Materials Education Symposia

6th North American Materials Education Symposium

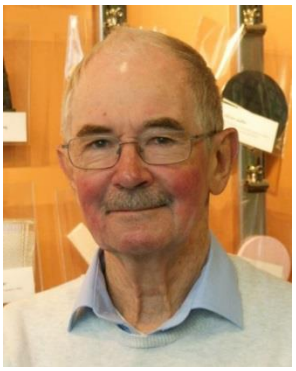
The Ohio State University
March 26-27, 2015

7th International Materials Education Symposium

University of Cambridge, UK, April 9-10, 2015

Foreword by Prof Mike Ashby

Chair of the Symposia's Academic Advisory Committee



Materials have played an enormous part in the technology advances of the 20th century. Emerging structural, functional, and bio-materials are poised to play an even larger part in the technology of the 21st century. Almost all the "Grand Challenges" identified as the essential technological and social advances for the next three decades have a material dimension. The part materials play in global and national economics and security is, today, so important that governments list the materials they perceive as "critical" and seek to assure access and to identify substitutes or alternatives should their supply chain be disrupted. For these (and many other) reasons, the education of materials-literate engineers and of informed and innovative materials scientists is essential for economic development and growth.

I'm delighted to say that our Materials Education Symposia have established themselves in the calendar as regular venues at which we can discuss these topics. They have three overall aims:

- **To share ideas, innovations, experiences, successes and failures;**
- **To provoke productive discussion around these issues; and**
- **To expand the links that form such a key feature of the Materials Community.**

This year's events were again well-attended and lively, and the report on the next few pages aims to give you a flavor of the presentations and discussions.

I am personally grateful to all those who joined me on the Academic Advisory Committee, helping to put together the strong program from the many excellent submissions. I am particularly pleased to acknowledge the support of our local hosts for the North American Symposium: Rudolph Buchheit, Alison Polasik, Peter Anderson, and Justin Diles from The Ohio State University. I would also like to thank the following for their continued support: ASM International; American Society for Engineering Education (ASEE), Materials Division; European Society for Engineering Education (SEFI); Federation of European Materials Societies (FEMS); International Federation of Engineering Education Societies (IFEES); and the University of Cambridge. Finally, thanks to the Education Team from Granta Design, who, as ever, oil the wheels and smooth the path on which these Symposia roll.

The North American Symposium

This year's North American Materials Education Symposium was hosted by Prof Rudolph Buchheit and colleagues at The Ohio State University. The strongest Symposium program yet drew sixty educators from the US, Canada, and beyond. Modeling and simulation was a particular focus, with other themes including innovation in teaching, the value of a wider view, and sustainable systems.

Modeling and Simulation—what can it offer materials teaching?

The Symposium was opened by **Cyrus Wadia, Former Assistant Director for Clean Energy and Materials R&D at the White House Office of Science and Technology Policy**. His subject was the Materials Genome Initiative, a policy push from the US Government that aims to get new materials to market twice as fast at half the cost. With a 2016 budget of $250M, the project funds the intersection of computational tools, experiment, and digital data in order to help a Materials community that is overly-fragmented. An education component is looking to fund post-doctoral positions in areas such as data handling and computational tools.

How can such simulations advance teaching?

How can such simulation advance materials teaching? **Alejandro Strachan of Purdue University** took up this question, describing the nanoHUB project, which provides anyone, expert or student, with access to simulations on Purdue servers. Simulations can be used in lectures to demonstrate phenomena such as stress and strain on a nanoscale. Students can change parameters and see what happens. **Tanya Faltens** discussed such a project, adding simulation to a lab class on Plastic Deformation. She recommended focusing efforts on conceptually difficult topics, reducing the total number of concepts covered.

Several speakers covered the topic of teaching computational materials science itself. **Richard LeSar of Iowa State University** recently published the book, *Introduction to Computational Materials Science*. He discussed its use and relevance, and key trends that might be reflected in a new edition, such as informatics and Integrated Computational Materials Engineering. **Susan Gentry of the University of Michigan** had demand from industry for employees with modeling experience, and so changed the curriculum to include a required programming course, use of computational models in lab classes, and a mandatory computational component in the final year reverse-engineering project.

Peter Anderson of The Ohio State University has seen enrollment increase and gathered positive feedback after integrating computational laboratories into the undergraduate materials curriculum. He recommended: splitting up the course between faculty; quizzing students before class so that they prepare; and avoiding writing code in the lab, but rather using existing code, and then asking students to modify and extend it post-lab. These skills, along with fundamental materials knowledge, were then integrated in a 4th year project in which students had to design a material.

Innovations in teaching

Innovation in teaching is always a big focus at the Symposia and, as **James Shackelford of the University of California, Davis**, remarked, online education is one area of innovation that has attracted both enthusiasm and skepticism in the last decade. UC Davis now has online offerings for Materials Science and Engineering including "flipped classroom" lectures, a hybrid course combining these lectures and traditional lab experiments, and a Massively Open Online Course (MOOC) entitled "Ten Things Every Engineer Should Know About Materials Science". Professor Shackelford recommended investing in getting the figures right (he worked with a graphic designer) and observed that online courses improve flexibility and accessibility for students. They do not, however, save cost. MOOCs have proved useful primarily for working professionals in life-long learning.

Prof. Lorna Gibson of MIT has also recently taught a Materials Science & Engineering MOOC. She was supported by the "MITx" team, and the first challenge was in understanding that she had to market her course! Course content was the same as usual, but without labs, although evaluation was different. Interestingly, offline students used the resource to catch up on lectures that they missed and for more worked examples, and three of the top five offline MIT students did not come to class. A proposed extension was a version of the flipped classroom with a "Lecture Party": students watch the videos with a teaching assistant.

Interestingly, three of the top five students did not come to class

Learning Catalytics is an online tool for surveying students during class—part of a Process Oriented Guided Inquiry Learning (POGIL) approach being applied by **Jerry Floro at the University of Virginia**. He wants students to develop life-long learning skills so that they teach themselves—an objective that requires more credit to be given for projects and participation. He found lectures are now more interactive, with students confident to ask questions. The pace is slower, but he can focus on subjects where students struggle.

Innovative practical projects that help students think more deeply about materials were the focus of two talks. **Mary Vollaro from Western New England University** allows students to pick their own projects, but helps "keep them in the tramlines". Students must do materials selection and modelling, then build and test a prototype. An example project was making skis out of bamboo flooring. **Justin**

Diles of The Ohio State University has involved architectural students in making walls and rooms out of composites at composite manufacturing sites. Students become more aware of the materials, learn craftsmanship and the challenges of scale-up.

Yawen Li of Lawrence Technological University is encouraging students to learn skills such as teamwork and entrepreneurship, as well as knowledge of biomaterials. She ran a problem-based learning project on hip implants and used techniques including: 'Think, Pair, Share', where students answer a question first individually, then in a pair, then in a four; and having students describe their findings in a poster, and judge each other's work, with extra credit for the winners.

Taking a wider view

Day two kicked off with **Professor Mike Ashby of the University of Cambridge and Granta Design** providing a compelling review of maps and their relevance to materials (pictured, right). He began with Mendeleev's Periodic Table: the first 'map' of chemistry and materials. A tour of materials property charts showed how our view of materials has evolved. We are slowly extending the amount of materials-property space that is filled, but much empty space remains, inviting discovery and innovation, just as Mendeleev did by identifying gaps in the Periodic Table that were eventually filled. We're also more interested in mapping many things beyond physical properties—for example, relating the Periodic Table map to the world map in order to think about where so-called 'critical materials' come from, and how this affects their supply. This last point illustrates how materials science is changing. The evolution from 1950s to the 1980s, in which separate disciplines such as metallurgy, plastics, and ceramics came together into materials science, is being followed by a change in which we need to think not just about *materials*, but about *materials systems*—bringing in issues such as energy generation and use, the supply chain, environmental impact, government regulation, and human health. So should we be teaching these?

"So should we be teaching these?"

Thinking about systems in this way means dealing with complexity and complication. **John Nychka of the University of Alberta**, Canada, covered these topics in a talk that ranged from the Big Bang to Haikus about the complexity of Design. He encourages students to understand the difference between things that are complex (i.e., that have many different elements) and those that are complicated (where there are unknown relationships between the elements) and to map out their knowledge using concept maps. This forces students to know the parts of an issue, order them, and characterize the relationships between them, and thus make visual and mental connections.

Ron Kander from Philadelphia University asked "how do we teach innovation?", which involves two different types of thinking (ideation + execution). He aims to stimulate interdisciplinary teams to create a common language. His methods even include improv comedy, to support students in acquiring the skills needed for systems thinking, sustainability and smart design. One student even built a Bat Suit!

One student even built a Bat Suit!

Two other speakers described more grounded virtual reality. **Dr. Pnina Ari-Gur of Western Michigan University** has created virtual labs to get around the problem that real labs are time-consuming, expensive, and occasionally hazardous for non-major students. Students move objects, rather than passively watching, safety aspects are still mentioned, and not all the students get the same data. They still have to write a lab report. **Jacob Gines of Mississippi State University** asked students to construct a simple wood joint, first manually, then using digital tools. It was very interesting to see how concepts for different joints changed between the two processes.

Poster session discussions.

Claes Fredriksson's talk on teaching resources for Materials Science & Engineering is covered in the International Symposium report.

Sustainable Systems

One way to increase systems thinking is via Sustainability. **Thomas Graedel of Yale University** introduced this topic by looking at the criticality of 62 elements and the factors affecting decisions to use these materials. Variables include not just properties and current degree of criticality, but where you are in the world, your timescale, likely status of the material in 5 years' time, and whether you can recycle or reuse it. We need tools to understand these factors—and we need to teach them.

Case Western Reserve University has introduced a new course on "Materials for Energy and Sustainability", explained **Mark De Guire**. The course covers three aspects of sustainability: materials as consumers of energy, raw materials and water; the role of materials in reducing environmental impact; and the use of materials in energy technology.

The Symposium closed with a series of presentations from our hosts, **The Ohio State University. Michael Cadwell** continued the sustainability theme, considering sustainability in the teaching of architecture as part of the wider remit of architecture to "envision, construct, and inhabit new worlds". **Andrew Heckler** switched the focus to a sustainable learning process for students. An effective program has identified students' difficulties in learning materials and put in place Essential Skills Practice (on topics such as how to read log plots) through online tools. Finally, **Glenn Daehn** spoke

about the importance of connecting teaching to topics that interest High School students for STEM outreach. He tells the story of an ex-Copper-mining town and, by connecting history and sustainability with copper extraction and processing, helps students understand more about materials.

Author panel discussion

Top textbook authors discussed the future of the text book

It was great to be able to take advantage of the presence of so many authors of widely-used materials and engineering textbooks to organize a short panel discussion on the future of the textbook. The panel noted that, while eBooks have overtaken paper books in other subjects, this does not seem to be the case in Engineering. The panel were unsurprised—the printed book is an artefact that stands the test of time, something you can write notes on, and navigate easily. Research in *Scientific American* has concluded that people that read physical books retain knowledge longer than those reading an eBook. The panel did agree that eBooks added value through flexibility, ability to incorporate and link to additional content, and ease of update. In summary, there is a place for both print and electronic media, but the paper book will live on for now!

Textbook authors (left to right): Elliott Douglas, Thomas Graedel, James Shackelford, William Callister, Mike Ashby, Lorna Gibson, Richard LeSar

Networking and social program

In addition to the main Symposium talks, 25 posters were presented over the two days of the **Poster Session**, while the **Social Program** provided ample opportunity for discussion and exchange of ideas—amply fed and watered through the Symposium Dinner at Schmidt's German Village Banquet House! Feedback on the event has been very positive, with many attendees anxious to reconvene next year when the venue will be the University of California, Berkeley from March 16-17, 2016.

The International Symposium

The International Symposium was held for the second time at Clare College, Cambridge—a popular venue that provided glorious Spring weather for two days of stimulating discussion involving over a hundred materials education professionals.

One of the two talks that were given at both Symposia was **Mike Ashby's** presentation on *Materials and Maps* (see above), and his closing call to think about 'material systems' provided one of the clear themes that emerged from the Cambridge event—others were: engaging students through practical projects; the state of online resources for teaching; and relating teaching to real-world challenges.

Getting 'hands on'—innovative practical projects

An old trick teaches new dogs

Veronique Vitry from the University of Mons in Belgium told us how 3,000 year-old technology is helping students learn metallurgy. While textbooks communicate the theory, and online tools like Steeluniversity can relate this to real processes, students don't get a strong, practical sense of how these processes work. Plant visits are increasingly difficult to arrange and large-scale processes are hard to replicate in a lab. The solution has been a one-week project in which third-year students build, use, and then dismantle a *bloomery*, an extractive process for iron, long-abandoned in practice, but which is not too dissimilar from modern processes and can be implemented at small-scale. This "old trick to teach new dogs" has been effective in exciting students, with demand for a repeat projects.

Another terrific example of returning to a traditional crafts was provided by **Dr Merce Segarra of the Universitat de Barcelona**. The project sprang from the IdM@ti collaboration of seven universities, which was established through meetings at past Materials Education Symposia. Interdisciplinary teams of students were challenged to manufacture bells for a concert—selecting and making the right alloys in Materials Science, moving to the Fine Arts faculty to cast the bells, and finally characterizing acoustics in Physics. The project developed students' skills and interest, although Dr Segarra warned that organization and logistics required a lot of work!

Materials Education Symposia

The materials community was offered lessons from a related field by **Alison Ahearn of Imperial College, London**, and **Oliver Broadbent of the Thinkup consultancy**. The "Constructionarium" is a one-week fieldwork project that gives novice Civil Engineering students real construction experience. Students build a four-storey tower, a mini oil platform, or a 20m steel bridge in five days flat. Twenty universities are now involved, with support from industry. Key ingredients are the involvement of both subject matter and pedagogical experts, deep immersion role-play ("be an engineer, don't just learn engineering"), realistic projects on a relatively large scale, and multi-modal learning.

> **"Be an engineer, don't just learn engineering"**

Laura Leyland from Birmingham City University was set an interesting challenge by her university. She was told "you have blank sheet of paper, design a new curriculum, we need it by September". The BSc in Motorsports Technology has been remodeled around a project to take an existing road car that has been in a crash, disassemble it, analyze it, and rebuild it as a racing car, with students learning materials and engineering fundamentals as they work on the car. Implementing such a radical change threw up challenges ranging from the bureaucracy of purchasing a damaged car to time constraints in creating the course material. The accelerated change process worked, but needed a lot of energy and senior support—more viable as a one-off than a sustainable, repeatable approach.

The role and maintenance of online resources

Mark Endean of the Open University and **Andrew Green of Materials e-Learning Technologies** gave us a 'magical mystery tour' of 30 years of online materials teaching resources—from laser disks, to CDs, to the Internet. They touched on tools such as the Open University's interactive phase diagrams, the MATTER project from the University of Liverpool, DoITPOMs, Steeluniversity, and the Granta Teaching Resources. Over the last two years, they have been working on the challenges of bringing such resources within a framework that allows them to be shared and maintained. A workshop on this issue was proposed for the next Symposium.

One of these resources, DoITPoMS (www.doitpoms.ac.uk), was reviewed by **Bill Clyne from the University of Cambridge**. Developed to support the Cambridge Materials Science Department's teaching, DoITPoMS is available as an open resources and widely used. Professor Clyne showed five

new lecture demonstration packages, including those on the shape memory effect and work hardening, with resources including interactive animations and videos. This led to a discussion on the value of such resources—again, the challenges of maintenance were raised.

Granta's Claes Fredriksson discussed research into Materials Science and Engineering curricula at five universities in Europe and North America, which has led to proposed developments in the CES EduPack resources, enabling them to better support some key topics in the 'science-led' teaching of materials: Materials Processing and Microstructure, Functional Materials, Defects and Failure, Material Characterization, Phase Diagrams and Crystallography. Feedback on this topic is welcome: http://teachingresources.grantadesign.com/databases-development-ongoing/material-science.

How do we teach 'digital natives'?

Mária Kocsis Baán of the University of Miskolc made a strong case for innovation in the use of ICT to meet the needs of today's students, who are "digital natives". She spoke with **Zoltan Kolozsvary of SC Plamaterm**, who reviewed advances in materials research. He pointed out that new developments in areas such as nano-materials mean that we are now often looking for problems that fit materials solutions, rather than vice-versa. Dr Kocsis Baan linked this to a need to teach competencies such as critical thinking, complex problem solving, and collaboration. The need for such a broader perspective was a theme of many other talks.

Materials systems, and broadening our perspective

Perhaps the most obvious example of Mike Ashby's call to think 'material systems' was **Sven Herrmann of the Ellen MacArthur Foundation**, who introduced the Circular Economy—the notion that we should look at product systems and work out how to cycle as much material back into the earlier stages of the product life cycle as possible. He encouraged attendees to build this approach into teaching. For example, can we ask students to think about what happens to material at end of product life?

Poster presenters line up for their 'teaser' talks

Contrasting his talk with Mike Ashby's exploration of the edges of the materials world, **Richard Schilling of Reutlingen University**, promised to instead disappear into the brushwood! He was interested in broadening our perspective by fitting into the materials map those classes of materials, many of them hybrid materials, which cannot be easily characterized by their electronic or atomistic structure. He argued for the inclusion of fibrous matter, foams, granular matter, and similar superstructures within the "materials zoo".

Hengfeng Zuo of Tsinghua University took us into the world of Industrial Design and identified the challenges when asking these students to think about materials: they have a different thinking mode (visual, not numerical) and limits in both their practical experience and theoretical knowledge of materials. He showed how these challenges are tackled through practical design projects.

Meanwhile, **Ian Mabbett of Swansea University** wanted us to think about the human, qualitative aspects of assessing teaching. Do engineers, trained to think quantitatively and answer 'yes/no' questions, struggle with more qualitative, people-oriented aspects? Results from initial research into these questions at Swansea indicate that this culture gap may exist, and on-going work aims to develop a toolkit to support better qualitative evaluation of courses.

Michael Lauring of Aalborg University in Denmark introduced research, now captured in a handbook to help architects learn how to make sustainable materials choices. This is not simply a matter of providing the right data about individual materials, but also of helping architects think about issues such as how construction influences heat consumption, and the impact of the whole construction system required to support use of a particular material.

Relating materials teaching to real-world experience

Many of the talks focused on the use of real-world examples to engage students, a trend that started with the very first talk of the conference from **Sybrand van der Zwaag of the Delft University of Technology**. He discussed how to engage engineering students in Material Science, when they are perhaps more interested in designing

Engaging students through self-healing materials

aircraft! He gets students thinking about "materials design" rather than seeing the subject as simply "the art of collecting facts". The topic of 'self-healing materials', and how development of these materials learns from nature, has proved to be one that grabs interest. He proved his point by getting the Symposium audience to think about how they would design their own self-healing materials.

Wolfgang Pantleon from the Technical University of Denmark spoke about the need to give students a better understanding of the role of processing, and his use of simulation to achieve this. The Hybrid Synthesizer tool in the CES EduPack software allows users to enter their own predictive models and, in fact, these models need not be restricted to hybrid materials. A microstructural evolution model for thermomechanically-treated copper has been added that enables students to plot on material property charts how the mechanical properties of the metal evolve with processing, for example, through deformation and recrystallization processes. They can relate this evolution to the microstructure, and more advanced students can be stretched by 'playing' with the underlying models.

Jose Pastor of the Universidad Politécnica de Madrid described an approach in which students propose their own case study of a complex materials selection problem (e.g., choosing a material for a heart valve). They must solve the problem and explain their solution to peers, with a significant part of the evaluation depending on grading by other students. The next step is to connect students from different universities via a case study competition as part of the upcoming Madrid Materials Week. So far, the number of entrants has been small, although spanning five different universities, seven degree subjects, and with good quality projects. It is hoped to build on this and drive participation in future.

Polymer selection: find the needle in the haystack

With **Steffen Ritter of Reutlingen** University in Germany, we searched the 'haystack' of possible polymers to find the 'needle'—the right polymer for a particular application. His students follow the whole process from polymer selection to actually mass-producing polymer products, so it is important that they are realistic about the challenges of choosing the right polymer. Dr Ritter reviewed the complexity of the plastics world, outlined a four-step selection method, and emphasized both the importance of data-handling tools in exploring the hundreds of thousands of available polymer grades, and the need to train students to be comfortable with incomplete data.

Peter Martin Skov Hansen of the University of Southern Denmark gets students thinking about product life cycles by giving them a vacuum cleaner to disassemble. They establish a Bill of Materials and perform an Eco Audit analysis. They are also asked to think about resource scarcity. The project is motivating for students, although they need support and guidance in drawing conclusions, since the results of the eco analysis are very dependent on interpretation.

Finally, **Erich Muller of Futation & MaterialSampleShop.com** in Denmark closed the Symposium with a very lively presentation of how he provides libraries of physical materials samples to schools, universities, and companies, and gives students a better feel for materials by letting them get "hands on" with some interesting examples. His examples included the 'bubber' modeling compound, steel fibres, micro suction tape, heating paint, and coded magnets.

Networking and social program

The main Symposium program was preceded by a two-day CES EduPack Short Course at the Cambridge University Engineering Department, attended by around 30 of the Symposium participants. As well as digging into the CES EduPack software in detail, and providing lots of hints and tips, the course included a popular new interactive workshop on **Teaching Sustainable Development**, reflecting the growing importance of this topic.

The busy **Poster Session**, with 36 posters over the two days, provided plenty of scope for discussion and networking—as always, the 'poster teaser' slots, during which each poster presenter gets two minutes to present their poster during the main session were a lively addition.

Participants were also able to enjoy the Social Program—relaxing, meeting old friends from what is now a well-established Symposium community, or making new contacts for first-time visitors. The **Symposium Dinner**, held in neighboring Trinity Hall College was a particular highlight (pictured, above). We hope to see you in Cambridge next year!

See you next year?

We look forward to next year's events, confirmed for:

March 17-18, 2016 – University of California, Berkeley.

April 7-8, 2016 – University of Cambridge, UK

Dec 9-10, 2016 – National University of Singapore

See www.materials-education.com for the latest details.