QAA MEMBERSHIP

QAA

Subject Benchmark Statement

Materials

October 2019

Contents

How can I use this document?

This is the Subject Benchmark Statement for materials. It defines the academic standards that can be expected of a graduate, in terms of what they might know, do and understand at the end of their studies, and describes the nature of the subject.

The UK Quality Code for Higher Education (Quality Code) sets out the Expectations and Core practices that all providers of UK higher education are required to meet. Providers in Scotland, Wales and Northern Ireland must also meet the Common practices in the Quality Code.

The Quality Assurance Agency for Higher Education (QAA) has also published a set of Advice and Guidance, divided into 12 themes, and a number of other resources that support the mandatory part of the Quality Code. Subject Benchmark Statements sit alongside these resources to help providers develop courses and refine curricula but are not part of the regulated requirements for higher education providers in the UK.

This Statement is intended to support you if you are:

- involved in the design, delivery and review of courses of study in materials or related subjects
- a prospective student thinking about studying this subject, or a current student of the subject, to find out what may be involved
- an employer, to find out about the knowledge and skills generally expected of a graduate in this subject.

Subject Benchmark Statements provide general guidance for articulating the learning outcomes associated with the course but are not intended to represent a national curriculum in a subject or to prescribe set approaches to teaching, learning or assessment. Instead, they allow for flexibility and innovation in course design within a framework agreed by the subject community.

It may be helpful to refer to relevant Advice and Guidance when using this statement.

Explanations of unfamiliar terms used in this Subject Benchmark Statement can be found in QAA's Glossary.

About the Statement

This Subject Benchmark Statement refers to the bachelor's degrees with honours (for example, BSc, BEng) and integrated master's degrees (for example, MEng, MSci) in materials.[1]

It has been produced by a group of subject specialists drawn from, and acting on behalf of, the subject community. The process is facilitated by QAA, as is the full consultation with the wider academic community and stakeholder groups each Statement goes through.

In order to ensure the continuing currency of Subject Benchmark Statements, QAA initiates regular reviews of their content, five years after first publication, and every seven years subsequently, or in response to significant changes in the discipline.

Relationship to legislation

Higher education providers are responsible for meeting the requirements of legislation and any other regulatory requirements placed upon them, for example, by funding bodies. This Statement does not interpret legislation, nor does it incorporate statutory or regulatory requirements. The responsibility for academic standards remains with the higher education provider who awards the degree.

Higher education providers may need to consider other reference points in addition to this Statement in designing, delivering and reviewing courses. These may include requirements set out by professional, statutory and regulatory bodies (PSRBs), and industry or employer expectations.

Sources of information about other requirements and examples of guidance and good practice are signposted within the Subject Benchmark Statement where appropriate. Individual higher education providers will decide how they use this information.

Summary of changes from the previous Subject Benchmark Statement (2017)

This version of the Statement forms its fourth edition, following initial publication of the Subject Benchmark Statement in 2002 and review and revision in 2008 and 2017.

This latest version of the Statement is the consequence of the revision to the UK Quality Code for Higher Education which was published in 2018. It has been revised to update references to the Quality Code and other minor changes within the sector. Changes have been made by QAA and confirmed by the Chair of the most recent review group.

There have been no revisions to the subject-specific content of the statement.

[1] Bachelor's degrees are at level 6 (integrated master’s at level 7) in *The Framework for Higher Education Qualifications in England, Wales and Northern Ireland* and level 10 (integrated master’s at level 11) in *The Framework for Qualifications of Higher Education Institutions in Scotland*, as published in The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies

1 Introduction

1.1 Materials science and engineering is an interdisciplinary subject combining chemistry, physics and, increasingly, biology with engineering so as to understand what makes any specific material, from graphene to wood, behave in a particular way. Traditionally, a wide range of material classes are studied, including metals and alloys, ceramics and glasses, and polymers and composites.

1.2 This understanding, or materials know-how, is generally achieved through the study of how a material's chemical and physical characteristics, from the atomic level to the macro-structural (engineering) level, combine to control all aspects of a material's properties, from its ability to efficiently harvest energy from sunlight or direct bone regeneration around a hip replacement, to its suitability for use in the construction of a low impact, carbon neutral house or the International Space Station.

1.3 Key to this field is the knowledge that the route used to synthesise or fabricate a material (that is, processing) significantly impacts its chemical and physical structure, and thus the characteristics and performance of the material. Knowledge of this processing-structure-property relationship is exploited to fine tune a material's behaviour, to model its performance under specific environmental conditions, and in the discovery and design of new materials.

1.4 This Statement is primarily concerned with honours degree courses with a major materials science or materials engineering component. However, parts are applicable to interdisciplinary courses with a minor materials component and to taught master's courses with significant materials science or engineering content.

1.5 Accreditation of a particular course 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 course review process. This Statement is primarily concerned with the bachelor's degree with honours and with integrated master's degrees (for example, MEng and MSci) which are required to complete the academic requirements for the achievement of Incorporated Engineer (IEng) and Chartered Engineer (CEng) status - in accordance with the United Kingdom Standards for Professional Engineering Competence (UK-SPEC), published by the Engineering Council UK; and Chartered Scientist (CSci) status - in accordance with the United Kingdom Standards for Chartered Scientist Status, as published by the Science Council UK.

2 Nature and extent of materials

2.2 The academic study of materials links the natural sciences[2] (at length scales from nm to mm) with engineering applications (at length scales from cm to km). At the core of the subject is how the (bio)chemical composition and physical microstructure of a material can be understood and, hence, designed or controlled by processing in order to optimally fulfil an engineering application.

2.3 The range of courses to which this Statement applies, is diverse and extends from science-based to engineering-based courses.

2.4 Materials science is predominantly concerned with understanding the relationships between the microstructure and composition of a material and its physical, chemical and mechanical properties; by using tools such as imaging, characterisation and simulation. Whereas materials engineering seeks to design or optimise a particular microstructure or composition, through synthesis, processing, manufacture or modelling in order to meet an engineering or product need. Materials engineering and materials science are strongly interlinked and cannot be delivered in isolation, although a particular degree course may choose to emphasise these two aspects differently.

2.5 Materials are central to the socio-economic wellbeing of a country. Materials scientists and engineers help to develop the materials required for new products, improve and lower the cost of manufacturing routes, and enhance the performance of existing materials. They consider the environmental impact and sustainability of their products, for example, by replacing materials that rely on scarce elements or are hazardous to health. They discover how to optimise the selection of materials and create sophisticated models and databases from which properties and service behaviour can be predicted.

2.6 Materials scientists and engineers may be employed in a wide range of industrial and commercial sectors, with careers in manufacturing, research, product or process development, production management, consultancy and technical sales, as well as education. As materials science and engineering is a broad underpinning subject, materials graduates may be involved with advanced transport systems (aircraft, automotive and high-speed rail), healthcare (implant materials, diagnostic methods and medical devices), energy generation (efficient thermal, photovoltaic, nuclear, wind), forensics, high-performance sports equipment, environmental protection (recycling and pollution control), electronics (from consumer products to novel smart devices), as well as many more traditional sectors (materials production, construction, packaging and domestic goods).

[2] Principally physics and chemistry, but also increasingly some biology.

3 Knowledge, understanding and skills

Introduction

3.1 This Section describes the knowledge, skills and attributes that materials graduates are expected to possess, including reference to materials-specific aspects, background science and generic skills.

In this section, knowledge and skills are grouped into three distinct areas:

i materials related
ii science and engineering
iii generic.

Materials-related knowledge and skills

3.2 Materials courses may be general or specialist, theoretical or applied. Degree courses offered by individual providers may vary considerably. However, it is expected that materials graduates will have an awareness of the full range of materials including metals, alloys, composites, ceramics, polymers, glasses and biomaterials.

3.3 A key to the application of materials is to understand the links between structure and properties, and between processing and structure. Hence, materials graduates have the ability to choose materials, and their synthesis/fabrication routes, in order to provide desired properties.

3.4 Materials graduates are also familiar with at least a majority of the concepts under each of the following headings:

Structure

i atomic bonding, crystalline lattices, defects and disorder, amorphous materials
ii phase equilibria and phase transformations, multiphase materials, thermodynamic and kinetic aspects
iii structure on the nano, micro, meso and macro scales

Properties

iv mechanical behaviour - elastic and plastic deformation, creep and fatigue, fracture, strengthening, toughening and stiffening mechanisms
v functional behaviour - the control through composition and structure of electrical, optical and magnetic properties as well as biocompatibility

Characterisation

vi structural characterisation - optical and electron microscopy techniques, electron and X-ray diffraction, scanning probe techniques, thermal analysis
vii compositional analysis - spectroscopic methods (electron/X-ray probe/ infra-red/ultra-violet techniques), chemical analysis
viii mechanical test methods
ix techniques for determining electrical, optical and magnetic properties
x functional analysis - biocompatibility testing (acellular, cellular and in vivo), accelerated ageing, environmental wear testing

Modelling and simulation

xi computational simulation of materials across the length-scales and corresponding timescales, from atomistic (classical and quantum) to finite elements

Processing

xii materials synthesis - vapour, liquid, colloidal, powder and solid-state deposition techniques
xiii bulk processing, heat and mass transfer, and fluid mechanics
xiv joining methods, surface treatment and the application of coatings
xv layered and additive manufacturing techniques, for example, 3D printing, including the creation of 'intelligent' products by incorporating sensors and so on

Application

xvi materials design - compositional variation and processing to achieve required microstructures and, hence, properties
xvii materials selection - consideration of all material types, materials processing methods and product costs
xviii degradation/durability of materials - effect of environment upon performance, corrosion, wear and biodegradation
xix lifecycle analysis, sustainability and environmental impact.

3.5 Materials graduates will have had opportunities, through practical work, for first-hand experience of a range of techniques and materials (artefact analysis, characterisation, processing, computational simulation, testing and so on) designed to develop the ability to plan, implement and interpret experimental investigations.

Scientific and engineering-related knowledge and skills

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

3.7 Such requirements include the following knowledge and skills:

i **Mathematics**: fluency in mathematics, and familiarity with a range of mathematical and computational methods, for expressing the laws of science, for formulating and solving problems, for experimental design and for assessing and presenting experimental data including competency in probability and statistics.

ii **Chemistry**: an adequate understanding of organic, inorganic and physical chemistry to support a range of materials subjects. Thermodynamics and kinetics are essential components, alongside chemical characterisation techniques, and chemical aspects of materials production, processing, stability and degradation.

iii **Physics**: a broad foundation in physics for understanding and characterising materials' structures and properties, including solid-state physics, waves and optics, electronics, and mechanics.

iv **Engineering principles**: including design, manufacturing and processing.

v **Biology**: appropriate understanding of biology where it is required to support course which include aspects of biomaterials or tissue engineering (for example, basic cellular structure and function, protein structure, physiology, pathology, regenerative medicine and so on).

Generic skills

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

i the ability to communicate in writing, orally and using graphical representations
ii the ability to demonstrate critical thinking in reviewing the state of the art and in the analysis of experimental data both in isolation and in the context of the wider literature
iii the relevant mathematical and computational skills
iv problem-solving skills
v competence in using information technology effectively, for example, to support oral presentation, literature searches and report writing
vi the ability to work in a team and an awareness of functions required for organisational success
vii the ability to manage time, resources, projects and finances
viii study skills needed for planning, monitoring and recording continuing professional development
ix an awareness of health and safety, sustainability and environmental issues, and of ethical considerations
x entrepreneurship and an awareness of issues related to intellectual property and its protection.

3.9 In addition to the above, graduates would generally have had opportunities to tackle open-ended problems, which provide opportunities to demonstrate problem-solving skills, creativity, leadership and team working. These activities would also embed aspects of ethics, health, safety and environmental considerations.

4 Teaching, learning and assessment

4.1 Existing materials courses 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 courses covered by this Statement encompass a wide range of types of material and are offered through many modes and patterns of study. Teaching, learning and assessment methodologies are justified in terms of the learning outcomes of the course and the background of the students. The methods used are made explicit to the students taking each course, and evaluated regularly (and modified where appropriate) in response to generic and subject-specific developments.

4.2 Course design is 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 undertaking a substantial project. The course develops in graduates, both independence of thought and the ability to work effectively in a team. Where appropriate, all teaching is placed within the context of social, legal, environmental and economic factors relevant to the production and use of materials.

4.3 Methods of assessment reflect the specified learning outcomes. There is a balance between the need to assess a student's understanding, knowledge and ability for the award of a qualification, and providing appropriate feedback that fosters a student's development. Where possible, assessment methods 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 continuing personal development.

4.4 Examples of teaching and assessment methods which might be appropriate for use within materials courses are given in Appendix 1. 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 subject.

Project work

4.5 Materials graduates are expected to have carried out a group (minimum requirement for bachelor's level) or individual project (minimum requirement for master's level). These projects develop competence in investigating, managing and applying knowledge, usually in the solution of a complex materials problem. Such a project is described in a report, which demonstrates the abilities to:

i understand the published literature on the topic of the investigation encompassing both what is known and the limits of current knowledge
ii use critical analysis in the evaluation of the current literature
iii formulate the problem in appropriate terms and select appropriate methodologies to undertake investigation
iv present findings in a clear and concise manner
v analyse findings qualitatively and quantitatively as appropriate, and use appropriate statistical methods to assess the uncertainty of any quantitative results
vi critically interpret and discuss findings in the light of current knowledge
vii summarise the main conclusions and provide an accurate synopsis of the work undertaken.

4.6 Team working and experience of leadership on a project is a necessary requirement for MEng course and CEng registration according to the UK-SPEC.

Professional experience

4.7 The opportunity for students to gain experience in or about the professional environment during the degree is highly recommended. This may be acquired via speakers from industry and commerce, materials-related work placements, site visits, or participation in external projects. Materials graduates are also familiar with the organisation and structure of business, the relevant legislative requirements and ethical professional behaviour.

5 Benchmark standards

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

Benchmark standards for honours degrees

Attainment level: threshold

i 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 a lack of 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.

ii 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.

iii Project or practical work is planned and executed with reasonable success but writing up may require help to identify the full significance of the results 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.

iv Practical or relevant competence is selective but may be good in specific areas.

v Generic skills may be good in certain aspects.

5.2 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, for example, production control.

Attainment level: typical

i Understanding of the subject and techniques is good, but generally confined to the information provided in the course. 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.

ii Routine calculations, explanations, interpretations and analysis are executed accurately. Understanding of relevant facts and techniques is good. There is a fluency and confidence in the method of approach over most of the subject.

iii 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.

iv Practical or relevant competence is demonstrated over most of the range expected. The ability to innovate is demonstrated.

v Students have good generic skills and time-management ability.

5.3 After an appropriate period of professional experience, the graduate is likely to 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: excellent

i Understanding of the subject and techniques is extensive, extending beyond the information provided in the course. Knowledge and techniques are applied quickly and readily to new situations, including unseen or open-ended problems. Both the problem and the solution can be critically appraised. New knowledge is acquired quickly and accurately.

ii 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 the method of approach.

iii Project or practical work is planned, executed and written up with little assistance. There is clear evidence of critical 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.

iv Practical (or relevant) competence is clearly demonstrated. The ability to innovate is also clearly demonstrated.

v Students have excellent generic skills and time-management ability.

5.4 A graduate at this level would be a highly sought-after honours graduate. After an appropriate period of professional experience, the graduate is likely to 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.

Integrated master's (MEng, MSci)

5.5 An MEng or MSci is an integrated master's course, which provides an extended and enhanced course of study. It is usually designed with reference to UK-SPEC or the Science Council CSci standards as a preparation for professional practice and attracts the more able student. The period of study is usually equivalent to at least four years of academic learning (five years in Scotland) and the course of study is both broader and deeper than a corresponding bachelor's degree with honours and has an increased emphasis on industrial relevance.

5.6 MEng or MSci students undertake both an individual research/design project and a more wide-ranging group project with strong industrial involvement, with master's level work in the later stages of the course that is more industrially-focused or advanced specialist interest modules in the final year. MEng and MSci students also have good generic skills, with particular emphasis on critical thinking and leadership. Further guidance can be found in the Subject Benchmark Statement for Engineering.

Threshold performance for integrated master's (MEng, MSci)

5.7 MEng or MSci graduates demonstrate greater attainment in the areas of fundamental knowledge and generic skills described above. Students are unlikely to be able to progress within/onto the master's course if they do not reach at least the typical attainment level for a bachelor's degree with honours.

Appendix 1: Examples of teaching, learning and assessment methods

This appendix contains examples of teaching, learning and assessment methods which may be appropriate for specific elements of materials courses. 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
Examples classes
E-learning tools
Guided reading
Student study groups
Peer mentoring
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
Work-placement reports
Learning logs/portfolios
Project reports
Self-assessment
Peer assessments
Critical review of literature

Appendix 2: Membership of the benchmarking and review groups for the Subject Benchmark Statement for Materials

Membership of the review group for the Subject Benchmark Statement for Materials (2019)

The fourth edition, published in 2019, was revised by QAA to align the content with the revised UK Quality Code for Higher Education, published in 2018. Proposed revisions were checked and verified by the Chair of the Subject Benchmark Statement for Materials review group from 2017.

Professor Peter Haynes (Chair)	Imperial College London
Dr Alison Felce	QAA

Membership of the review group for the Subject Benchmark Statement for Materials (2017)

Details provided below are as published in the third edition of the Subject Benchmark Statement.

Professor Cris Arnold	Swansea University
Professor Zoe Barber	University of Cambridge
Professor Peter Haynes (Chair)	Imperial College London
Dr Karin Hing	Queen Mary University of London
Professor Stuart Lyon	University of Manchester
Professor Rachel Thomson	Loughborough University

Student reader

Amanda Diez Fernandez	Imperial College London

QAA officer

Simon Bullock	QAA

Membership of the review group for the Subject Benchmark Statement for Materials (2008)

Details provided below are as published in the second edition of the Subject Benchmark Statement.

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.

Membership of the original benchmark statement group for Materials (2002)

Details below are 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)

Fourth edition - October 2019
QAA2553

© The Quality Assurance Agency for Higher Education 2019
Southgate House, Southgate Street, Gloucester GL1 1UB
Registered charity numbers 1062746 and SC037786

Tel: 01452 557 000
Website: www.qaa.ac.uk