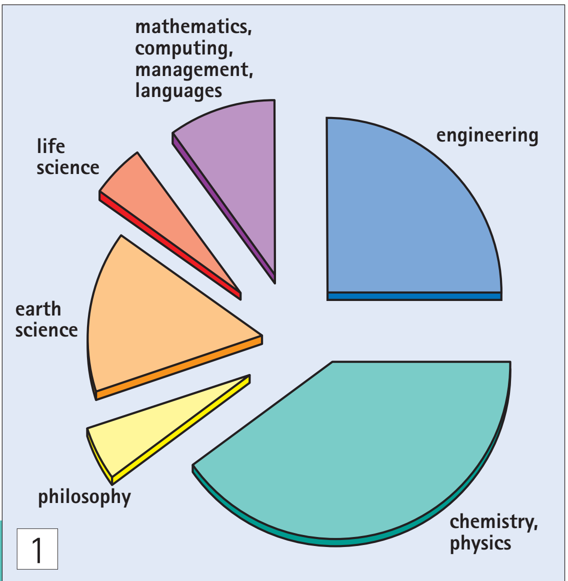
The multidisciplinary future for **materials education** – boosting creativity and biology

Harry Bhadeshia highlights the findings of his research into future approaches to materials education – departments should focus on the multidisciplinary nature of the subject, incorporating biology and greater creativity into their teaching, and should concentrate on fostering a healthy postgraduate population drawn from a variety of backgrounds

All the components of a materials science education are covered by 'pure' subjects. So how and why does 'materials science' exist? And what must be done to ensure a healthy future for materials education? The answer may be that materials science must play to its strengths – ie emphasise the very fact that it is multidisciplinary in nature. Materials science does not exist as a subject unless it is multidisciplinary – realising this and building upon it will ensure a quality future for its education and the continued production of excellent materials scientists.

The topics that materials science shares with various 'pure' disciplines are shown in table 1, and its components are represented approximately in figure 1. Service courses such as mathematics, computing, management and languages are not included. The figure and table show that students could, in principle, obtain a materials science qualification by selecting appropriate lecture courses already given by 'pure' subject departments. So why isn't materials taught this way? And why are there some outstanding university materials departments?



An approximate illustration of the components of materials science

For a start, the multidisciplinary nature of a materials course requires a coherent group of teachers. This cannot be provided by staff separated in space, philosophy and commitment. In addition, the 'pure' subjects, with the exception of engineering, do not allow for a pragmatic approach to real-life problems in the same way that materials does. An unwritten law in materials science might be that 'problems must not be reduced until they can be solved, and any solution must recognise the complexity inherent in technology'. For example, the fatigue of a metal depends on a very large number of variables. And yet the pure scientist insists on simplistic models that are unable to represent the complexity of a rotating shaft made from a 20-component, multiphase, heterogeneous steel exposed to random and cyclic stresses in a harsh environment.

Solving such problems inevitably requires the use of science alongside empirical knowledge – materials scientists are trained in this way. In a similar vein, qualified people from pure subjects frequently have difficulty communicating effectively with those in the outside world, because real-life problems cross the boundaries of the disciplines. My perception is that a pure department cannot do enough to solve this problem, whereas materials scientists are exposed to all of the physical sciences, engineering and commerce throughout their university careers, and so come well-equipped to relate to real-life circumstances.

Young researchers, rather like those involved in the financial markets, prefer challenges, risks and tangible outcomes. The complexity inherent in materials science provides these challenges, making research exhilarating, with outcomes that can be felt. This is another benefit of stand-alone materials science departments.

Of course, materials teaching must be done in such a way as to produce people with the attributes to tackle such problems, and this is where enhanced creativity in the teaching process becomes vital. There are tremendous opportunities for well-qualified materials scientists, with flair, intelligence and adaptability. Industry and commerce are careful about who they employ. Those materials departments that produce students without the required mix of qualities must be at risk.

So what teaching methods can inspire students and turn them into the desired graduates described above? I don't know the answer, but there are some ground rules that can make learning exciting and stimulating:

- The act of bringing ideas into being is exciting – a task must be set that is genuinely seen to be new. This also means that the task must be different for each year that the course runs.

- There should be no unique answers, otherwise the problem is reduced to the more-barren 'science'.
- The task should be stated with brevity. The aim is not to lead the students but to allow the ideas to originate freely.
- There must be a considerable element of education hidden in the form of fun.
- Issues of safety may require some supervision – there is an education element in this.

The multidisciplinary nature of materials lends itself to such a teaching method. For example, instead of a fully scripted practical class, a one-line task could suffice – 'Use an appropriate method to efficiently and economically produce a grain structure of size 25µm in Al, Cu and Fe.' It would be left to the students' imagination to figure out a definition of grain size, how to measure it and how to produce it. Only the simplest of guidelines are needed for the written report, which should carry proof of success, a cost analysis and science in sufficient detail to reproduce the work.

Materials science is, in my view, the fastest developing of all the related subjects, not in terms of subject size but in terms of knowledge and the way it affects the quality of life. There are so many silent revolutions in materials, with materials technology that is so good and implemented so rapidly that people are unaware of it. That is why the best universities have always recognised the need for the stand-alone materials science department.

Yet even in the best departments, things must change. The information in table 1 reveals why. While there is no doubt that the traditional connections between materials science and engineering, physics, chemistry and earth sciences will continue to thrive, an examination of the shared components shows that materials has probably penetrated into all reasonable areas of these pure subjects. It is hard to see how it could be helpful for materials to try and understand and teach astrophysics, signal analysis or mapping, other than in some niche areas.

By contrast, biology is ready for materials – and I don't just mean emulating nature, or developing biomaterials, as has happened in the past. The human body is now being treated almost like the cellular automaton of Von Neumann, essentially a self-reproducing machine with embedded instructions. There is immense speculation in the subject (much of which is bizarre), but focusing on the realities it seems possible for quality of life to be improved using artificial tissue, artificial blood, materials that allow the controlled release of drugs, bone replacement therapy, and so on. The distinction between the 'living' and the 'synthetic' is becoming increasingly blurred.

This is where materials science could benefit from vision, innovation and collaboration with those who really know biology. Materials needs to replicate its past collaborative success with physics, chemistry, engineering and (to a lesser extent) information technology. However, an understanding of biology and materials, in a depth that is sufficient to teach effectively, is not going to be an easy evolution in materials departments. Possibly the best approach is to build up an intense research effort in this area, so that the best teachers are generated over the next decade. The history of university-level teaching highlights that undergraduate courses are best organised by those who have a deep understanding of the subject and have a passion that comes from research. I personally have little respect for some universities that divorce teaching and research.

I know of one university where all undergraduates are now required to take biology, irrespective of career choice. This is nothing new. In the past, another university required all candidates (including those taking humanities) to achieve a first class in mathematics in order to qualify with a first class in their own subject. Mathematics was regarded as an essential part of any education. Something similar could be done with biology, to speed the rate at which disciplines other than biology assimilate developments in that subject.

Developments in information technology could prove vital in such advances in teaching. There has been considerable effort in the development of software for materials education, an example being the MATTER project in the UK. Its aim is to produce interactive educational software for students and teachers, particularly for dealing with concepts that are difficult to grasp or visualise.

Of course, such quality software has a cost. Commercial software may cost as much as an expensive book, and students tend not to purchase the soft-

Table 1 – Subjects shared with the materials science undergraduate curriculum

Engineering	Shared?
Structural mechanics, structural design	Yes
Materials selection and engineering applications	Yes
Heat & fluid transfer, elastic & plastic deformation	Yes
Micro, macro and composite structures, tribology	Yes
Vibration, noise and sound engineering	No
Circuits, electromagnetics, signal analysis	No
Aerothermal engineering, aerodynamics, turbulence, engines	No
Optical communications, communication networks	No
Soil mechanics, geothermal modelling, complex analysis	No
Chemistry and Physics	
Molecules, polymers, metals, ceramics, semiconductors	Yes
Diffraction, imaging, chemical and spatial characterisation	Yes
Thermodynamics and kinetics, solutions and surfaces	Yes
Corrosion, catalysis, electrochemistry, spectroscopy	Yes
Mechanical, electrical and magnetic properties	Yes
Oscillation, waves, dynamics, quantum mechanics	No
Organic reactions, organometallics, molecular orbitals	No
Astrophysics, atomic physics, relativity	No
Biology, Pathology and Zoology	
Transplantation and drugs	Yes
Cells, disease, sexuality, emotions	No
Genetics, organisation and expression, biogenesis	No
Intercellular comms., immunology, nervous system, memory	No
Virology, pharmacology	No
Earth Sciences and Geology	
Phase equilibria, diffraction, imaging, structure, kinetics	Yes
Earth, palaeontology, sedimentation, tectonics, seismology	No
Maps, hydrosphere, ecology	No
Philosophy	
Natural philosophy, sociology, ethics, morality	No

ware but instead use it at specific locations at which site licenses have been purchased. This makes the exploitation of the software more difficult. The World Wide Web offers new possibilities. Undergraduate textbooks could become redundant as many teachers now create 'living books' on the web. These can be changed and updated frequently, are free, offer animation, and can be accessed from anywhere in the world at any time, including downloading for off-line working. This is probably the best way forward for information technology in the teaching of materials science and its associated multidisciplinary components in the future.

Having addressed materials education so much, it may seem odd to suggest that materials departments should not be overly worried about their small numbers of undergraduates. But this, again, is a conclusion that arises from the multidisciplinary nature of materials.

Materials science is taught in schools, but isn't identified as such. Universities, where students choose their 'future' on entry, therefore do not inspire entry in materials science. As a result, the undergraduate population in materials will always be small.

Yet there is a demand for good materials scientists, for real-life positions that demand the multidisciplinary skills already discussed. This is why materials departments have larger research than undergraduate schools. Research students are recruited from the pure subjects and integrated into the materials 'culture'. This greatly reinforces the multidisciplinary character of the subject. Uniquely, research students come from backgrounds in materials science, physics, chemistry, engineering (civil and mechanical), biology, mathematics, earth sciences, commerce and history. A small undergraduate population is, in this light, a positive advantage for keeping alive the mixing of subjects.

So for materials science to continue to thrive, departments should obviously endeavour to increase undergraduate numbers but not be unduly concerned as long as the graduate student population is the greater component of the output of qualified people. Departments must in particular ensure that they continue to attract research students from other disciplines, especially biology, which will be such a vital component of future education. This will maintain materials science's major advantage and distinction over other areas – that it is a truly multidisciplinary subject and career, and as such, an exciting and stimulating prospect for a broad range of students.

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Further reading

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