THE MATERIALS CURRICULUM: WHAT EUROPE WANTS.

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ABSTRACT

The largest ever survey of European attitudes to Materials Engineering education was carried out at Euromat 2009 in Glasgow, following the publication of the UK National Student Profile for Materials. The views of the delegates on both technical and CDIO-type content are reported in this paper. Areas of agreement are identified, alongside topics where there are significant national differences.

KEYWORDS

Materials Science & Engineering; Bachelor degree; Masters degree; survey; subject profile

INTRODUCTION

Education in Materials takes place in the context of modern society. Students have to choose to study the discipline and those who make this choice bring with them attitudes and expectations derived from their social and educational background. These attitudes and expectations have changed quite rapidly over the past one or two decades. Some of these are fairly obvious: The rise of computing and the internet has changed the availability and accessibility of information. Others are more subtle but no less important; social networking has had an impact on the way people learn and share both information and understanding; the day of the single career with a single employer has probably disappeared for ever – portfolio careers, with regular bursts of new learning or training, are probably here to stay; this could, perhaps should, alter the learner's expectations of their initial undergraduate education. In some ways undergraduate education has become a mass-market product and is perceived by many of its "customers" as a utilitarian product, only worth the investment of time, money and effort if it results in a quantifiable payback in terms of enhanced salary or career opportunity.

Other changes are evident in education and some of these are discipline-based. There has been a move away from passive education (chalk and talk) towards active learning (exemplified by, but not restricted to, CDIO; problem-based learning; team work; dialogue between staff and students). Single-subject programmes (metallurgy, polymer science, ceramics) have been replaced by the more general materials science or materials engineering. There has also been a trend to associate the study of materials with engineering rather than science, driven partly by professional accreditation and to some extent by the needs of industry and other employers. In an attempt to make Materials more popular as a subject of undergraduate study, many universities have offered combinations of disciplines designed to be attractive to students who do not see themselves as engineers in a mainstream discipline such as mechanical or civil engineering. Examples include biomaterials, sports materials and aerospace materials.

Against this background, the UK Centre for Materials Education (UKCME) has developed the first UK National Subject Profile for Higher Education Programmes in Materials. While the details of this study are specific to the UK, many of the lessons and conclusions have wider currency. In this paper we will describe some of the key findings of the study, and then present the results of a survey carried out at Euromat 2009 in which delegates were asked, inter alia, their opinions of the appropriate content for a materials education.

THE UK NATIONAL SUBJECT PROFILE

The major restructuring within many UK universities in recent years has often left materials exposed as a taught discipline, especially where student numbers are relatively low. While materials research is still buoyant, the bottom line in higher education is often undergraduate and taught-postgraduate numbers.

The National Subject Profile for Higher Education Programmes in Materials 2008 [1] is a snapshot of materials education at university level in the UK. The profile reveals that about half of the 21 materials course providers say they have responded to declining numbers by developing new courses, as well as investing in recruitment and schools liaison activities.

Companies have also been experiencing difficulties – for instance, steelmaker Corus reported at the European Steel Companies-Universities Joint Conference [2] that it only recruited 17 of the 33 materials graduates needed in 2006.

The Higher Education Funding Council for England, which funds all English universities, has identified metallurgy and materials engineering as strategically important and vulnerable, and an additional £1,000 per student per year is being provided for three years from 2007/8 to support the teaching of these disciplines at six universities with the most related undergraduate students – Birmingham, Cambridge, Leeds, Manchester, Oxford and Exeter.

The overall number of materials graduates has remained fairly constant over the last few decades, but over the last ten years, fewer than two-thirds of 400-plus graduates from materials-related undergraduate programmes have been from traditional materials science and engineering courses.

Post-graduate Masters materials courses remain buoyant with just over 300 graduates each year from the 26 UK universities offering advanced materials qualifications. Many of the established courses do rely heavily on overseas students, and university-industry collaborations have been a feature of recent postgraduate programmes.

The National Subject Profile [3] has highlighted that materials is widely recognised as a discipline of critical importance to the economy. However, interdisciplinarity has become an important feature, leaving specialisation to postgraduate level. This is, of course, the pattern in a number of countries.

Demographic trends

The UK’s undergraduate materials students are, and always have been, predominantly male, although females now account for just over a quarter of the student body. The bio/medical and sports materials programmes are attracting equal numbers of men and women (Figure 1).

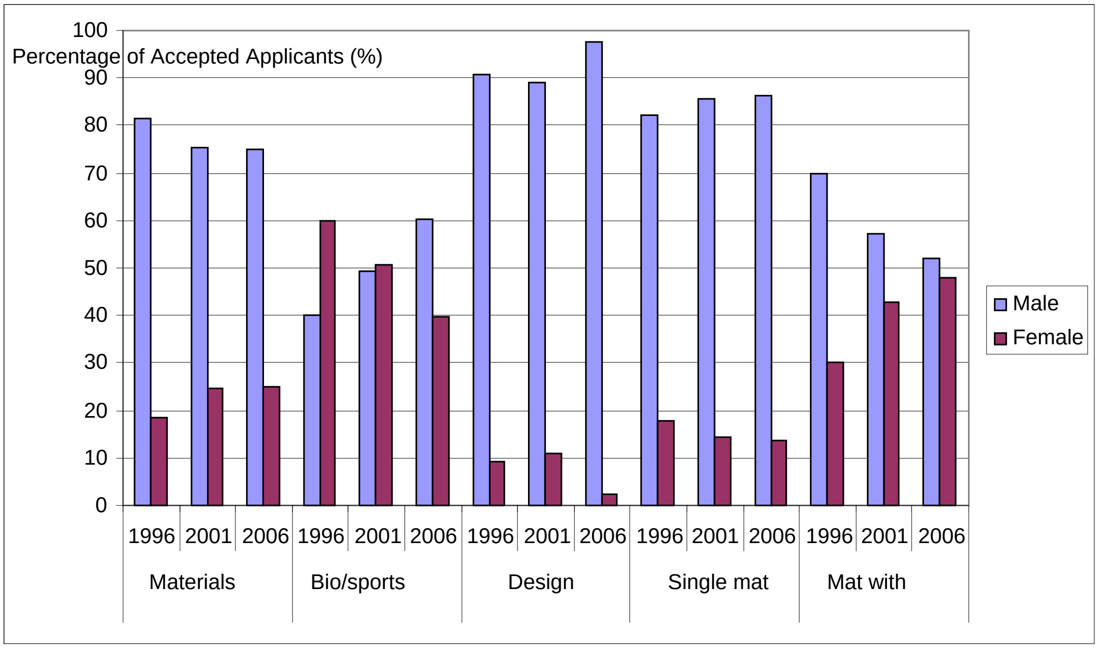

Figure 1: Gender of Accepted Applicants within each Materials programme category in 1996, 2001 and 2006

Although materials undergraduates are principally from the UK, overseas students make up about one third of the cohort, with the majority choosing ‘traditional’ materials science and engineering rather than newer interdisciplinary programmes. Overseas students take up most places on taught-postgraduate courses, where they can often study for a Masters degree in one calendar year rather than two, as in most other countries.

Students who enter undergraduate materials programmes in the UK are also coming from an increasingly diverse academic background. Most UK full-time materials students still enter university with ‘A’ levels, but in 2006 less than a fifth had ‘A’ levels in all three of mathematics, physics and chemistry, compared with over twice as many 10 years previously (Figure 2). The drop is a reflection of a national trend. The interdisciplinary bio/medical- and sports-related materials programmes typically ask for ‘A’ level chemistry in combination with biology, and hence can admit students without mathematics and physics. The increasing population of overseas students also comes with a variety of entry qualifications.

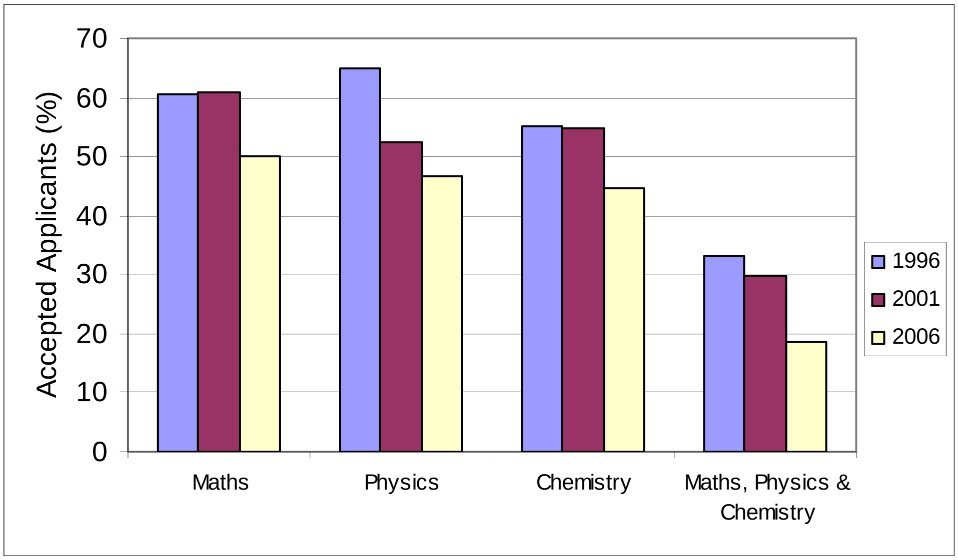

Figure 2: Proportion of accepted applicants onto undergraduate full-time Materials programmes in 1996, 2001 and 2006 who have an A-level in Maths, Physics and Chemistry, and the proportion that have all three A levels. Note that those students who have all three (Maths, Physics & Chemistry) A-levels are also included in the individual 'A' level data.

Coping with a range of academic backgrounds was highlighted as a major challenge faced by materials teaching staff who participated in the National Subject Profile. Many materials programmes have had to make significant adjustments by developing new modules/activities and providing remedial teaching, especially in the first year.

These changes have an impact on content and some traditional recruiters are increasingly looking towards graduates with the four-year MEng "Integrated Masters" degree rather than three-year Bachelors degrees.

The MEng was introduced by UK universities in the mid 1980s in response to a growing perception among university staff, engineering institutions and employers that an additional year of study was needed to match the competencies of graduates from elsewhere in Europe and cope with the ever-increasing breadth and depth of materials knowledge. Industry also expected graduates with business and group-working skills. The MEng is now the degree standard for chartered engineer status, although pan-European comparability is still being discussed.

Changing content

The typical materials student in the UK is taught for 17–20 hours each week, with around 11 hours of lectures, four to five hours of laboratory work, two to three hours of design and/or computer classes, and two to three hours of tutorials and/or seminars in their first and second years. In the final year of an MEng, students spend about 11 hours per week doing individual and group project-work to develop teamwork and problem-solving skills.

Although some programmes incorporate more varied teaching approaches such as problem-based learning, the lecture still remains the most-deployed teaching technique, as the apparently most cost-effective knowledge-transfer activity. However the chalk-and-talk lecture, with students producing copious hand-written notes, has largely been supplanted by PowerPoint presentations and lecture handouts.

The National Subject Profile found that just over half of the total teaching time is spent studying materials-specific topics (see breakdown in materials-specific topics in Figure 3), with the remainder covering topics such as mathematics, business and underlying science. This satisfies the IOM3 professional accreditation requirement of at least 50% materials-specific content.

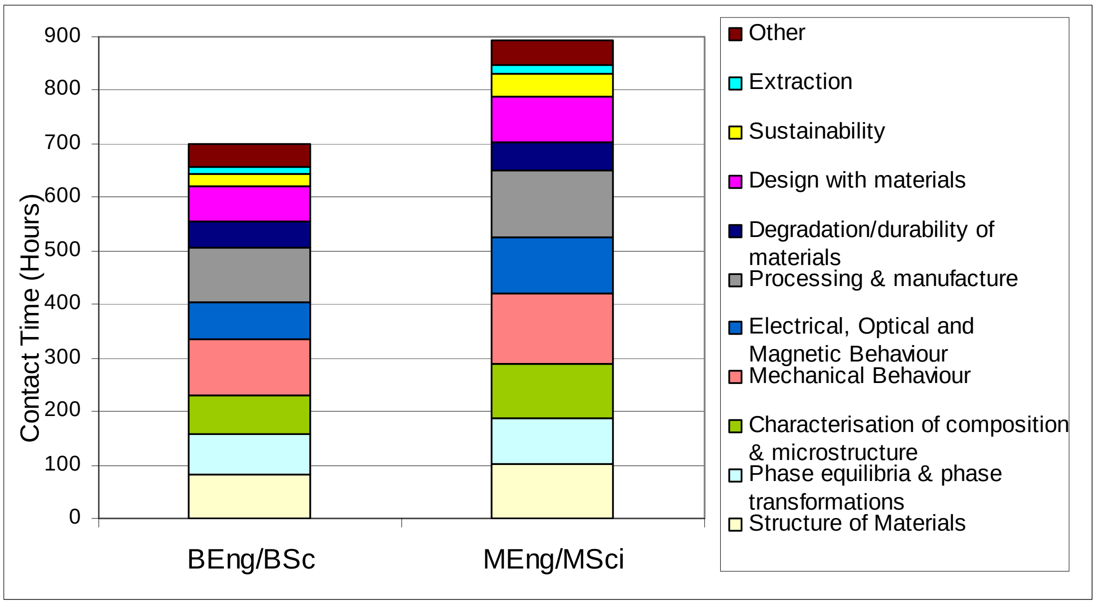

Figure 3: Average materials teaching contact time over whole degree programme for different aspects of the Materials curriculum in general MSE undergraduate programmes. BEng/BSc programmes are three years in length while MEng/MSci are programmes with four taught years.

Universities are more aware than ever before that their undergraduate programmes must produce the workforce that the UK economy needs, with the skills that employers value. The National Subject Profile found that materials degree courses largely embed the majority of these into the core technical modules.

The Subject Profile includes retrospective views from more than 120 materials graduates who had completed an undergraduate degree post-1998 and embarked on a materials-related career. Over 80% had completed a traditional materials science and engineering degree, or a specialist degree in metallurgy or polymers, with fewer than 20% having chosen an interdisciplinary programme.

Most respondents were satisfied with the materials knowledge they had acquired in terms of its relevance and usefulness. They rated underlying science and engineering, mechanical behaviour and characterisation of composition and microstructure as the most useful areas and felt they would have benefited from more teaching on these topics (Figure 4).

MATERIALS SUBJECT AREA	HOW USEFUL KNOWLEDGE HAS BEEN SINCE GRADUATION	GRADUATES WOULD BENEFIT FROM MORE TEACHING IN THESE AREAS	MATERIALS SUBJECT AREA
'Underlying Science & Eng'	1.48	0.80	'Characterisation of composition & microstructure'
'Mechanical Behaviour'	1.40	0.76	'Mechanical Behaviour'
'Characterisation of composition & microstructure'	1.35	0.74	'Underlying Science & Eng'
'Structure of Materials'	1.28	0.73	'Processing & manufacture'
'Processing & manufacture'	1.16	0.71	'Degradation/durability of Materials'
'Degradation/durability of Materials'	1.06	0.70	'Design with Materials'
'Phase equilibria & phase transformations'	1.05	0.66	'Mathematics'
'Design with Materials'	1.05	0.63	'Sustainability'
'Mathematics'	0.97	0.58	'Phase equilibria & phase transformations'
'Sustainability'	0.67	0.54	'Structure of Materials'
'Extraction'	0.50	0.36	'Extraction'

Figure 4: 'How useful' the Materials knowledge in each Materials subject area has been to graduates since graduation, and the benefit to graduates of more teaching in that subject area. A ranking of 'Essential' (=2), 'Desirable' (=1) and 'Not useful/did not study' (=0) was used to indicate 'usefulness'. A ranking of 'Yes, a lot more' (=2), 'Yes, a little more' (=1) and 'No' (=0) was used to indicate the perceived benefit of more teaching in each subject area.

Graduates of both traditional materials degrees and interdisciplinary programmes said there would be little benefit in increasing the amount of mathematics teaching. Overall, the NSP concluded that universities are getting subject coverage levels right.

Skills in employment

Data obtained from the Higher Education Statistics Agency show that six months after graduation about half of all materials graduates are in full-time employment, with two-thirds of the remainder either in full-time postgraduate education or working and studying part-time. These proportions are roughly half-way between those for physical science graduates (a higher proportion undertake further study) and other engineering graduates (a higher proportion go into full-time employment).

The majority of materials graduates work in manufacturing industries, but they also enter retail trade, and health, education and financial services.

The graduates surveyed were also asked whether their studies gave them the competencies, skills and attributes that are needed when employed. They agreed with a separate survey of the materials academics who taught them that report writing, written communication, problem solving and project planning are the most important workplace skills relevant to a materials career. While graduates thought they had been well equipped with three of these skills, they felt more experience in project planning would have been worthwhile.

Materials academics also believe that laboratory skills are important. However, although graduates from traditional materials degrees acknowledge that they have been well trained in laboratory skills, they said they had not found this particularly relevant or beneficial to their career. Possibly this reflects the decline of the materials laboratory in industry, or perhaps materials graduates would be more likely to supervise technical staff.

It is also interesting, in the context of CDIO, that neither traditional materials graduates nor their teachers consider entrepreneurship, ethics, environmental issues and safety legislation to be particularly relevant or important in early careers. However, ethics and safety legislation were 'very relevant' to bio/medical disciplines.

Finally, materials graduates were asked, 'Do you believe that materials and materials related disciplines are a good choice of subject to study at undergraduate and/or taught postgraduate level?' Positive comments were received describing materials as 'underpinning everything we do and make'.

EUROMAT 2009 SURVEY

During a plenary session on education at the biennial Euromat conference in Glasgow in 2009 [1] more than 300 delegates completed a survey designed to reveal their attitudes to materials education. The respondents came from many different countries, from academe, from industry and government, and 40 or so of them were doctoral research students. For the purpose of statistical analysis they were categorised into three work groups; academic; industry and government, or; student, and seven country groups: UK, Swiss, German, French, Benelux, Rest of Europe and Rest of World. Some of the key findings are summarized below. In all cases where a difference between national or employment groups is commented on, the difference is statistically significant at the 95% confidence level or better.

What is materials education for?

There was strong agreement that Materials programmes should serve the needs of industry, with a smaller proportion of people believing that they should serve the needs of a research career. The students were significantly less enthusiastic about Bachelors degrees meeting the needs of industry, while German respondents were less in favour of Masters degrees meeting industrial needs. There was general enthusiasm, somewhat lower among the Swiss, that Masters degrees should meet the needs of a research career.

These views contrasted with the responses to the question whether current programmes <u>actually</u> met the needs of industry or research. There was a lower level of agreement that this was the case, with delegates from the Rest of Europe showing the greatest degree of scepticism about Masters programmes actually meeting the needs of industry.

A surprising number of respondents felt that there would be merit in a Europe-wide core curriculum for the discipline (62%) while a slightly smaller fraction – but still a majority – thought that this was a good idea for Masters level programmes (57%). There were national differences, with respondents from the UK and Switzerland least enthusiastic for a core curriculum at either Bachelors or Masters level. Students were the least in favour of a core curriculum at Bachelor level, but they still favoured it by a small majority. Industrial delegates were most strongly in favour (73% in each case).

What should a materials graduate have studied?

The questions asked here were fairly general. Respondents were almost unanimous that the science of materials should be studied, with a strong preference that this should embrace a wide range of classes of material (metal, alloy, polymer, ceramic, semiconductor, composite …). This mirrors the findings of the UK National Subject Profile (NSP). They also supported the teaching of mathematics. Respondents were divided whether one class of materials should be studied in detail, and on the whole opposed to the idea that one specific material should be studied in detail at Bachelor level. Responses were neutral about the inclusion of extraction of materials or ethical issues, negative towards project management, and only slightly positive towards environmental impact and recycling. Again, the NSP results confirm that these views are supported by UK graduates (perhaps with the exception of the view about project management).

French delegates were the most strongly opposed to studying one material in detail (89% strongly opposed). UK delegates were the most strongly in favour of studying a range of materials classes (76% strongly agreeing). Only an average of 10% of respondents felt that project management or finance should be given a high priority – a further negative response to some key CDIO topics.

What should a Masters graduate have studied?

Delegates agreed that a Materials Masters programme should, like a Bachelor programme, focus on the science of materials and mathematics, with coverage of a wide range of materials types. The responses to the remaining questions however differed significantly from those for the Bachelor qualification. Respondents reported that they felt that one class of materials could be covered in detail, with a significant minority happy for the programme to focus on a single material. There was significantly greater acceptance of environmental and recycling issues and a slightly warmer response towards project management than for Bachelors programmes.

There were some national differences, with almost half of the delegates from Benelux giving a high priority to the study of extraction while a third of UK respondents gave a low priority to ethical issues.

What non-technical competencies should a materials Bachelor graduate have?

The four most important non-technical attributes were reported to be the ability to speak and write English, competence working in a team and the ability to give a confident verbal presentation. Behind these, positive responses were also recorded for having 3 months experience in industry, being able to speak two languages and being able to plan, undertake, manage and report a research project. Much less support was given to the need to have studied or worked in two countries or the aspiration to become a professional engineer after graduating.

Within this general picture respondents from the Rest of the World were more strongly in favour of Bachelor graduates working in another country, while only 31% of Swiss thought that fluent English speaking was of high importance, compared with 60% of UK and 72% of Rest of

Europe delegates. This attitude was repeated with 32% of Swiss delegates (contrasting with about 6% of other delegates) giving a low importance to the writing of accurate English.

UK and Swiss respondents gave a significantly lower priority than all other countries to the ability to speak two languages (8% and 10% respectively compared to an average of 35% for the other countries). The Swiss were the least concerned about the ability to plan and run a research project.

What non-technical competencies should a materials Masters graduate have?

For Masters graduates the order of priorities of the respondents were very similar to those for Bachelors graduates, but in every case the response was stronger. In other words the delegates felt that each of the items mentioned above was more important for a Masters graduate than it was for a Bachelor graduate.

The British were by far the least enthusiastic about working in another country (44% gave it a low priority compared to only 10% of other delegates). Delegates from the Rest of the World were least concerned that the graduate should have experience of working in industry. Unsurprisingly industrial respondents were most enthusiastic about industrial experience (72% gave it a high priority compared with about 50% of academic and student respondents). More surprisingly, industrial respondents were significantly less concerned about the fluent speaking of English than either of the other groups (52% giving it a high priority compared with more than 80% of other respondents).

Awareness of support available for materials education

The vast majority of respondents reported no familiarity either with software or with organisations which exist to support the teaching and learning of materials. A significant minority had not heard of either podcasts or problem-based-learning, two of the most widespread educational tools currently available. This is in agreement with the finding from the NSP that both techniques were used in less than 2% of materials teaching.

This perhaps indicates that across the whole of Europe newer teaching techniques have not yet gained significant ground, with most teaching methodologies at present still being similar to those which have been deployed for the past 50 years.

The visibility in society of the discipline of Materials is often discussed within professional bodies and universities. The opinion of the respondents to this survey was that school leavers are moderately well informed about Materials. The two countries with the greatest concern about visibility in schools were the UK and Benelux, where fewer than 10% of the respondents felt that school leavers are well informed. This contrasts with other countries in which more than 75% of school leavers were thought to be well or moderately well informed about the subject.

The final question revealed encouraging answers for the profession of Materials: A large majority of respondents agreed that Materials is an appropriate discipline to study at Bachelor level. The lowest level of support was 62% from the French delegates, and the highest 92% from the UK.

DISCUSSION AND CONCLUSIONS

What do we learn from both the UK NSP and the wider Euromat survey? Are the results what we might expect? They certainly reveal that Materials is a vibrant discipline throughout Europe. Its curriculum appears to have changed to embrace a wider range of materials and single-material programmes such as metallurgy or ceramics have been replaced by materials science, sometimes in combination with user communities (sport, aerospace, automobile, medicine). There appear to have been only relatively modest changes in teaching style and methodology despite the widespread availability of computers, IT and the internet. However there is no evidence of widespread dissatisfaction, by students or employers, with materials programmes at Bachelor or Masters level.

In the context of CDIO, there are a number of messages to be read. We must first note that although 50 responses were from outside the university sector (a large number in absolute terms), about 200 were from within. The first conclusion is that attitudes across Europe are not uniform. We found significant differences among countries – indeed all the differences reported in this paper are statistically significant. For instance there are major differences of emphasis on a number of issues between the French, the Swiss and the British.

The second difference refers to the purpose of the degree. Although industrial employers were clear that a Bachelor degree should meet the demands of industry, students were much less enthusiastic about this. Employers were also the most strongly supportive of a unified European curriculum for Bachelor degrees (73% in favour), although both academics and students also voted in favour (62% and 58% respectively). From the point of view of educators this reveals a somewhat surprising and alarming lack of confidence in the autonomy of universities!

The main significance for CDIO lies in attitudes to the non-technical curriculum. Key professional attributes such as team working and fluency in writing and speaking, particularly in English, were regarded as important by most respondents. However the Swiss were unenthusiastic about the need for fluency in English or indeed the speaking of two languages. This is surprising from a country with many common languages – perhaps it was to be taken for granted. Equally surprising, at least to these authors, was the low priority placed by employers on the speaking of English. In the context of current discussions about the role of internationalisation in CDIO, it is interesting to note that the British were least enthusiastic about the need for a student to work in two or more countries.

Project management at bachelor level was regarded as important by very few respondents, with only a slightly stronger appeal at Masters level. Other topics which are emphasised by the CDIO syllabus but were less well received in this survey were ethics, recycling and environmental impact. We might interpret this as indicating that the CDIO movement is still ahead of popular opinion even among engineering employers!

Implications for the future

It is of course difficult to predict what will happen to Materials education in the context of advances in IT and increasing interest in education on one hand, but a global recession on the other. One clear issue, which must apply in every country, is that changing the methodology of Materials education in order to improve its quality and the employability of its graduates – for instance by introducing problem-based-learning - will be more expensive than doing nothing (at least until numbers fall sufficiently for unchanged programmes to be forced to close). Also, if programmes are to change to better meet the needs of industry, then an increased involvement of industry in the form of money or staff time will be needed.

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Appendix with some of the questionnaire data

Number of responses, N=253. Printed below are the total numbers of responses to each question.

Academic	Industry	Government	Student
161	28	22	37

Bachelors degree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Should meet needs of					
Industry	6	20	19	75	116
Research	9	11	44	75	72
Actually meets needs of					
Industry	21	37	56	62	42

Research	13	28	58	66	38

Masters degree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Should meet needs of					
Industry	4	7	20	73	116
Research	2	3	17	47	150
Actually meets needs of					
Industry	13	26	46	75	45
Research	6	14	35	76	73

European curriculum

	Yes	No
Euro Bachelor curriculum:	146	88
Euro Masters curriculum:	133	101

Technical content

Bachelors degree	Low	Medium	High
The science of materials	6	54	186
A wide range of types of Materials	13	81	156
One class of materials in detail	72	118	47
One material in detail	146	75	19
Extraction of Materials	75	121	41
Ethical issues	52	115	74
Project man & finance	95	107	30
environmental impact	26	119	94
Recycling and reuse	25	113	99
Mathematics	14	103	127

Masters degree	Low	Medium	High
The science of materials	3	25	217
A wide range of types of Materials	10	76	161
One class of materials in detail	11	95	140
One material in detail	56	110	77
Extraction of Materials	74	122	41
Ethical issues	33	116	77
Project man & finance	49	116	69
environmental impact	11	94	134

Recycling and reuse	10	101	136
Mathematics	16	86	139

Non-technical content

Bachelors degree	Low	Medium	High
studied or worked in another country	108	97	38
three month's experience in industry	42	93	106
Speak English fluently	16	93	134
Write correct English	24	114	103
Speak at least two languages	60	101	71
Team competence	22	95	124
plan, undertake, manage and report a research project	53	119	66
Be able to give a confident verbal presentation	22	105	117
professional materials engineer within a few years	73	102	46

Masters degree	Low	Medium	High
studied or worked in another country	30	89	121
three month's experience in industry	18	96	127
Speak English fluently	2	40	201
Write correct English	4	62	177
Speak at least two languages	27	95	123
Team competence	9	68	167
plan, undertake, manage and report a research project	5	29	206
Be able to give a confident verbal presentation	3	25	213
professional materials engineer within a few years	35	108	78

Is Materials an appropriate degree programme to study at undergraduate level?

Yes	No
174	59

Please apply to the authors at goodhew@liv.ac.uk for details of the data analyses.