Granta EduPack White Paper

Teaching Materials and Processes to First and Second Year Students

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Approaches to materials teaching

Engaging the interest of first and second year students is a challenge. In teaching students of Physics and of Materials Science it makes sense to start at the atomistic level, building upwards through the physics of bonding, crystal structure and band theory, the thermodynamics and kinetics of alloys, finally arriving at material properties (*Figure 1, reading left to right*).

Students of Engineering often find this too remote from the goals that motivate them. Engineers make and manage things. What do they need to know about materials to choose and use them successfully? First, they need a perspective of the world of materials: the "menu" of metals, polymers, glasses, ceramics, composites, and of processes that can shape, join and finish them. Second, some understanding of the origin of these properties and how they can be manipulated. Third, they need methods for selecting from these menus the materials and processes that best meet the requirements of a design. Fourth, they need access to data for materials attributes and, since the quantity of data is large and the methods tedious to implement by hand, computer-based tools to enable their implementation.

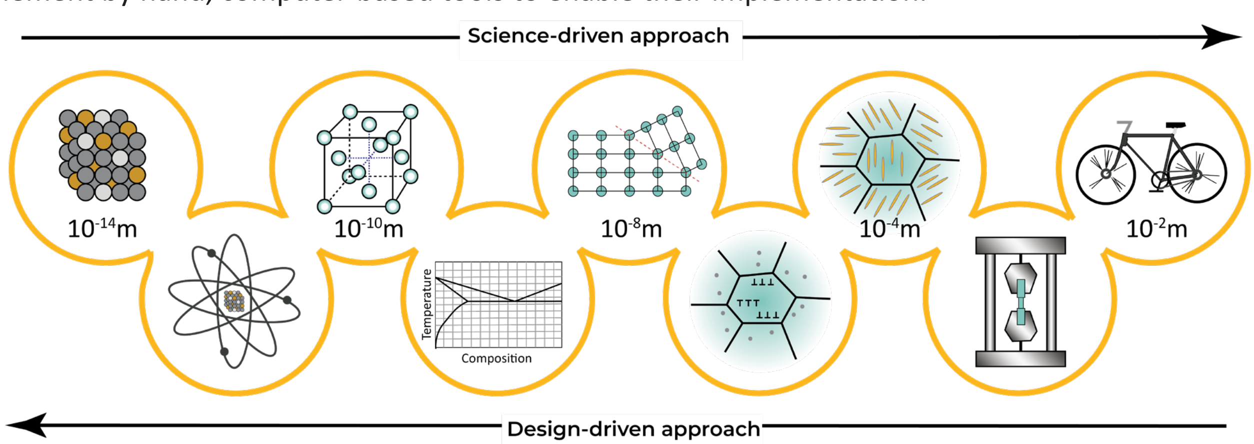


Figure 1. Two alternative approaches (much simplified) to the teaching of materials

At the University of Cambridge, working with the Ansys Materials Education Division (formerly Granta Design) and colleagues at many other universities, we have developed an approach to teaching engineering students about materials and processes that is structured to give students this understanding. It starts with an introduction to design methods and the ways in which information about materials enters the design process. Material properties are presented in property charts that provide an overview of the ranges of the properties and become a selection tool for choosing materials to meet given design constraints. Once the relevance of a property to design is established, it becomes logical to "drill down" to the underlying science, demonstrating where the property comes from and how it can be manipulated (*Figure 1, reading right to left*).

Explore the resources that accompany Ansys Granta EduPack:

- PPT lecture units
- Worked examples
- Case studies
- White papers
- Materials charts

Design-driven and science-driven approaches both need tools and resources to engage and inspire students. In developing our design-driven courses we have created a number of such tools and resources that have proved to be particularly valuable for introductory courses of whatever teaching approach.

Organizing information

Students nowadays turn more and more to visual ways of learning. A visual introduction to materials appeals to students of all subjects and degrees. Structuring the information in an explicit way also helps the student navigate through the families of materials without feeling lost. Because materials properties also depend heavily on the manufacturing processes with which they are brought to life, links between the realms of materials and processes are also explicitly provided. Information on suppliers and references to external data sources is provided and interlinked. *Figure 2* shows the structure of the database and the links that exist between each data table. *Figure 3* shows examples of images that appear in the materials database associated to some of the materials, appealing directly to specific and diverse engineering and science degrees.

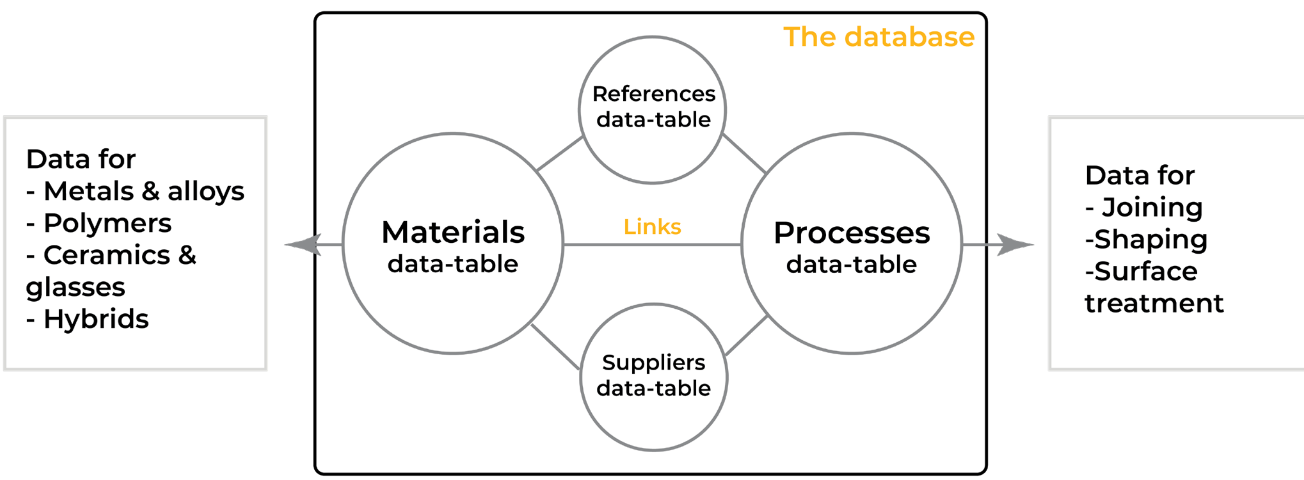


Figure 2. The structure of the information in Ansys Granta EduPack

Figure 3. Examples of materials from different materials families, appealing to students of all backgrounds

Property charts, selection, and science

Figure 4 is an example of a material property chart (elastic modulus, E, plotted against density, ρ). The range of the axes is chosen to include all materials, from the lightest, softest foams to the stiffest, heaviest metals. The properties of a given family of materials (polymers, for example) cluster together; the *sub-range* associated with one family is, in all cases, much smaller than the *full range* for that property. Data for one family can be enclosed in a family-envelope, as the Figure shows. Within it lie bubbles enclosing classes and sub-classes. All material properties can be presented in this way. They provide a tool-set for material selection to meet a specified design constraint, the methods for which are integral to our design-driven course.

Within introductory courses, whether design-driven or not, the charts can be used to explore another set of questions. Why do members of material classes cluster in the way they do? What determines where clusters lie on the charts? Why are some properties so obviously correlated? How can properties be manipulated to better meet design requirements? These questions are a natural lead-in (and one the engineering student sees as relevant) to the underlying science of the material classes: the atomic bonding and packing determining density, melting point and stiffness; the defect structure determining hardness, strength, toughness; the transport properties and the magnetic behavior.

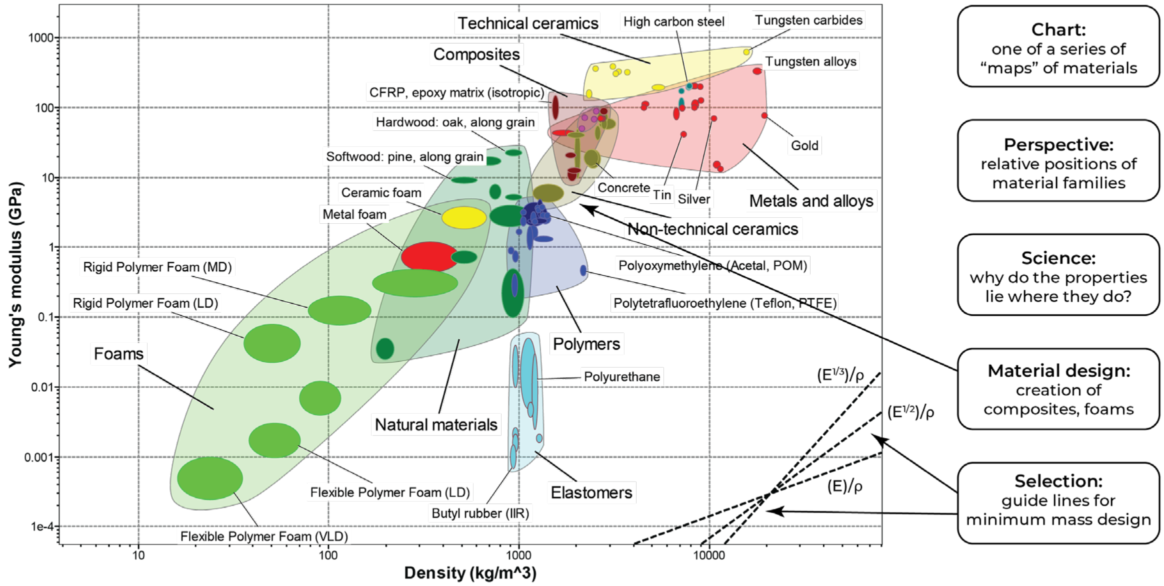


Figure 4. An example of a materials property chart and its use to give a perspective, to allow selection, to explore how properties are manipulated, and to introduce the underlying science

Acrylonitrile butadiene styrene (ABS)

Datasheet view: All properties | Show/Hide | Find Similar

Polymers and elastomers > Polymers > Thermoplastics >

Description

Image

Caption

1. ABS pellets. © Shutterstock 2. ABS allows detailed moldings, accepts color well, and is non-toxic and tough enough to survive the worst that children can do to it. © Gettyimages

The material

ABS (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and, in self-extinguishing grades, are used for the casings of power tools.

Composition (summary)

Block terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and styrene (40-60%).

General properties

Density	1.03e3	-	1.06e3	kg/m^3
Price	* 1.72	-	2.01	USD/kg
Date first used	1937			

Mechanical properties

Young's modulus	2.07	-	2.76	GPa
Shear modulus	* 0.74	-	0.987	GPa
Bulk modulus	* 3.84	-	4.03	GPa
Poisson's ratio	* 0.391	-	0.407	
Yield strength (elastic limit)	34.5	-	49.6	MPa
Tensile strength	37.9	-	51.7	MPa
Compressive strength	* 39.2	-	86.2	MPa
Elongation	5	-	60	% strain
Hardness - Vickers	* 10	-	15	HV
Fatigue strength at 10^7 cycles	* 15.2	-	20.7	MPa
Fracture toughness	* 1.46	-	4.29	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.0145	-	0.0193	

Figure 5. Part of a record for ABS from Granta EduPack Level 2

Choose the Granta EduPack Database that best suits the needs of your current teaching:

Introductory Databases:

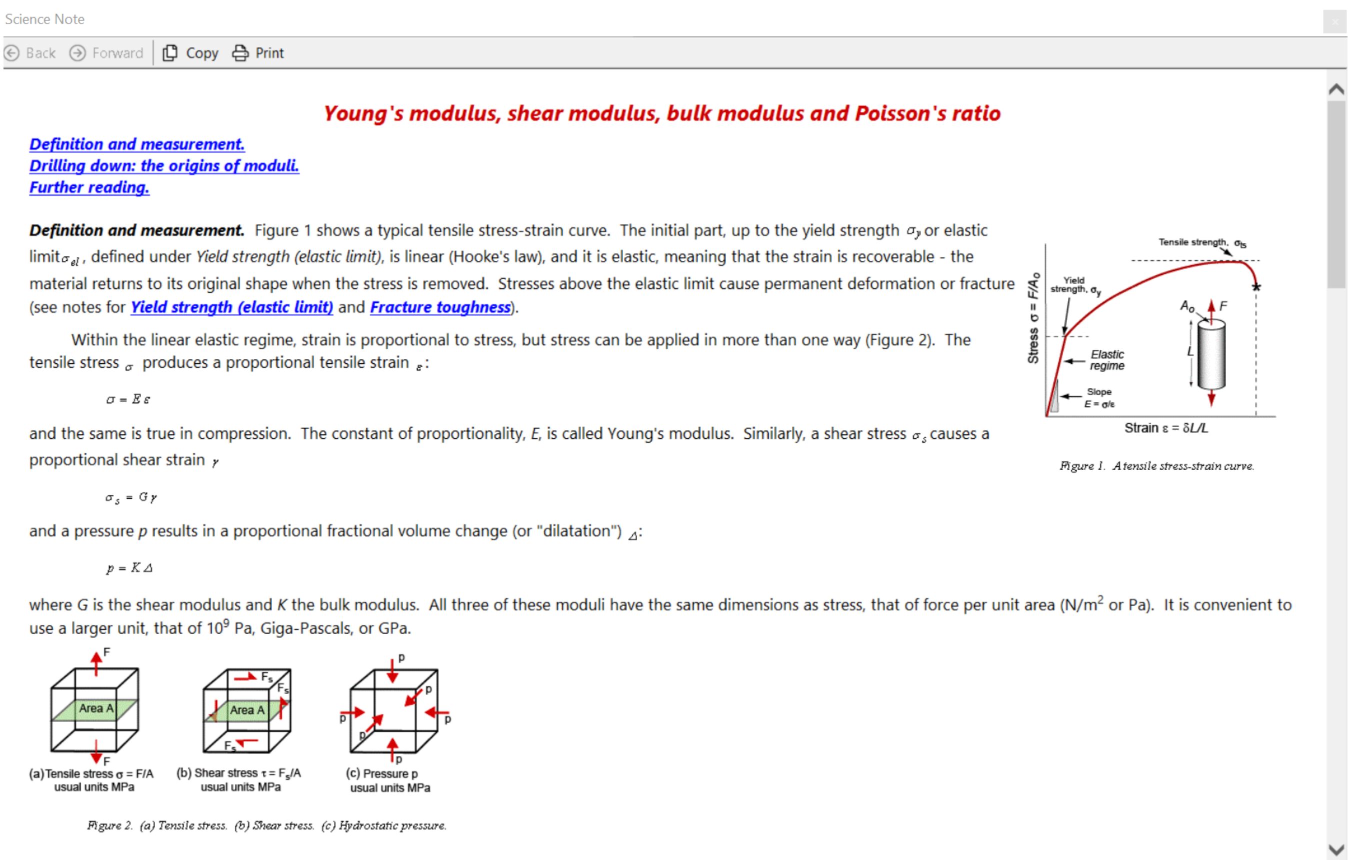
- Level 1
- Level 2
- Level 2 Bioengineering
- Medical Devices
- Level 2 Sustainability
- Architecture
- The Elements
- Design
- Materials Science & Engineering

Advanced Databases:

- Level 3
- Level 3 Eco Design
- Level 3 Aerospace
- Level 3 Polymer
- Level 3 Bioengineering
- Level 3 Sustainability

Encouraging use of these charts to explore the materials world stimulates student interest. But, as understanding progresses, more detail is needed. The Granta EduPack software, developed specifically for education, can help, allowing students to create charts with any combination of properties, to zoom in on any part to increase resolution, and to access records for the attributes of any material (*Figure 4* was created with the software [1]).

The package includes selection tools to meet complex design requirements and backs this up by giving access to the underlying science. *Figure 5* shows part of a material record. It starts with a description of the material and an image of a familiar object made from it – a way of conveying information relevant for industrial design. That is followed by a table of material properties, a list of typical uses, and, in a higher level of the software, design guidelines, technical notes and notes concerning its impact on the environment. Each field name (e.g., "Young's Modulus") in a material record is linked to text files, known as Science Notes, giving a definition of the attribute, a description of how it is measured and explanation of its origins, and further reading. Figure 6 is an excerpt of a Science Note.


Science Note

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Young's modulus, shear modulus, bulk modulus and Poisson's ratio

Definition and measurement.
Drilling down: the origins of moduli.
Further reading.

Definition and measurement. Figure 1 shows a typical tensile stress-strain curve. The initial part, up to the yield strength σ_y or elastic limit σ_{el}, defined under *Yield strength (elastic limit)*, is linear (Hooke's law), and it is elastic, meaning that the strain is recoverable - the material returns to its original shape when the stress is removed. Stresses above the elastic limit cause permanent deformation or fracture (see notes for ***Yield strength (elastic limit)*** and ***Fracture toughness***).

Within the linear elastic regime, strain is proportional to stress, but stress can be applied in more than one way (Figure 2). The tensile stress σ produces a proportional tensile strain ε:

$$\sigma = E\,\varepsilon$$

and the same is true in compression. The constant of proportionality, *E*, is called Young's modulus. Similarly, a shear stress σ_s causes a proportional shear strain γ

$$\sigma_s = G\,\gamma$$

and a pressure *p* results in a proportional fractional volume change (or "dilatation") Δ:

$$p = K\,\Delta$$

where *G* is the shear modulus and *K* the bulk modulus. All three of these moduli have the same dimensions as stress, that of force per unit area (N/m^2 or Pa). It is convenient to use a larger unit, that of 10^9 Pa, Giga-Pascals, or GPa.

Figure 1. A tensile stress-strain curve.

Figure 2. (a) Tensile stress. (b) Shear stress. (c) Hydrostatic pressure.

Figure 6. Excerpt of a Science Note for Young's Modulus

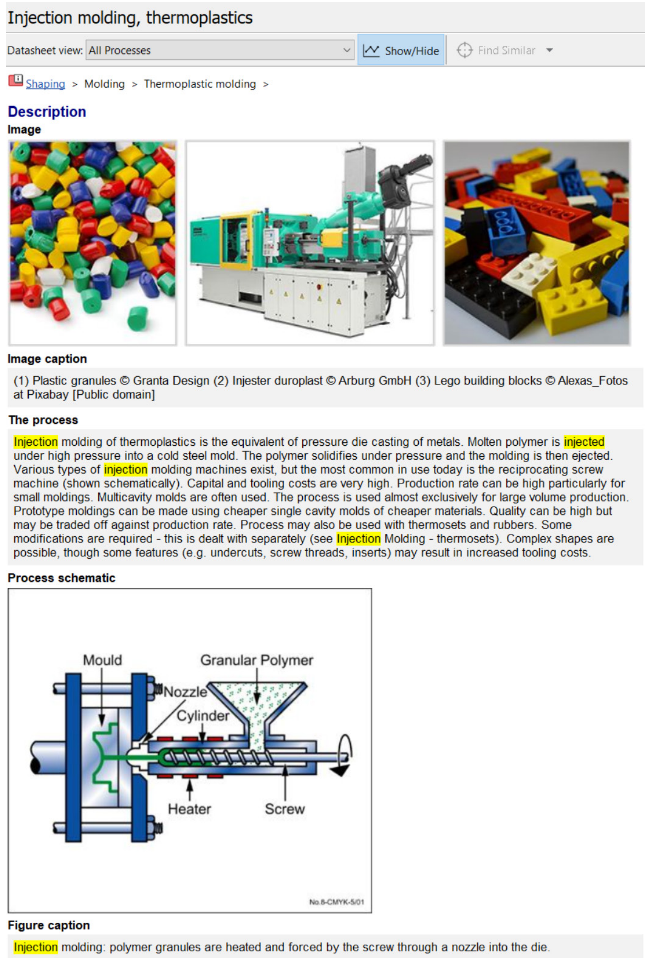

Figure 7. Part of a record for Injection Molding, thermoplastics from Granta EduPack Level 2

Finally, each material record is linked to appropriate members of a parallel database of manufacturing processes: those that can shape, join, finish, and decorate it, providing further information on how a particular manufacturing process works, what are the constraints and limitations, what shapes it can produce, and also some environmental and economic data. A very simple cost model is provided, letting the student be familiarized with concepts like the economic batch size, production rate, and tooling cost.

Finally, each process record is linked back to the materials that it can shape in the materials database. *Figure 7* shows part of a manufacturing record for injection molding. We have found that the Granta EduPack software provides a simple, highly visual and engaging framework within which students can explore rich content, "drilling down" to the fundamental science and making a direct connection between this science and design applications. Such connections help to build a materials perspective and understanding and can be particularly valuable in developing an enthusiasm for the subject amongst first and second year students.

A different take on the Environment

Granta EduPack enables a quick, early design overview of the environmental impact of products, looking at the different phases of the products' life cycle in terms of energy consumption and carbon footprint.

Distinguishing between the different phases of life (raw material production, product manufacture, transportation, use, disposal and end-of-life) allows students to assess which phases impact the most and how best to mitigate for that in the early stages of design. The Eco-Audit tool can compare different alternatives to a reference design, showing improvements on either energy consumption or carbon footprint. This makes it much easier to identify where different materials or manufacturing processes impact the most and what can be done to minimize their impact. *Figure 8* shows one such comparison for water bottles made of PET and glass. Up to 10 alternatives can be compared on the same plot. Granta EduPack provides some tips on how to minimize the impact for each phase of life, noting that any changes made can affect the other phases as well, enabling the discussion of design trade-offs.

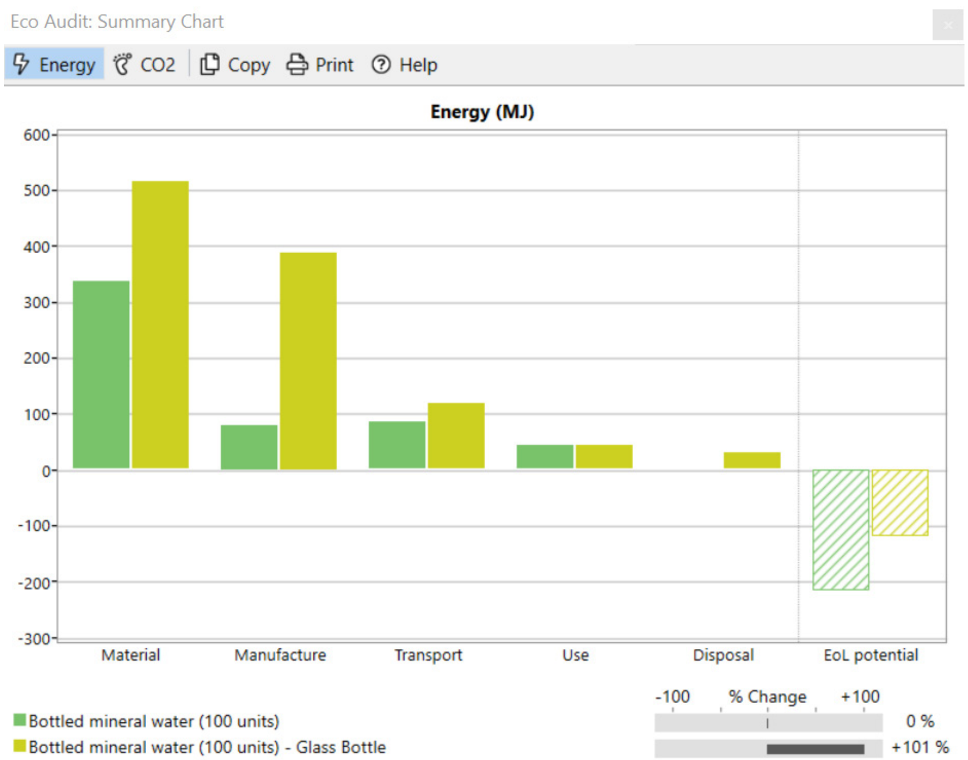

Figure 8. A comparison of different materials for the manufacturing of water bottles. The context is the following: 100 bottles (1 liter each) are manufactured in France, filled, and shipped to the UK, where they are refrigerated for two days before consumption. The picture shows the comparison between a PET bottle and a glass bottle, both recycled at their respective en-of-life.

Supporting texts and resources

The computer-based tools of Granta EduPack can only provide one component of a rounded introductory materials course. We have developed a series of supporting lectures and exercises that can help lecturers to build such a course. The choice of supporting textbook(s) will also be vital.
The Granta EduPack software introduces materials fundamentals in a manner that complements any introductory materials text regardless of the approach (science or design-led) or the text from which it is taught. For example, Callister's "Materials Science and Engineering: An Introduction" [2], Budinski's "Engineering Materials" [3], or Askland's "The Science and Engineering of Materials" [4], all of which take the science-led route, can be augmented and reinforced with software-based exercises to explore the world of materials.

We have developed the design-led approach in a number of texts, of which two are appropriate for first and second year teaching. The text “Materials: Engineering, Science, Processing and Design” [5] introduces key methods and illustrates their application to the use of materials in mechanical, thermal, electro-magnetic, and optical design. It offers a high degree of integration with Granta EduPack, including exercises using the software. “Materials and Design” [6] addresses issues of industrial design, providing an introduction to materials for students of product design. “Materials Selection in Mechanical Design” [7] is a more advanced text, developing the methods to a higher level, one appropriate for third, fourth year and masters level teaching. The text “Materials and the Environment” introduces students to issues of sustainability and eco-design [8]. All four have numerous exercises for which solution manuals are available.

Engage with your students in an exploration of the world of materials by:

- Innovating in materials selection
- Broadening perspectives on what’s possible
- Uncovering the relationships between material, shape, processing and cost
- Introducing the influence that materials have on the environment

Project-based teaching

Granta EduPack provides a resource for project-based teaching. The projects that we use for first and second year students focus on analyzing material choice for familiar products, avoiding at this early stage the need for a detailed understanding of complex systems.

In the Bicycle Project, for example (see *Figure 1)*, students are first asked to select a component of a bicycle (frame, forks, saddle, spokes, brake-cable…) and a user group (e.g., children, shoppers, touring use, sprint, mountain biking…) for which the design is intended. They are then asked to formulate the requirements if the product is to meet the needs of that group and the objective appropriate to it (minimizing weight or cost, maximizing robustness…). These provide the inputs for the Granta EduPack software, which delivers a ranked list of suitable candidates, datasheets for their properties, and suggested manufacturing routes.

Redesign to reduce the environmental impact of a product is a rich source of projects. The students must decide which phase of life (material production, product manufacture, product use, disposal at end of life) poses the greatest environmental problem, and then select appropriate materials to minimize this. Granta EduPack provides all the resources to enable projects of this sort.

Summary

First and second year students need a materials perspective, methods, tools and understanding to enable the rational selection and use of materials. Strong links with design, for example via a design-driven teaching approach, can provide immediate integration with the other engineering subjects. Whatever approach is adopted, the simplicity and visual impact of property charts offer valuable support, particularly within computer-based tools such as the software available as part of Granta EduPack. Experience shows that students like such tools, which motivate them to explore materials for themselves. Such software also provides exportable skills: students gain an insight into professional-level engineering tools.

References

[1] Ansys, Ansys Granta EduPack 2021R2, https://www.ansys.com/products/materials/granta-edupack
[2] Callister, W.D. (2010) “Materials Science and Engineering: An Introduction”, 8th Edition, J. Wiley and Sons, NY, USA
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[5] Ashby, M.F., Shercliff, H., and Cebon, D. (2009) “Materials: engineering, science, processing and design”, 2nd Ed., Butterworth Heinemann, Oxford UK.
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[7] Ashby, M.F. (2011) “Materials Selection in Mechanical Design”, 4th Ed., Butterworth-Heinemann, Oxford, UK.
[8] Ashby, M.F. (2012) “Materials and the Environment”, 2nd Ed., Butterworth-Heinemann, Oxford, UK.

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Document Information

This white paper is part of a set of teaching resources to help introduce students to materials, processes and rational selections.

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