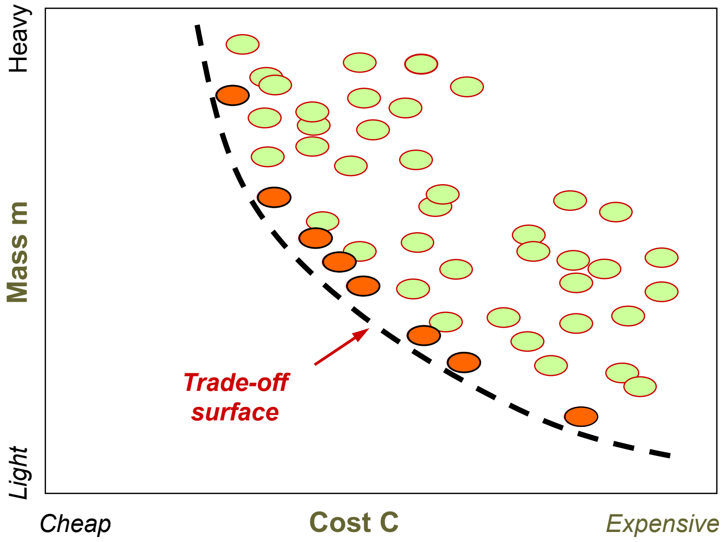

Figure 22. A Diagram from Lecture Unit 8 showing a trade-off between Cost and Mass

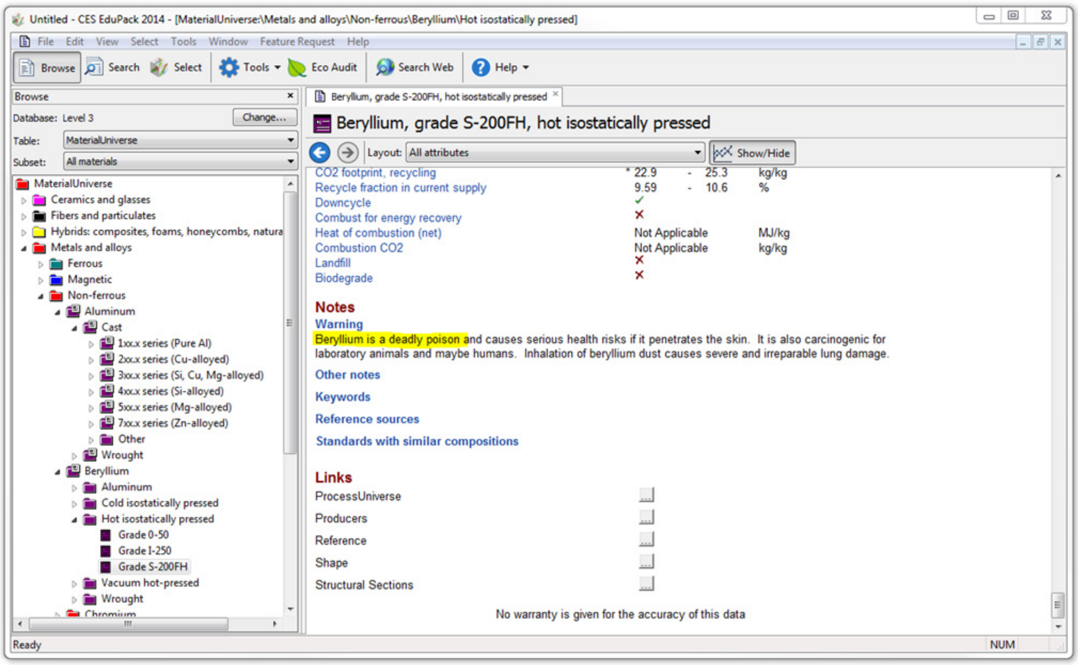

Figure 23. Reading the fine print is important

There is lots of useful data in the supplementary information section in the data records. For example, in the Beryllium records, which show up frequently due to high strength and stiffness, it mentions that **Beryllium dust is toxic** (see Figure 23). Reading the records can lead the student to adapt constraints, *e.g.*, add non-toxic, or to loosen constraints as none of the candidate materials appear viable. Students can see that if they change their criteria slightly, different results show up.

> There is often, contrary to high school education, no "right answer"...

Open-ended solutions are something that undergraduates need to become comfortable with. Indeed, in industry, once a high performing material is chosen, the purchasing department may well add other criteria, such as the reliability of the supply chain, or the fact that they can bulk buy a material. These **broader strategic issues** for Materials Selection are something that the non-educational part of Granta Design works on with industry.[11]

Materials Design Projects – Prediction of Properties and modelling

The Hybrid Synthesizer tool, available in advanced editions of CES EduPack, enables the student to predict (estimate) the properties of hypothetical materials based on simple models. There are 5 models built in as standard: *Cellular Structures*, *Sandwich Panels*, *Multilayer Materials*, *Controlled Thermal Expansion,* and *Composites (simple bounds)*. A model writing guide helps more advanced students and teaching researchers to create models for themselves. The models are written out in detail in the accompanying white paper[12] so that **students can understand the assumptions made and the basis for the predicted properties**. In the tool, students are able to choose a model, *e.g.*, Sandwich panels, choose the materials involved from the Materials Universe, and enter information about the geometry, such as the number and thickness of the panels. A basic record is then generated for the hypothetical material, with a cut down set of properties (see Figure 24). These materials can then be charted alongside the usual materials in the MaterialUniverse and the usual selection process can be carried out to see if the hypothetical material would perform better than materials currently available, in a particular application.

[11] GRANTA MI for Industry "*Supporting your Business Strategy*" Granta Design Ltd [www.grantadesign.com/strategy]

[12] Ashby, M.F. "*Paper: Hybrid Synthesizer*" Granta Design Ltd 2011 [www.teachingresources.grantadesign.com/Type/Papers/PAPHSZEN11]
Ball, N.; Bream, C.; Bateson, J. "*Guide: The Hybrid Synthesizer - Model Writer's Guide*" Granta Design Ltd [www.teachingresources.grantadesign.com/Type/Papers/PAPHSWEN13]

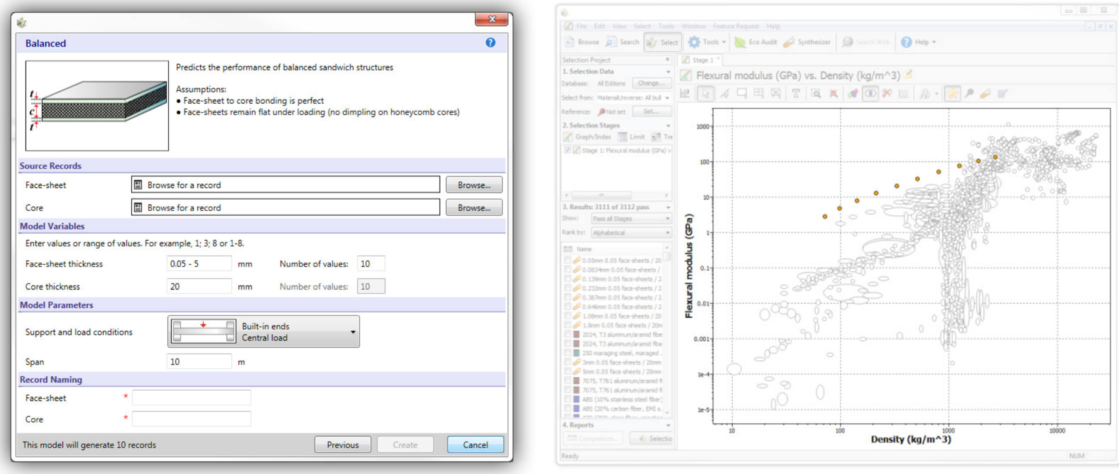

Figure 24. The Hybrid Synthesizer tool

Students can be given projects to understand the model and to trial different material combinations and geometries to optimise performance for a given application. This is particularly suitable for courses on **light-weighting in aerospace or automotive** structures where composites, metal foams, or other hybrids are common.

Reverse Engineering Projects

One type of project that is set by many universities is a project where a product is taken apart and the components are analysed, *i.e.*, what it is made of and how it was manufactured is investigated. An example of this type of project using CES EduPack has been contributed to Granta's Teaching Resource Website by Rob Wallach of the Materials and Metallurgy department of the University of Cambridge[13]. CES EduPack helps in a couple of ways. Firstly, each material record has a section called **Typical Uses**. The search function can be used to scan this text and identify a short list of typical materials that the object could be made from. There is also other information to broadly characterize a material, such as a list of the polymer Recycle marks commonly seen on packaging, and images of materials, including, where possible, a surface finish image. Once the materials have been identified, the links between material and process records in CES EduPack can be used to find out which processes could be applied to that material. From there, cost and batch size information can be used to narrow down further. Different processes become economic at different scales of production—this is reflected in the attribute *Relative cost index* in Level 2. This is generated using a **cost model**, which includes batch size as a parameter. So if, as is likely, the students are disassembling a cheap, mass produced object, they can take that information into account when contemplating a likely process route, **adding realism to their learning.**

---

13 Wallach, R. "*Case Studies: Investigation of a Manufactured Article*" University of Cambridge [www.teachingresources.grantadesign.com/Exercises/EXEIMPEN10]

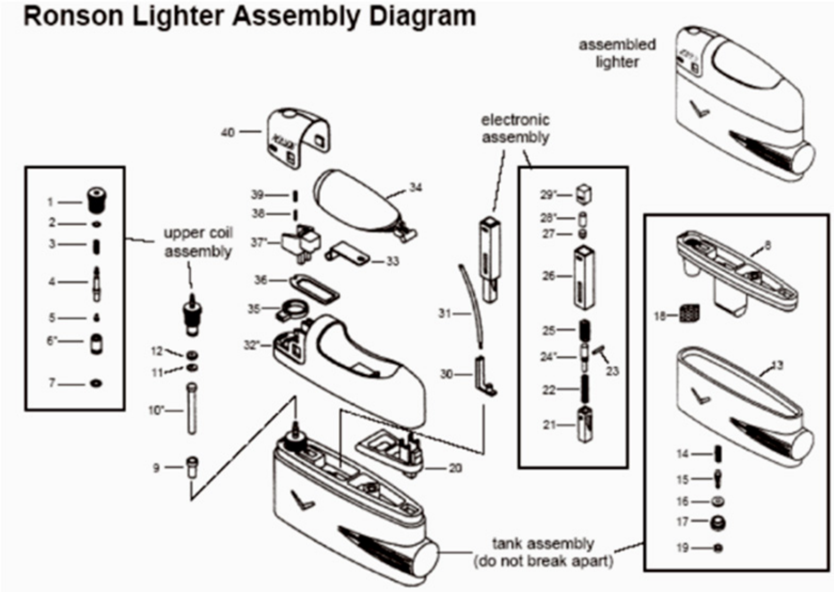

Figure 25. Assembly/Disassembly diagram from a contributed project on the teaching resources website

Capstone Design Projects and Problem-Based Learning

Capstone Design Projects – Creativity, Specification, Communication

Many universities have extensive design projects in the final year of the degree. The purpose is usually threefold: to learn about the design process, to cement the knowledge gained in technical courses in the previous years, and to gain valuable skills that they will need in future jobs such as project management, teamwork, and communication. During these projects CES EduPack can help in several ways (see Figure 26).

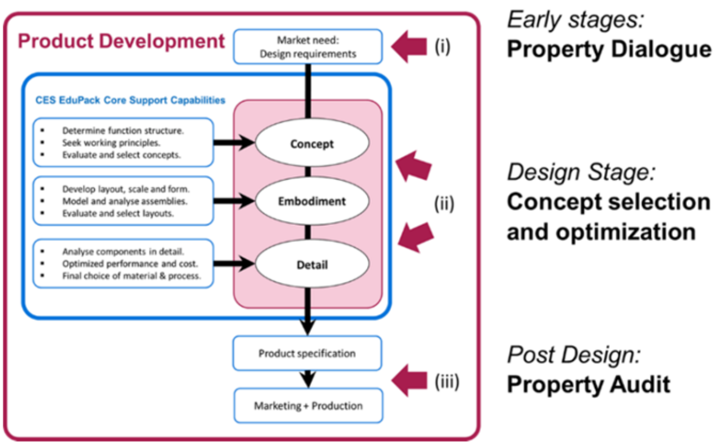

Figure 26. *CES EduPack aiding students throughout the Product Development process*

At the early stages of a project it can be used to **generate ideas** by searching for information about similar products. The limit stage (mainly used for screening) presents a list of properties; this **forms a handy checklist for potential constraints**, and can be used as the basis of a questionnaire if speaking to potential customers or the instructor if they are representing the customer in the project (this is described in more detail in a paper describing a Product Development Course using CES EduPack.[14]). During the concept development stage, different options can be worked through. Some options can be quickly discounted by roughly working out costs using the materials price data and the relative cost model in the Process Universe. Proper material and process selection can be performed on the leading idea, and different approaches, such as Eco Design and **Design for Manufacturability**, can be catered for using data from CES EduPack. Depending on the structure set up by the educator, it may be necessary to communicate the design idea and material choice to a customer, to the supervisor, or possibly within the design team in order to get agreement to move forward to a build stage.

> At this stage, the charts created as part of the selection become an excellent way to communicate different options and the trade-off between these

One example of a decision based on material properties could be the choice between a cheap steel option *vs.* a light expensive aluminium option, given constraints on mechanical performance. Notes can be added to each selection stage in CES EduPack, and the selection **saved as a project and shared** between team members or sent to the instructor for review.

Sustainable Development Projects – Stakeholder perspectives, fact finding and synthesis

The Sustainable Development Edition of CES EduPack facilitates a new level of project work with the software. The project methodology, described in detail by Mike Ashby in the paper Materials and Sustainable Development[15] and a forthcoming book, provides a for general assessment of technologies.

It involves 5 steps:

1. Articulation Statement (prime objective and scale)
2. **Stakeholders and Concerns**
3. Fact-finding
4. Synthesis (impact on the three capitals)
5. Reflection

[14] Fredriksson, C,; Eriksson, M.; Melia, H.; “Facilitating the Teaching of Product Development", Proceedings of the 121st ASEE Annual Conference, June 16-18 2014, Indianapolis, USA.

[15] Ashby, M.F.; Ferrer, D.; Bruce, J.; “*Paper: Materials and Sustainable Development*” Granta Design, Universitat Politecnica de Catalunya 2013 [http://teachingresources.grantadesign.com/Type/Papers/PAPSSDEN13]

Students are guided through a process by which you can review if a technical development is sustainable while maintaining an open ended but systematic and fact-based framework for learning. They normally work in groups participating in the process over several weeks, gathering data from CES EduPack, but also from newspaper articles, the internet, and so on. When tested at three universities, one of the areas that the students found most difficult was **identifying stakeholders, understanding their concerns, and prioritizing them**. The methodology helps the students to assess the importance and influence of different stakeholders (see Figure 27).

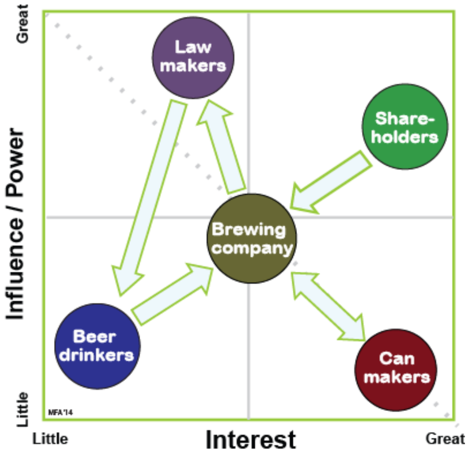

Figure 27. Sustainable Development project to help students address stakeholder concerns

One of CES EduPack's strengths is its data

CES EduPack is designed to facilitate self-learning in an interactive and engaging manner. The ease, with which students can access referenced, comparable data means that fact-finding can be done more quickly and reliably. In the case of Sustainable Development Projects, students have access to extensive data (see Figure 28). This covers ***Materials***, particularly geo-economic and eco-properties; where they are sourced and whether they are "critical", ***Legislation and Regulations*** that pertain to the environment, health, resources *etc*, ***Energy Storage*** *and* ***Low Carbon Power Systems*** which is relevant to understand technology and climate change, and data about ***Nations of the World*** that affects social sustainability as well as the supply chain. Students can be encouraged to follow the links at the bottom of each record to find out where the data is coming from and form an opinion about whether they consider them **reliable or biased sources.**

Figure 28. Data useful for Fact-Finding regarding Sustainability

Accreditation

No teaching resource, be it textbook or software, can help a student achieve a learning outcome by itself. It is by the educator that students are guided through the most important topics, in a logical order, at the right level, and with an opportunity to question and see different examples. The higher one climbs in Bloom's taxonomy, the more the support from the educator is required. However, as we have demonstrated in all the examples given in this paper, the software can help to support teaching that fulfils many key learning outcomes at all the levels of the Taxonomy. This is very helpful in the design of Curricula that comply with modern outcome-based systems for quality assurance. One example where CES EduPack is helpful is when introducing the CDIO (Concept Design Implement Operate)[16] Syllabus in Engineering programs.

In Figure 29, we display key areas at the second level headings for the CDIO criteria where we think students work with CES EduPack can help. In order to secure accreditation in some of the major accreditation systems around the world, this is a good starting point. In Figure 29, we have matched the CDIO criteria with ABET accreditation criteria, which clearly shows the similarities. CDIO and the European EUR-ACE system for accreditation can be matched in a very similar way and the conclusion is the same. CES EduPack can help the Educator arrange learning activities to help Students achieve learning outcomes in courses and engineering programmes, which in turn facilitates accreditation and quality assurance.

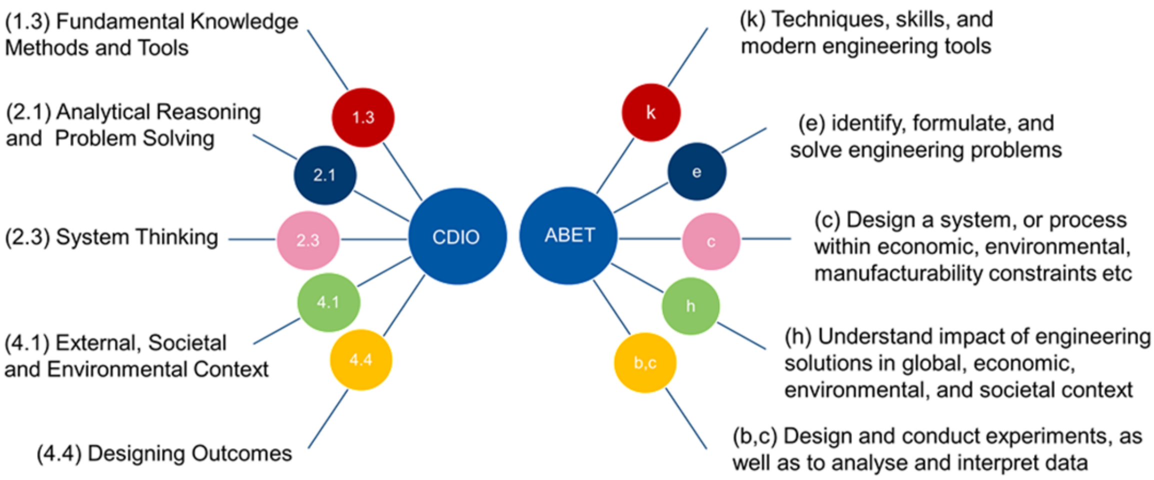

Figure 29. *Examples of Learning Outcomes and accreditation criteria that can be supported by CES EduPack*[17]

[16] Conceive Design Implement Operate [www.CDIO.org]

[17] Image from: Vakhitova T. and Fredriksson C., "Practical Competences as Learning Outcomes using CES EduPack", Journal of the Association for Engineering Education of Russia (AEER): Engineering Education 2013, (13) p. 16-23

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
The selection methodology supported by CES EduPack is used by industry, and indeed you may be interested by the case studies available on our website[18] from real industrial companies.

(e) identify, formulate and solve engineering problems
Converting the messy, sometimes contradictory, often non-technical needs expressed by customers into design requirements and then on to a system of constraints and objectives, is a skill students can practice many times by working through the exercises provided on the Teaching resources Website19.

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
We have shown how we can support manufacturability and eco constraints, the process universe contains a relative cost index model and price details of materials are regularly updated, so that students may also take cost in to account.

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
The Sustainable Development Edition is purposely designed so that students can think about societal impact and the global context with a datatable on the nations of the world.

(b) design and conduct experiments, as well as to analyse and interpret data
Lastly, in order to make smart decisions using the results from CES EduPack you need to understand the data, how accurate it is and what it can and can't tell you. This critical thinking is encouraged through exercises and case studies.

Summary

In summary, students can learn about materials properties, formulate complex problems in a simplified model, experience projects with no right answer, weigh-up pros and cons, reflect on data sources, appreciate different stakeholder perspectives and understand lifecycle thinking.

CES EduPack is specifically designed for teaching. It is an excellent data source and a rational materials selection tool, but it can do so much more when skilfully applied by a talented educator.

Acknowledgments to freepik.com