Materials

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Preface

Subject benchmark statements provide a means for the academic community to describe the nature and characteristics of programmes in a specific subject or subject area. They also represent general expectations about standards for the award of qualifications at a given level in terms of the attributes and capabilities that those possessing qualifications should have demonstrated.

This subject benchmark statement, together with others published concurrently, refers to the **bachelor's degree with honours**[1]. In addition, some subject benchmark statements provide guidance on integrated master's awards.

Subject benchmark statements are used for a variety of purposes. Primarily, they are an important external source of reference for higher education institutions (HEIs) when new programmes are being designed and developed in a subject area. They provide general guidance for articulating the learning outcomes associated with the programme but are not a specification of a detailed curriculum in the subject.

Subject benchmark statements also provide support to HEIs in pursuit of internal quality assurance. They enable the learning outcomes specified for a particular programme to be reviewed and evaluated against agreed general expectations about standards. Subject benchmark statements allow for flexibility and innovation in programme design and can stimulate academic discussion and debate upon the content of new and existing programmes within an agreed overall framework. Their use in supporting programme design, delivery and review within HEIs is supportive of moves towards an emphasis on institutional responsibility for standards and quality.

Subject benchmark statements may also be of interest to prospective students and employers, seeking information about the nature and standards of awards in a given subject or subject area.

The relationship between the standards set out in this document and those produced by professional, statutory or regulatory bodies for individual disciplines will be a matter for individual HEIs to consider in detail.

This subject benchmark statement represents a revised version of the original published in 2002. The review process was overseen by the Quality Assurance Agency for Higher Education (QAA) as part of a periodic review of all subject benchmark statements published in 2002. The review and subsequent revision of the subject benchmark statement was undertaken by a group of subject specialists drawn from, and acting on behalf of, the subject community. The revised subject benchmark statement went through a full consultation with the wider academic community and stakeholder groups.

QAA publishes and distributes this subject benchmark statement and other subject benchmark statements developed by similar subject-specific groups.

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[1] This is equivalent to the honours degree in the *Scottish Credit and Qualifications Framework* (level 10) and in the *Credit and Qualifications Framework for Wales* (level 6).

The Disability Equality Duty (DED) came into force on 4 December 2006[2]. The DED requires public authorities, including HEIs, to act proactively on disability equality issues. The Duty complements the individual rights focus of the *Disability Discrimination Act* and is aimed at improving public services and outcomes for disabled people as a whole. Responsibility for making sure that such duty is met lies with HEIs.

The Equality and Human Rights Commission[3] has published guidance[4] to help HEIs prepare for the implementation of the Duty and provided illustrative examples on how to take the Duty forward. HEIs are encouraged to read this guidance when considering their approach to engaging with components of the Academic Infrastructure[5], of which subject benchmark statements are a part.

Additional information that may assist HEIs when engaging with subject benchmark statements can be found in the *Code of Practice (revised) for providers of post-16 education and related services*[6], and also through the Equality Challenge Unit[7] which is established to promote equality and diversity in higher education.

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[2] In England, Scotland and Wales.

[3] On 1 October 2007, the Equal Opportunities Commission, the Commission for Racial Equality and the Disability Rights Commission merged into the new Equality and Human Rights Commission.

[4] Copies of the guidance *Further and higher education institutions and the Disability Equality Duty, Guidance for Principals, Vice-Chancellors, governing boards and senior managers working in further and higher education institutions in England, Scotland and Wales*, may be obtained from www.equalityhumanrights.com/en/forbusinessesandorganisation/publicauthorities/disabilityequalityd/pages/disabilitye.aspx

[5] An explanation of the Academic Infrastructure, and the roles of subject benchmark statements within it, is available at www.qaa.ac.uk/academicinfrastructure

[6] Copies of the *Code of Practice (revised) for providers of post-16 education and related services*, published by the Disability Rights Commission, may be obtained from www.equalityhumanrights.com/en/publicationsandresources/Disability/Pages/Education.aspx

[7] Equality Challenge Unit, www.ecu.ac.uk

Foreword

This subject benchmark statement represents a minor revision to the original statement published by QAA in 2002. The original statement was written by a broad range of academics from the materials discipline. The original statement was compiled by materials experts from HEIs in the United Kingdom (UK) and subjected to wider review amongst the materials community. This minor revision has been overseen by the Director of the Higher Education Academy Subject Centre for Materials, the UK Centre for Materials Education, Professor Peter Goodhew, and the Chair of the original benchmarking group in 2002, Professor Frank Sale. It has also gone though a process of consultation with the wider community.

The revised statement for materials provides a vision for the context of the subject. It also acknowledges that the range of joint degrees and interdisciplinary programmes that materials applies to is diverse and extends from science-based programmes to engineering-based programmes. The statement has been designed to encourage diversity of provision and encourage HEIs to explore new ways of enhancing their students' knowledge and understanding in this rapidly developing discipline. It has been generally restructured for greater clarity as well as being updated to include references to sustainability, lifecycle analysis and environmental considerations. References to integrated master's degrees (eg Master of Engineering (MEng)) have also been strengthened. The levels of attainment have been realigned into the three levels: excellent; typical; and threshold.

This benchmark statement also frames the specific and generic transferable skills that a materials graduate would be expected to have acquired on successful completion of the programme. It sets out the standards of student attainment at a number of levels and states the threshold level for successful achievement of a bachelor's degree in a materials specialism. Finally, the statement provides examples of a range of teaching, learning and assessment methods.

October 2007

1 Introduction

1.1 Since the Stone Age the development of materials has been fundamental to the advancement of civilisation. Without an understanding of materials we could not fly the Atlantic, surf the internet or replace a heart valve. Tomorrow's developments await further advances in materials.

1.2 This statement is primarily concerned with undergraduate programmes with a major materials science or materials engineering component. However, parts will be applicable to interdisciplinary programmes with a minor materials component.

1.3 Accreditation of particular programmes by the professional engineering institutions, for their own membership requirements, is an entirely separate exercise, but this statement is intended to assist professional institutes during the accreditation and programme review process. This statement, revised in 2007, is primarily concerned with the bachelor's degree with honours and with integrated master's (eg MEng) degrees which are required to complete the academic requirements for the achievement of Chartered Engineer (CEng) status in accordance with the *United Kingdom Standards for Professional Engineering Competence* (UK-SPEC) published by the Engineering Council UK (www.engc.org.uk).

2 Materials as an academic discipline

2.1 The academic study of materials encompasses aspects of the physical sciences and of engineering (see figure 1). There are two central themes: the link between structure (on length scales from sub-nm to mm) and chemical, physical and mechanical properties; and how control of microstructure through processing can be used to optimise engineering performance. Modelling is increasingly used to predict both microstructure and properties.

2.2 The range of programmes to which this benchmark statement applies is diverse and extends from science-based to engineering-based programmes.

2.3 The study of materials science develops a basic understanding of the part played by selection of materials and choice of manufacturing process in meeting an engineering specification. The study of materials engineering must have its foundations in materials science. The respective weightings of these two aspects should be a conscious element of programme design.

2.4 Materials are central to the economic well-being of the country. This is reflected by developments in areas of materials such as 'smart' materials, layered materials, soft solids, nanotechnology, sensors and biomimetics. Materials scientists or engineers help to develop the materials required for new products, find better lower-cost manufacturing routes, and enhance the performance of existing materials. They consider the environmental impact and sustainability of their products. They discover how to optimise the selection of materials and create sophisticated databases from which properties and service behaviour can be predicted.

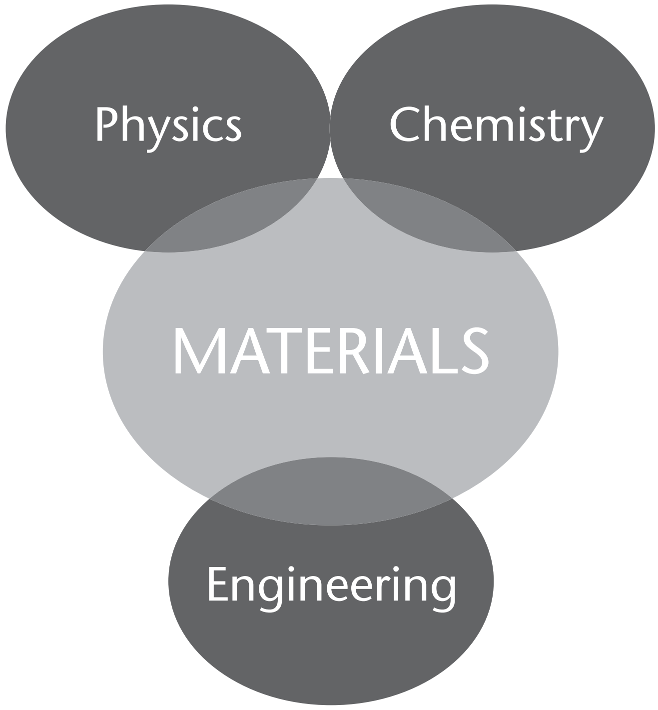

Figure 1.

2.5 Materials scientists or engineers may work in the manufacturing, processing or user industries, in research, production, management or in sales. They may be concerned with mass-produced artefacts such as cars, tableware, or building materials, or specialist products such as those needed for micro-electronics, sports equipment, replacement body parts, energy generation or aerospace. Some of the relevant themes and linkages between them are set out in figure 2.

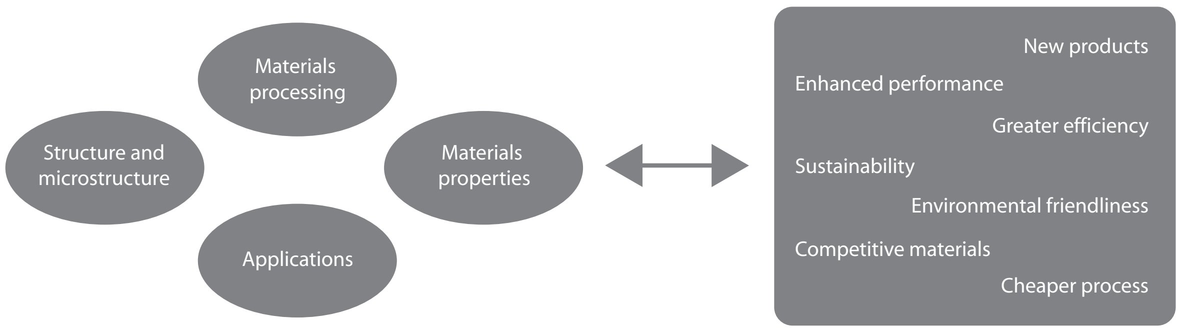

Figure 2.

3 Subject knowledge, understanding and skills

3.1 This section describes the knowledge, skills and attributes that a materials graduate would be expected to possess, and includes reference to materials-specific aspects, background science and generic skills. The knowledge and skills are grouped into materials, scientific and engineering, and generic.

Materials-related knowledge and skills

3.2 Materials programmes may be general or specialist, theoretical or applied. Degree programmes offered by individual institutions may vary considerably. However, it is anticipated that materials graduates will have an awareness of a range of materials, and some familiarity with relevant concepts associated with most of the following:

- **structure of materials** - electronic, atomic, bonding, crystalline, amorphous and multiphase; and structure on the nano, micro, meso and macro-scales
- **phase equilibria and phase transformations** - thermodynamic and kinetic aspects
- **characterisation of composition and microstructure** - spectroscopy; optical and electron microscopy; electron and X-ray diffraction; scanning probe techniques; thermal analysis; and some aspects of traditional chemical analysis
- **mechanical behaviour** - elastic and plastic deformation and fracture, for example, creep and fatigue; strengthening, toughening and stiffening mechanisms; mechanical test methods; and continuum mechanics
- **functional behaviour** - semi, dielectric and optical conducting; and magnetic materials
- **biomaterials** - materials that interact with biological systems; materials of biological origin; and biomimetics
- **processing and manufacture** - processing and synthesis of materials via gaseous, liquid, colloidal, powder, solid state and deposition techniques; joining and fabrication methods; surface treatment; heat and mass transfer; and fluid mechanics
- **degradation/durability of materials** - effect of liquid and gaseous environments on the performance of different material types; wear of materials; and biodegradation
- **materials selection** - consideration of all material types, including material processing methods, and product costs; selection criteria for materials and production processes
- **design with materials** - this area is key to the use of materials. Graduates in materials should have the ability to select appropriate compositions and use processing to achieve the required microstructure, hence the required structural and functional properties in a product, often in order to meet specifications
- **lifecycle analysis, sustainability and environmental impact**
- **interaction and application** - interaction between composition, processing, microstructure and properties, leading to appropriate application of materials.

3.3 Materials graduates should have had opportunities, through practical work, for first-hand experience of a range of techniques and materials (artefact analysis, characterisation, processing, testing etc) designed to develop the ability to plan, implement and interpret experimental investigations. Experience of computer modelling techniques is also desirable.

Scientific and engineering-related knowledge and skills

3.4 In order to understand the materials topics discussed above, materials graduates will need to acquire an adequate knowledge of mathematics and sciences to prepare a foundation for learning within the materials discipline. Examples of these requirements are given below. It is not expected that materials graduates will be required to study all of these (eg biology). Materials graduates will also need to acquire adequate engineering knowledge and skills in order to understand aspects of materials production and service and to be able to communicate effectively within the engineering profession at large.

3.5 Such requirements include:

- **mathematics:** the need to understand mathematics as a method of communicating results, concepts and ideas (eg apply a range of statistical methods to the planning of experiments and the interpretation of data); and use mathematical and computational tools (eg the modelling of structure, properties or processing of materials) for solving complex problems
- **chemistry:** the need to develop an adequate understanding of chemistry to support a range of materials disciplines. Aspects of organic, inorganic and physical chemistry may be required to varying depths. The chemistry content should be sufficient for the understanding of important topics such as thermodynamics and kinetics and the chemical aspects of materials production, processing, stability and degradation
- **physics:** the need to have a broad foundation in physics for the understanding of materials. This foundation will need to sustain the development of the understanding and characterisation of materials structure and properties (eg waves, optics and solid state physics). Many applications of materials will require additional topics, such as electronics and mechanics, to be developed
- **biology:** the need for an adequate understanding of biology (eg basic cellular structure and function, basic protein structure etc) in order to support aspects of biomaterials programmes.

General engineering principles

3.6 In addition to the above, materials engineers will be expected to appreciate the interrelationship between materials engineering and engineering design. In addition, students (particularly those studying for a four-year MEng) will need a foundation of engineering science in order to understand manufacturing/processing/fabrication methods and predict the service performance of materials (eg strength of materials and mechanics of solids; and principles of manufacture including computer-aided engineering and computer modelling).

Generic skills

3.7 Those graduating with a degree in materials will have good professional judgement, be able to exercise original thought, and, having gained experience, take responsibility for the direction of important tasks. In order to demonstrate these skills they will need to possess:

- the ability to communicate in writing, orally and using graphics
- the relevant mathematical and computational skills
- problem-solving skills
- the ability to exercise original thought
- competence in using information technology effectively
- the ability to work in a team
- the ability to manage time and resources
- an awareness of functions required for organisational success
- study skills needed for continuing professional development
- an awareness of sustainability and environmental issues
- problem-solving and creativity skills.

3.8 In addition to the above, graduates would be expected to have had opportunities to tackle open-ended problems which provide opportunities for the demonstration of problem-solving skills and creativity.

4 Teaching, learning and assessment

4.1 Existing materials programmes have been developed over many years and deploy a diverse range of teaching, learning and assessment methods to enhance and reinforce the student learning experience. The programmes covered by this statement encompass a wide range of types of material and are (or will be) offered through many modes and patterns of study. Teaching, learning and assessment methodology must always be justified in terms of the learning outcomes of the programmes and the background of the students. The methods used should be made explicit to the students taking each programme, and should be evaluated regularly (and modified where appropriate) in response to generic and discipline-specific developments[8].

4.2 Curriculum design must be informed by research, scholarship and an understanding of the potential destinations of graduates. It is not possible for students to achieve a satisfactory understanding of materials science and engineering without significant exposure to laboratory work and without undertaking a substantial project. Many projects should be research-led and the curriculum would be expected to develop in graduates both independence of thought and the ability to work effectively in a team. Where appropriate, all teaching needs to be placed within the context of social, legal, environmental and economic factors relevant to the production and use of materials.

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[8] The UK Centre for Materials Education (the Higher Education Academy Materials Subject Centre established by the higher education funding councils) should be able to provide advice if this is required.

4.3 Methods of assessment should reflect the specified learning outcomes. A balance should always be struck between the need to test a student's understanding, knowledge and ability for the purposes of awarding a qualification and providing an appropriate and valuable incentive to student development. Where possible, assessment methods should reflect the demands that graduates are likely to face in their future careers, including problem-solving and the need to express technical material clearly and accurately in writing. An important element of assessment is that students are given feedback to allow continued personal development.

4.4 Examples of teaching and assessment methods which might be appropriate for use within the materials discipline are given in Appendix A. However, these lists are not intended to be either prescriptive or comprehensive, since imaginative innovation in teaching often plays a large role in motivating students and expanding their interest in the discipline.

Project work

4.5 Materials graduates would be expected to have carried out an individual research project. These projects would develop competence in investigating, managing and applying knowledge, usually in the solution of a complex materials problem. Such a project will be described in a report, which will demonstrate the abilities to:

- analyse quantitatively and assess the uncertainty of results
- understand the published literature on the topic of the investigation that demonstrates both what is known and the limits of current knowledge
- select the methodology to undertake investigation
- present findings in a clear and concise manner
- interpret and discuss findings in the light of current knowledge
- summarise the main conclusions and provide an accurate synopsis of the work undertaken.

4.6 It is also desirable that graduates will have participated in an activity involving teamwork. Such teamworking on a project is a necessary requirement for MEng and for CEng registration according to the UK-SPEC.

Industrial experience

4.7 This may be acquired via, for example, speakers from industry, industrial placements, industrial visits, and industrial projects. Many materials graduates will also be familiar with the organisation and structure of business, economic analysis, environmental issues (health and safety at work, the *Control of Substances Hazardous to Health* regulations, pollution, recycling etc) and ethical professional behaviour.

5 Standards and levels of student attainment

Honours degree

5.1 The standards of student achievement are divided into three attainment levels: excellent; typical; and threshold for an honours degree in materials.

Attainment level: excellent

- Understanding of the subject and techniques is extensive, extending beyond the information provided in the programme. Knowledge and techniques are applied quickly and readily to new situations, including any unseen or open-ended problems. Both the problem and the solution can be critically appraised. New knowledge is acquired quickly and accurately.
- Routine calculations, explanations, interpretations and analysis are executed swiftly and accurately. Understanding of relevant facts and techniques is excellent. There is a fluency and confidence in method of approach.
- Project or practical work is planned, executed and written up with little assistance. There is clear evidence of original thinking in the analysis and discussion of results, with excellent understanding of literature and of relevant practice. There is a clear plan of future work.
- Practical (or relevant) competence is clearly demonstrated. The ability to innovate is also clearly demonstrated.
- Students have excellent generic skills and time-management ability.

5.2 A graduate at this level would be a highly sought-after honours graduate. After an appropriate period of professional experience, the graduate would become an excellent practitioner capable of exercising sound judgement. Career prospects could include research, innovation or technical management with the expectation of significant managerial responsibility. There is likely to be rapid progress to a senior executive position.

Attainment level: typical

- Understanding of the subject and techniques is good, but may be more confined to the programme. There is an understanding of what knowledge and techniques can be applied to new situations. The methodology for solving problems can be clearly demonstrated. New knowledge is readily acquired.
- Routine calculations, explanations, interpretations and analysis are executed accurately. Understanding of relevant facts and techniques is good. There is a fluency and confidence in method of approach over most of the subject.
- Project or practical work is planned, executed and written up with guidance. Results are analysed and discussed in a competent manner. There is good understanding of literature and relevant practice with suggestions for future work.
- Practical or relevant competence is demonstrated over most of the range expected. The ability to innovate is demonstrated.
- Students have good generic skills and time management ability.

5.3 After an appropriate period of professional experience, the graduate would become a good practitioner capable of exercising sound judgement. Career prospects could include research, innovation or technical management, with the expectation of significant managerial responsibility and the possibility of achieving a senior management position.

Attainment level: threshold

- Understanding of the subject and techniques is basic and selective. There is a recognition of what generic knowledge should apply to a new situation, but there may be less confidence in how to use it. The methodology for solving problems can be explained even if it cannot be applied. New knowledge is acquired with perseverance.
- Routine calculations, explanations, interpretations and analysis can be identified but may require checking and assistance to complete the task. There is general competence in answering questions concerning routine aspects. There is selective knowledge of terms and their application. Some assistance may be required in explaining fundamental concepts. Mistakes can be identified, but not necessarily rectified.
- Project or practical work is planned and executed with reasonable success but writing up may require help. The full significance of the results may not be immediately identified and some assistance may be required in their interpretation and discussion. A list of essential literature may be quoted without critical analysis. There is an indication of future work.
- Practical or relevant competence is selective, but may be good in specific areas.
- Generic skills may be good in certain aspects.

5.4 A graduate at this level would be a good potential trainee for either a technical or general management position. After an appropriate period of professional experience, the graduate is likely to develop into a good practitioner in a specific field, where an awareness of materials is essential but without the need to apply fundamental knowledge on a regular basis, eg production control.

Integrated master's (MEng)

5.5 An MEng is an integrated master's programme in engineering which provides an extended and enhanced programme of study, it is usually designed with reference to UK-SPEC as a preparation for professional practice and attracts the more able student. The period of study is typically equivalent to at least four years of academic learning (five years in Scotland) and the programme of study should be both broader and deeper than a corresponding bachelor of engineering honours programme and have an increased emphasis on industrial relevance. MEng students are expected to undertake both an individual research/design project and a more wide-ranging group project with strong industrial involvement, and to undertake master's level work at the higher levels of the programmes. MEng students would also be expected to have good generic skills. Further guidance can be found in the subject benchmark statement for engineering (2006).

[9] The subject benchmark statement for engineering can be found at www.qaa.ac.uk/academicinfrastructure/benchmark/statements/Engineering06.asp

5.6 There should be a clear distinction between the attainment levels of identifiable bachelor's and MEng cohorts when taking common modules within a programme. This may be done by establishing separate learning outcomes for modules taught in common.

Threshold performance for integrated master's (MEng)

5.7 As above, with greater attainment in fundamental knowledge and generic skills. It would be expected that MEng graduates would reach at least the typical attainment level.

Appendix A - Examples of teaching and assessment methods

This appendix contains examples of teaching and assessment methods which may be appropriate for specific elements of materials programmes. The lists are intended to be illustrative and not exhaustive.

Teaching/study methods

Formal lectures
Interactive lectures
One-to-one tutorials
Small group tutorials
Laboratory classes, structured or open-ended
Exercise classes
Computer-based learning
Video footage
Guided reading
Student study groups
Peer tutoring
Library/information retrieval tasks
Field trips/works visits
Training during work placements
Case studies
Problem-based learning
Individual projects
Team projects
Reflective journals
Concept mapping

Assessment methods

Timed examinations
Open-book or untimed examinations
Laboratory examinations
Oral examinations
Computer-aided assessment
Problem-solving tasks
Essays
Oral presentations
Poster presentations
Laboratory reports
Workplacement reports
Learning logs/portfolios
Project reports
Self-assessment
Peer assessments

Appendix B - Membership of the review group for the subject benchmark statement for materials

The revision to this subject benchmark statement was coordinated by:

Professor Peter J Goodhew	University of Liverpool
Emeritus Professor Frank Robert Sale	University of Manchester

The review involved extensive consultation across the sector.

Appendix C - Membership of the original benchmarking group for materials

Details below appear as published in the original subject benchmark statement for materials (2002).

Dr Cris Arnold	University of Wales, Swansea
Dr Chris Bowen	University of Bath
Professor Robert Freer	University of Manchester Institute of Science and Technology
Professor Peter Goodhew (Vice-chair)	University of Liverpool
Dr Marianne Gilbert	Loughborough University
Dr Henry McShane	Imperial College, London
Professor Panos Tsakiropoulos	University of Surrey
Dr John Parker	University of Sheffield
Professor Frank Sale (Chair)	University of Manchester
Dr Ray Smith	Queen Mary and Westfield University, London
Dr John Sykes	University of Oxford
Dr Michael Wise	Tetronics Ltd, Faringdon, Oxon (previously University of Birmingham)

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