Materials Education and Sustainable Development

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Director, Education Division
Granta Design Ltd., Cambridge

Materials Education Symposium (3MES)
Anadolu University, Turkey
November 1, 2013
Granta Design Ltd.

**Founded:** 1994 by Professors Mike Ashby and David Cebon, Engineering Department, University of Cambridge

**Ownership:** the founders, the University of Cambridge, ASM International and the employees
Materials development enables new products

Circa 1900
Cameras

1945
Planes

Today

Cameras

Planes

http://teaching.grantadesign.com
Materials: How did we get here? Where are we going?

Era of “try it and see” to Era of predictive modelling

Physical sciences
A bridging science
Applied sciences
Broadening horizons: rising to global challenges

Material and the **Grand Challenges**
*inescapable – newspapers, television, internet….*

- Shelter (*built environment*)
- Energy
- Mobility (*transport*)
- Water
- Environment
- Sustainability

*(Food, healthcare, population, space, security)*

- Link to Systems, Economic, Legislative, Societal and Political issues

Mike Ashby, 2013

http://teaching.grantadesign.com
Which students need materials knowledge?

**US student enrollment on full-time bachelor’s degree (2011 data from ASEE)**

- Mechanical: 100,000
- Civil: 50,000
- Chemical: 30,000
- Engineering (general): 20,000
- Biomedical: 10,000
- Aerospace: 8,000
- Industrial/Manufacturing: 6,000
- Metallurgical & Materials: 4,000
- Eng. Sci & Eng. Physics: 2,000

95% Engineering related

5%
The materials available to engineers

James Stuart, The first Professor of Engineering at University of Cambridge (1875-1890)

- **In his day**: a few hundred materials
  - *No polymers* – now 10,000’s
  - *No light metals* – now 1,000’s
  - *No composites* – now 100’s ……

- **Today**: 160,000+ engineering materials!

**Challenge**: How to best teach materials?
What are universities for?

- Creation
- Preservation
- Transmission

of knowledge and understanding
What are universities for?

- Creation
- Preservation
- Transmission

of knowledge and understanding

- Information
  - Things
  - Ability to find information

- Knowledge
  - Things you know
  - Ability to use information

- Understanding
  - Things you know and understand
  - Ability to
    - use knowledge under new circumstances
    - create new knowledge,

“The most useful knowledge is that grounded in deep understanding”

Boulton and Lucas, 2008
How do we teach?

- **Traditional**: lectures, text, exercises, labs
  - **Project-based** teaching
  - Active learning – debate about the broader issues
  - Secondments, internships

- **Learning through interaction**
- **Learning in isolation**
  - Self-teaching units
  - Remotely-delivered classes:
  - Use of social networking sites for teaching
  - e-learning more generally:

  e-learning is a disruptive technology. Where can it help? Where can’t it?
The case for e-learning

- **Timely:** students have grown up in a technological environment
- **Accessible:** fit education around existing job
- **Diverse:** customized education
- **Democratic:** available to those who would not otherwise have access
Where can the computer help?

- **Information**
  - Find information
  - Rapid access to data and information

- **Knowledge**
  - Use information
  - On-line instruction, quizzes
  - Tools to manipulate data, and to use information

- **Understanding**
  - Use knowledge under new circumstances
  - Create new knowledge, innovate
  - ?
Are we too pre-occupied with informatics of teaching?

John Henry Newman (1852) in “The Idea of a University”:

“One generation forms another ..... We must consult the living man and listen to his living voice ... by familiar intercourse. Thus is created a clear atmosphere of thought, which the student also breathes”

Understanding

- Use knowledge under new circumstances
- Create new knowledge, innovate

Face to face Instructor-led teaching

- The teacher as role-model
- Inspiration through example
- Capacity for independent thought
- Confidence to tackle seemingly-impossible tasks
The evolution of Materials teaching

Yesterday
- Metallurgy
- Polymer science
- Ceramic science

In parallel with
- Mechanics, Structures
- Materials science
- Environmental science
  - Economics
  - Design

Today

Tomorrow
- Encompassing
  - Technical
  - Economic

- Materials systems and design
  - Environmental
  - Societal issues

Some things don’t change
- Laws of nature
- Principles of mathematics
- The scientific method
- etc…
### Teaching materials to engineers?

<table>
<thead>
<tr>
<th>Increasing depth</th>
<th>Discipline-based</th>
<th>System-based</th>
<th>Society-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing breadth</td>
<td>specialist as outcome</td>
<td>Integration with design</td>
<td>Integration with society</td>
</tr>
<tr>
<td><strong>Information</strong></td>
<td>Novice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facts, data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Knowledge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of information (shallow comprehension)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Understanding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Origins, context, relationships (deep comprehension)</td>
<td></td>
<td></td>
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<tr>
<td><strong>Synthesis and innovation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension, innovation, creation</td>
<td></td>
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</tr>
</tbody>
</table>

Achievable balance

Creative generalist

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![Images of historical figures](http://teaching.grantadesign.com)
We develop comprehensive resources to support and help enhance Materials, Design and Sustainability related teaching

Outcomes: With CES EduPack students can

- Gain a strong perspective of material properties
- Select materials to meet engineering requirements
- Quickly assess the environmental impact of products
- Explore sustainability issues
- Investigate how creating new materials can enable new products
Granta Design – What We Develop?

Education

Many of the world’s leading universities & colleges

Industry and Research

Many of the world’s leading companies and research labs
CES EduPack is typically used in undergraduate programs

- Materials science
- General engineering
- Polymer engineering
- Aerospace engineering
- Architecture
- Bio-engineering
- Product design
- Environmental engineering
- Sustainability assessment
Who uses CES EduPack?

Over 800 Universities and Colleges worldwide
(75 as a Campus-wide materials, design and sustainability resource)
Supporting campus-wide materials teaching

The CES EduPack resource

Materials science, Polymer science,

Engineering design
Design for the environment

Product design, Industrial design

Aerospace, Sports science

Civil Engineering and Structures

Mechanical, Manufacturing and Bio Engineering

Architecture and the Built Environment

Research

4th year

3rd year

2nd year

1st year

Mike Ashby, 2013

http://teaching.grantadesign.com
What is Sustainable Technology?
A materials perspective for teaching complexity in engineering

Mike Ashby
Didac Ferrer

Department of Engineering
University of Cambridge,
Granta Design, Cambridge and
Universitat politècnica de Catalunya

This lecture unit is part of a set created by Mike Ashby to help introduce students to materials, processes and rational selection.

The Teaching Resources website aims to support teaching of materials-related courses in Design, Engineering and Science. Resources come in various formats and are aimed primarily at undergraduate education. Some of the resources are open access and students can access them. Others are only available to educators using CES EduPack.

www.grantadesign.com/education/resources

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Fuel efficient, but sustainable?
Safe, but sustainable?

SUSTAINABILITY ?

- Energy
- Materials
- Environment
- Emissions
- Safety
- Legality
- Social acceptance
- Space
- Economics
What is this talk about?

Mission statement

Provide a framework within which a student can form critical, independent assessments of “Sustainable Developments”

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

Report of the Brundtland commission of the UN, 1987

▪ But how?

▪ And where do materials fit in?

▪ “Sustainability” vs. “Sustainable development”
Triple Bottom Line accounting

Corporate sustainability report:
- Financial bottom line
- Social / ethical performance
- Environmental performance

- Dow Jones Sustainability Index

- But what can Engineer do?

- Decouple – unpack meaning
Macro-economic view: the Three Capitals

- **Natural capital (Planet)**
  - Atmosphere, land, fresh water, oceans, biosphere, material and energy resources

- **Manufactured and financial capital (Prosperity)**
  - Built environment, Industrial capacity, Financial health, (GDP)

- **Human and Social capital (People)**
  - Education, health, skills, knowledge, happiness

- **Comprehensive capital**
  - Sustainable development = Growth in Comprehensive capital
  - How link to projects claiming Sustainable Development?
Articulations of sustainable development

- **Reduce dependence on oil**
  - Bio-fuels
  - Bio-polymers
  - Competition with food production (People)

- **Stimulate low-carbon economy**
  - Carbon taxes
  - Increase energy price (Prosperity)

- **Stimulate circular materials economy**
  - Mandatory recycling
  - Inhibits use of advanced materials (Planet)

Each articulation has a **Prime Objective** with a physical scale and time scale.
The Stakeholders

Stakeholders
- Who are they?
- What are their concerns?
- What power do they have?

- Government
- The public
- Local communities
- Owners
- Manufacturers
- Suppliers
- Trade Unions
- Customers
- Lobbyists
- Investors
- National press
- Managers, colleagues, team

Stakeholder diagram

- Users
- Makers
- Unions
- Green Lobby

Mike Ashby, 2013
Map of Articulations

What do we learn?
Group under

- Materials
- Environment
- Design
- Regulation
- Society
- Economics
Analysing an “articulation”

- Design and Manufacture
- Regulation, Legislation
- Economics
- Material Supply Chain
- Environment and Energy
- Society, Social equity

Economics
Analysing an “articulation”

1. Objective
2. Stakeholders
3. Fact-finding
4. Debate impact
5. Reflect

Factual questions – research systematically
Impact on capitals involves judgment
Define the articulation

Reflection

Sustainable development
Natural capital
Manufactured capital
Human capital

Design and Manufacture
Regulation, Legislation
Economics

Materials, Supply chain
Environment and energy

Prime Objective
- Motivation?
- Scale?
- Timing?

Stakeholders
- Who?
- What concerns?
- What power?
Example: The electric car

Global car production: 60 million units per year
15% of global fossil fuel CO₂ release comes from cars

Background

Governments offer incentives: 20% electric by 2020

Prime objective and scale

- Decarbonize road transport
- 16 million cars/year by 2020
Step 2: Stakeholders and concerns

- National and local government
  - carbon targets

- Car makers and distributors
  - sales

- Labor Unions
  - employment, rights

- Drivers, Automobile Associations
  - range anxiety, cost

- Environmental campaigners
  - carbon footprint
Step 3: Fact-finding

Students (in groups) research facts

Material Supply Chain
- Neodymium
- Lithium
- Environment
  - CO2 footprint
  - Recycling

Design
- Magnets
- Batteries

Regulation, Legislation
- Battery Directive

Economics
- Price

Society, Social equity
- Range anxiety

Economics
- Price

Design
- Magnets
- Batteries

Regulation, Legislation
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- Magnets
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- Battery Directive

Economics
- Price

Society, Social equity
- Range anxiety

Economics
- Price
CES EduPack database for fact-finding

Materials and Nations of origin

Energy and Power

Legislation and Regulation

Nations of the World

Links
Fact-finding: Materials

Bill of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>790</td>
</tr>
<tr>
<td>Cast iron</td>
<td>151</td>
</tr>
<tr>
<td>Wrought aluminum (10% recycle)</td>
<td>30</td>
</tr>
<tr>
<td>Cast aluminum (35% recycle)</td>
<td>64</td>
</tr>
<tr>
<td>Copper / Brass</td>
<td>26</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.3</td>
</tr>
<tr>
<td>Glass</td>
<td>39</td>
</tr>
<tr>
<td>Thermoplastic polymers</td>
<td>94</td>
</tr>
<tr>
<td>Thermosetting polymers</td>
<td>55</td>
</tr>
<tr>
<td>Rubber</td>
<td>33</td>
</tr>
<tr>
<td>Platinum, exhaust catalyst</td>
<td>0.007</td>
</tr>
<tr>
<td>Electronics, emission control</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Neodymium 1.5 kg
Lithium 4.8 kg

16 million cars per year, 4.8 kg Lithium per car
= 76,000 tonnes per year

Lithium

<table>
<thead>
<tr>
<th>Producing Nation</th>
<th>Tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>12,600</td>
</tr>
<tr>
<td>Australia</td>
<td>11,300</td>
</tr>
<tr>
<td>China</td>
<td>5,200</td>
</tr>
<tr>
<td>Bolivia</td>
<td>5,000</td>
</tr>
<tr>
<td>Argentina</td>
<td>3,200</td>
</tr>
<tr>
<td>World</td>
<td>34,000</td>
</tr>
</tbody>
</table>

Li demand = 230% present world production
Fact-finding: Design

Alternative batteries?
Seek high energy density (MJ/kg)

- Lead-acid
- Nickel cadmium
- Nickel metal hydride
- Lithium ion

Best battery: Lithium-ion 0.6 MJ/kg
Factor 75

Gasoline 0.6 MJ/kg
Fact-finding: Regulation

- **US CAFÉ Standard** – *Fleet mileage standard*
- **EU Automotive Fuel Efficiency Standard** – *Fleet mileage standard*
- **EU End-of-Life Vehicles Directive** – 85% recycled by 2015
- **EU Battery Directive** – *No batteries to landfill*
Decarbonize road transport?

Charge vehicle from the National Grid, gas / coal fired.

- CO₂ footprint, gas fired power \( \approx 140 \text{ g / MJ} \)
- Delivered energy to propel small car \( \approx 0.6 \text{ MJ / km} \)
- Efficiency of battery – electric motor set \( \approx 85\% \)

Carbon footprint of electric car \( \approx 140 \times 0.6 / 0.85 \)

\( \approx 100 \text{ g / km} \)
### Step 4 Integration – impact on the 3 capital

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>NATURAL CAPITAL</th>
<th>HUMAN CAPITAL</th>
<th>MANUFACTURED CAPITAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Drain on scarce resources (rare earths) • Potential for recycling high</td>
<td></td>
<td>• Supply chain for lithium, neodymium inadequate</td>
</tr>
<tr>
<td>ENVIRONMENT</td>
<td>• 100 g CO₂/km = Objective not achieved • Gain possible if grid decarbonised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REGULATION</td>
<td>Mandatory recycling</td>
<td></td>
<td>• Lack of recycling infrastructure for lithium, neodymium</td>
</tr>
<tr>
<td>SOCIETY</td>
<td>• Range anxiety not met • Creates jobs</td>
<td></td>
<td>• High cost of car an obstacle</td>
</tr>
<tr>
<td>DESIGN</td>
<td></td>
<td></td>
<td>Technically proven</td>
</tr>
</tbody>
</table>
Step 5 – Reflection

- **Short term – 7 years**
  - Not in envisaged scale and time

- **Long term – 25 years**
  - Establish infrastructure
    - Low carbon grid,
    - Material supply chain
    - Li and Nd recycling facilities
  - Re-think (re-define?) car use

Sustainable?
Running the project

Method has been trialled in University of Illinois Urbana Champaign, UPC (Barcelona), and at Cambridge – positive feedback

Instructor introduces project
Students in groups
Discuss as class
Students in groups
In-class debate
Open question to class

Backed up with CES EduPack Sustainable Development database, teaching aids
“Sustainable technology” has many interpretations. Central to all is the concept of the value of Natural Capital (the planet’s natural resources), of Human Capital (the health, education and social development of the human population of the planet) and of Manufactured Capital (the value of man-made institutions, infrastructure and wealth). The many different articulations of sustainable technology aim to support one or another of these but few support all three. Progress is possible only with well-balanced trade-offs and compromises between them. Introducing students to this complexity is challenging. The 5-step method and the Sustainability database described here are contributions towards meeting it. The database has the usual CES EduPack data-tables for materials and processes, expanded to contain the counties of origin of materials and a measure of their criticality (the security of the supply chain). The CES EduPack search engine allows selection of materials to minimize material usage while meeting design requirements. The database has a data-table of legislation, prompting students to think about ways to meet design requirements while complying with national and international guidelines, restrictions and reporting requirements. It has a datatable of the 210 Nations of the world, providing background on the economic, political and social conditions in countries from which materials might be drawn or goods manufactured. It has data-table for Power generation and Energy storage providing necessary background about energy. The data-tables are linked, making connections that allow the complexity to be explored.
Acknowledgements

We wish to acknowledge the insights and helpful critical reviews

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• Professor Jordi Segalas Coral and students of the UPC, Barcelona

• Professor John Abelson and students of the University of Illinois

• Our associates at Granta Design, Cambridge.
To end: three questions for discussion

1. Can e-learning replace interaction-based learning?

2. What should we be doing today to get to where we want to be tomorrow?

3. What experience can we share about using Grand Challenges to force systems thinking about materials?
Dr. Cyrus Wadia - Assistant Director of Clean Energy and Materials R&D at OSTP, the White House, USA speaks to 140 delegates on day one of the Cambridge Symposium about the US MGI initiative.

Prof. Mike Ashby thanks supporting organizations and delegates on behalf of the organizing committee for again making the Cambridge Symposium a stimulating and extremely enjoyable event.

www.materials-education.com
We hope that you will be able join us for at least one symposium

5th North American
University of Illinois at Urbana-Champaign
Symposium: March 20-21, 2014

6th International
University of Cambridge
Symposium: April 10-11, 2014

1st Asian
National University of Singapore
Symposium: Dec 11-12, 2014

Abstract deadline for talks 7 November 2013

Please send abstracts of 150 – 300 words to abstracts@materialseduction.com
Thank you

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