STEM-ED Scotland

Building a New Educational Framework to Address the STEM Skills Gap

A fundamental review from a 21st century perspective

Report by STEM-ED Scotland
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STEM-ED Scotland

STEM-ED Scotland is a partnership aiming to champion world class education in Science, Technology, Engineering and Mathematics

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Executive summary

This project sets out ‘a new Educational Framework’ for STEM education, up to a level qualifying the learner to progress to higher education (HE) in Scotland. The project is set in a post-school context, for learners returning to study in a college.

Context

This study was approached in a ‘green field’ spirit, building afresh without reference to current provision, using up-to-date perspectives of what is most important, and deserves most priority, in STEM education. At present, college students take either a selection of the standard school individual subject qualifications or, more often, units of school courses may be selected from a variety of levels and subjects and are then aggregated into an Access course for HE. Whichever tack is taken, the courses studied, and their assessment, are very content focused. We believe that such an approach is out-of-date and can be much improved on.

In the Scottish school system, there is a major curriculum reform under way, driven by the *Curriculum for Excellence* vision *(CfE)*. The new model developed in this project is, we believe, absolutely in tune with the basic principles underlying this reform. Our approach is skills led, it focuses on deep learning, it is learner active in style of delivery, and it adopts a broader view of learning than has been traditional. All of these characteristics are championed by *CfE*. However, particularly in its cross-disciplinary connectedness, our approach is significantly further developed than seems likely to emerge from the current review of school subject qualifications.

The principles that informed our analysis are derived from earlier work:

- the Scottish Science Advisory Committee’s 2004 publication *Why Science Education Matters*
- earlier research projects of STEM-ED Scotland, analysing
    - views of academics across Scotland’s universities
    - industry views across sectors in Scotland
    - interests and perceptions of school pupils in Scotland.

Conclusions have been reinforced through regular discussions among STEM-ED partners.

The STEM disciplines have strong interconnections. Modern science is thoroughly quantitative, and a strong mathematical underpinning is vital to understanding. Most research frontiers depend on interdisciplinary insights and collaborations, as in biomedicine, nanotechnology, environmental science, renewable energy and space exploration. Modern industry too requires cooperative working across specialisms. This does NOT mean that teachers and academics should not be subject specialists, because depth of knowledge is critical to future success. However, cross-disciplinary connections should be recognized, appreciated, and indeed highlighted.

Design principles for a new framework

The driving educational priorities adopted are:

i. to engage the learner's interest and active participation in study
ii. to build the key STEM-relevant skills
iii. to develop and progressively deepen understanding of core ideas, insights, tools and strategies
iv. to explore a wide range of specific applications reinforcing the power, reach and value of the skills and core ideas in a way that provides challenge and attainable achievement.

The main purpose of learning in this context is to support future application of the skills and understanding gained, thus ensuring readiness for further study or for progressing in a career. These priority outcomes do not include an aim to ensure the retention of fine details of the specific applications studied! Retention of detail tends to dominate current assessment regimes. In this approach assessment should be designed to demonstrate growing capability, to the learner as well as to the assessor.

We have classified and documented the STEM-relevant skills under nine headings:

S1 Learning, study, self-organization and task planning
S2 Interpersonal communication and team working
S3 Numeracy: assessing and manipulating data and quantity
S4 Critical and logical thinking
S5 Basic IT skills
S6 Handling uncertainty and variability
S7 Experimentation and prototype construction: design and execution
S8 Scientific analysis
S9 Entrepreneurial awareness

Each of these areas is considered under a series of sub-headings and for each sub-heading we have provided 'characteristic statements about the learner' that should characterize possessing the skill at a given level of study. A particular study exercise can then be audited to confirm which sub-skills are addressed.

In relation to core understanding, the sciences are treated somewhat differently from engineering, technology and mathematics. For the sciences we have reviewed 'the key explanatory models and storylines' across physics, chemistry, the biosciences and earth systems science. This is a much more detailed statement of 'the big ideas of science', which many authors have referred to and generally expressed as a concise list of around a dozen one- or two-line statements. We believe our much fuller version is much more useful for informing course design: our statements could be described as ‘ideas about the world’ expressed in a way that one would hope that a learner reaching a given level would understand. Our statements are designed to reflect the expected level of core understanding at the point of entry into higher education. In addition to all of this we also highlight one ‘idea about science’ which is about recognizing the boundary between objective scientific analysis and the subjective task of policy making.

For mathematics, engineering and for computing & information sciences we describe, rather concisely, key techniques, insights and methodologies where experience and skills should be developed by the same stage. In the case of mathematics, skills and knowledge interplay rather intimately, and our list of areas most prominent at the immediately pre-HE level has to be integrated carefully with the earlier learning referenced within our list of skills under the numeracy heading.

A specific exemplar: new *Access to STEM* course

The above approach was applied to the design of a new *Access to STEM* course, as a potential alternative to the existing *Access to Science and Technology* programmes that are run by several colleges across Scotland. These courses are accepted as preparation for entry to relevant first-year degree programmes in all universities in Scotland. Our new course is pitched to provide a suitable platform for entry to all first-year science, engineering, mathematics and computing programmes.

In terms of our full listing of key explanatory models and storylines in the sciences, it would be impractical to address every aspect in a single year’s course. They are the hoped-for destination in understanding from the whole period of 3–18 education. We propose that the full list should be a reference resource for the course. In practice we selected shorter lists of key study areas for each of the sciences to be covered in the *Access to STEM* course itself, which in effect ensures that a large proportion of the storylines are addressed, and explicitly referenced.

On the other hand we designed the course to address all of the skills areas we had identified. For mathematics, engineering and computing & information science the earlier analysis had already selected relatively concise lists of key themes to be addressed, and these were all accommodated.

We settled on a course model with 25 Units, with the full course organized to involve five cycles, in each of which a set of five Units would be studied. Each Unit is characterized by a main theme, as indicated by its title, but the way in which each is addressed is such that cross-links abound, where the same ideas or skills are applied in quite different contexts. The interconnections and interdependences of the STEM subjects, and their reliance on a common base of skills, is made evident.

An indication of the novelty of this course design can be seen from a simple list of the Unit titles.

The course design, with its 25 Units, was arrived at on ‘green field’ principles, to implement the model we had formulated and to meet the demands we had placed on it. In judging the scale of the learning effort required we concluded that the first cycle should be set at the preceding year level. This would be accommodated either within a lower-level preparation course, which is already taken by many access course students, or by well-qualified entrants being exempted, or being given a cut-down version in a short bridging course.

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Numeracy	Energy sustainability	Calculus	Statistics	Information systems
Atoms and molecules	Reactivity	Eukaryotic cells	Materials	The universe
Forces, motion, energy	Electricity	Radiation	Prosthetics	Nanotechnology
Earth processes	Equations and graphs	The human organism	Industrial chemical processes	Genetics
Ecosystems	Study of a domestic appliance	Investigation of a large infrastructure project	Commercial case studies	Analysis of a commercial application

The course would involve the learner in portfolio building and include regular formative assessment exercises. Time would be allocated for reflective review between cycles, and for final review and assessment after cycle 5.

Once the Units were fully designed we carried out a number of audits, tracking the considerable range of cross-references made to the various skills, concept lines, methodologies and themes that the course was designed to address.

Other applications of the new model and initial progress towards implementation

We have done some work in sketching how the new model might be applied in STEM courses in colleges, including in programmes geared for technical apprenticeship entry. We also make some brief and tentative suggestions about how our basic analysis, and the skills-led approach, might be adapted for higher education.

We have begun a process of dissemination, and have identified a number of potential opportunities for partial implementation. We have a forward programme for these efforts, which will continue after the publication of the Report.

We are clear that an incremental approach is sensible in implementing the new model. It involves a sea change from current practice, with lessons undoubtedly to be learned through initial piloting, albeit that considerable net benefit is anticipated. We are seeking to promote small-scale pilots initially, to test the impact of the model through single Units within larger existing programmes. We would then seek intermediate-scale implementation ahead of a full-blooded adoption of our *Access to STEM* programme.

Chapter 1: Introduction

The range, scale and pace of developments in science and technology over the past few decades is set only to accelerate in the future. This demands a fundamental reappraisal of education across science, technology, engineering and mathematics (STEM) subjects.

Education in STEM areas has traditionally followed a slow and painstaking 'knowledge ladder' model. Each discipline tends to be pursued in relative isolation, with an internalized focus on a succession of specific topics core to its own territory. Skills development typically receives much less overt attention, being perhaps assumed to happen naturally with experience, as if by osmosis. Problem solving is given a quite high profile, but in contexts dominated by a drive to achieve mastery of a range of standard short procedures directly related to specific detailed topics of study. To a large extent this sort of approach dominates STEM education worldwide.

A modern perspective places a much enhanced emphasis on development of skills, exercised across a broad range of contexts, and working from a basis of a clear understanding of key science concepts, principles and methodology. This report presents a re-thought and optimized educational framework based on such an approach. Our remit has been to do this in a 'post-school' context, considering how to structure education for learners progressing or 'returning' to study at college level, with the aim of entering university-level education in STEM subjects, and for those headed for, and beginning, employment in a technical role in industry. This remit is within the area of responsibility of our funding body. If our new model is indeed found to be successful it would be important to consider how it could be adapted to the much larger area of school education. At this stage, however, our restriction to the post-school scene is both appropriate and convenient; it considerably reduces the complexity of the task and avoids interfering with major ongoing changes to the whole school curriculum in Scotland currently following through the Government's *Curriculum for Excellence*[1] reforms.[2]

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[1] *Curriculum for Excellence* derives from a Scottish Government Report published in 2004. See: **http://www.scotland.gov.uk/Publications/2004/11/20178/45862**. For an update on progress see: **http://www.ltscotland.org.uk/understandingthecurriculum/whatiscurriculumforexcellence/index.asp**

[2] STEM-ED Scotland, through a separate on-going project, has been exploring optimum 'learning pathways' for concept and skill development across STEM subjects, in line with the Government's guidance under *Curriculum for Excellence* (see **http://www.gla.ac.uk/stem/routemapforstemeducation**). The Scottish Government is funding a small-scale project to develop a framework for progression in STEM from early years to senior

The task addressed in this project remains a large one. In order to flesh out a new model at a level of detail sufficient to support implementation, we have concentrated the major part of our effort on the full design of a one-year, full-time course, *Access to STEM*. This would prepare a learner for study at university or equivalent level in Scotland, and could provide a direct, and in our view much improved, alternative to a number of *Access to Science & Technology* courses currently run under the Scottish Wider Access Programme (SWAP). This specific framework embraces the important skills and understanding to be achieved by level 6 in the Scottish Credit and Qualifications Framework (SCQF).[3] At this level our new course should make it possible for an individual to be well qualified to enter first-year higher education study (at level 7) in any science, engineering, mathematics or computing discipline.

Such is the nature of these subjects at the start of the twenty-first century that the breadth of prior learning implied by this is widely regarded as extremely beneficial, no matter which specialism is focused on subsequently. The skills are largely generic, and they are reinforced by being deployed in a range of different subject contexts. While each discipline is associated with a distinctive set of core concepts and ideas, there is in most cases considerable overlap and applicability of these across discipline boundaries. Our model encompasses ideas in physics, chemistry, the biosciences and earth systems science, alongside mathematics, engineering and computing science.

While our major effort has been on the level 6 *Access to STEM* model course we have explored applying the new approach at lower levels (still in a post-school context) and we have also made some general comments on the follow-through to level 7 (ie for first-year university and Higher National Certificate courses in Scotland). See Chapters 7 and 8 below.

secondary level, taking two 'big ideas' in science and illustrating connectivity with other curriculum and subject areas.

[3] For detail on the SCQF model see **http://www.scqf.org.uk/TheFramework/The-Framework-Home.aspx**

1.1 The new context for education in science, engineering and technology

Science and its practical applications advance at an ever growing rate. Whole new directions of advance are triggered by developments unforeseen a few years earlier. Examples over recent times include the emergence of the internet, stem cell technologies, superconductivity and optoelectronics. Practitioners must be adaptable in re-orientating their expertise for new contexts. The cutting edge frontiers in research are in the majority of cases interdisciplinary, and industrial success generally depends on coherent exploitation of expertise from different root specialisms. In multidisciplinary teams it is widely recognized as important that the collaborating specialists should each have some broad level of understanding of the nature of the issues and constraints affecting other aspects of the whole project or process.

The Scottish Government regards it as a key strategic objective to ensure that future strength in science and engineering is at an internationally competitive level. This will not be an easy ambition to realize, as similar strategies are being embraced by very many other countries. Scotland does have an internationally strong existing university science base. It has a number of highly innovative companies, but the overall level of research and development (R&D) investment by its industrial base lags well behind many international competitors. There are concerns about the 'pipeline' of young people progressing through schooling to STEM-based careers, in terms of both the overall numbers interested in pursuing learning in 'core' science and engineering areas, and the relative proportion of the higher-level achievers from school choosing these routes. Industrialists emphasize these concerns particularly in relation to engineering. An international study has demonstrated that, the more developed a country is, the less its young people feel attracted towards science or engineering careers, the less interested they are in science, and the more sceptical they are about the benefits of science to society.[4] For a similar study in Scotland the conclusions were very closely in line with this international picture.

There are many initiatives being pursued across the world driven by an aim to improve STEM education. These overwhelmingly are partial initiatives, based on selected aspects or stages of the curriculum in specific subjects. Many observers have commented that, on a broader view, the curriculum approach is fundamentally the same in different countries, changing only very slowly and incrementally over many decades, and very

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[4] Svein Sjøberg, 'Young people, science and technology: Attitudes, values, interests and possible recruitment', ERT, Brussels, October 2008, available from: **http://www.ils.uio.no/english/rose/publications/english-presentations.html**
STEM-ED Scotland conducted this international study in Scotland, and reports are available in the section relating to 'Pupil views' at: **http://www.gla.ac.uk/departments/stem/projects/**

much focused on factual learning about the details of a long list of specific detailed topics. In Chapter 2 we document the International Review carried out at the outset of this project.

With its espousal of the *Curriculum for Excellence* vision, Scotland has created an opportunity to break out of this mould, to develop a whole new approach geared to increase interest, appreciation and understanding, and to build the relevant skills more effectively. This paradigm change will not be achieved easily, and it can be accomplished only with the active engagement of the academic and industrial communities that best understand the challenges of working at the cutting edge. Here again Scotland has an advantage in its size; it is possible to bring together the various interests in a single and representative forum to confirm and support a consensus view of what new models might look like. STEM-ED Scotland attempts to provide just such a forum.

1.2 The modern priorities in STEM education

The traditional model for science education was established over a century ago, and was heavily focused on 'knowing' in some detail about a comprehensive collection of topics believed to comprise a particular science subject or an area of application in engineering. In the modern context described above, this approach is no longer appropriate. Detailed knowledge has expanded exponentially: in the nineteenth century it was possible to be a polymath with a grasp of the frontiers across the sciences. In the early twentieth century such comprehensive detailed knowledge was necessarily restricted to the whole of a single subject discipline, and by the end of the century this narrowed further to a detailed expertise in a single sub-field.

In the modern context there are concerns that this knowledge-building focus tends to leave learners 'unable to see the wood for the trees' — among the mass of detail, key underlying principles and models may not be fully appreciated. As study flits from topic to topic, continuity and interconnecting rationale may not be recognized. Much detail is learned about specific sub-topics, and this knowledge is retained for recall at the examination at the end of a year of study, though quickly allowed to decay thereafter.

Detailed knowledge, factual data, is indeed very important in science — respect for evidence is the fundamental cornerstone of science as a way of understanding and interacting with the world. However, the expertise of a scientist or engineer depends most crucially on their understanding of underlying concepts and models, and on applying characteristic skills and methodologies. The detailed factual evidence matters, and two of the important skills needed are accessing available known relevant details, and planning and pursuing practical investigations to in-fill knowledge gaps.

Among the skills that STEM specialists require is an ability to communicate with others, first with other professionals in the pursuit of their work goals, but also to a wider audience. We live in an age where appropriate applications of science can be controversial, and where society as a whole tends to be sceptical about the value of developments in various areas and the motives of those carrying these through. Science has very important consequences for future human lifestyles and well-being, and a focus on 'science literacy' should be an important aspect of education for everybody, including those who might later become STEM specialists.

Priorities for STEM education are set out below under five headings.

(a) Engage interest and commitment to STEM studies

- Ensure an appreciation of the significance of science to the present and the future.
- Establish a recognition of the unique value of objective scientific methodology.
- Recognize that science can be applied in socially useful or destructive ways and that decisions on applications require social judgements and pose ethical dilemmas which are beyond science itself and are matters for society as a whole to judge, through informed debate.
- Communicate the level of interest and excitement felt by many professionals working in STEM fields, and seek to encourage the learner to share such enthusiasm.
- Nurture pro-active attitudes, a determination to pursue excellence, and an inclination and the confidence to show initiative.

These aims should be influential when identifying the programme of topics to be studied in a given course, and in the learning and teaching approach to be taken, as illustrated in the exemplar course described in Chapter 6.

(b) Progressively and systematically strengthen the skills required for effective practice

This is reviewed in Chapter 3 below, categorized under nine headings, Explicit detailed analysis is required to ensure that any specific course is designed to advance these skills, across all nine areas, in a balanced and effective way. Under each skill heading a table is set out, describing typical proficiency standards by means of a series of ‘characteristic statements’ for each of SCQF levels 5, 6 and 7.

(c) Introduce and steadily deepen understanding of the main explanatory concepts, models and storylines of the sciences

This is reviewed, with a particular focus on SCQF level 6, in Chapter 4 below, supported by Annex A.

- The value and appeal of the models and storylines of the sciences lie in their explanatory and predictive powers; it makes for dry and relatively indigestible education to introduce these directly and abstractly in their own right — it is much better to highlight them as aids to the understanding of specific applications.

- The study of relevant applications needs to be carefully planned to build on prior levels of knowledge and understanding; a vital aim in the overall design of a course should be to reconnect with previously introduced concepts and models, and to deepen and extend understanding of these core ideas in the course of study of the topics investigated.

- On completion of the study of an application, explicit attention should be directed to reviewing the broader concepts and models that have been visited and advanced; it is useful at this stage also briefly to refer to a range of other areas which this basic science underpins.

- Annex A has been drafted as a reference document describing the key science exploratory models and storylines, expressed appropriately for completion of SCQF level 6.

(d) Develop the techniques and methodologies that are tools of the trade for the different STEM areas

This is reviewed in Chapter 5 below, identifying strands in mathematics, engineering, computing science, and ‘Ideas about Science’ that should appropriately be addressed at SCQF level 6.

(e) Select and schedule a sequence of specific applications to be studied

- There will be many ways to implement a programme based on priorities (a)—(d) above, though it is a far from trivial exercise to design a programme that meets all of these priorities; this is explored in more detail in Chapter 6 below, where a full exemplar course is described for the *Access to STEM* course.

- The main focus for curriculum design should be to select applications likely to engage interest whilst systematically advancing the relevant range of skills and understanding.

- From the perspective of learners, the day-to-day activity of learning science and engineering will be dominated by applications addressing very specific topic areas or issues, but they should be aware that the main purpose is to understand the basic underlying concepts and approaches that are transferable to other areas, and they should recognize the latter as the substance of their education.

- Direct teaching of mathematics will tend to have a different emphasis: here the fundamental operations and tools require more focused attention. Nonetheless the basic relevance of the analytical tools developed should be brought to light by being applied to a broad range of problems illustrating their use in science and engineering (and in social subjects also).

- In teaching topics in science and engineering, the use and reinforcement of mathematical skills should be an important part of the skills development thrust.

Chapter 2: International review

There is not much existing research that is focused on re-engaging people post-school. There is much more focus on the school system, where a lot of hard thinking has been going on, with quite a diverse range of analyses and initiatives. There is a consistency in the concerns driving change, but a variety of responses.

2.1 Attitudes to science and technology

An important aim for our framework project is to engage interest and commitment to STEM studies as it has been shown that it has become difficult to attract students to this area.

A recent report[5] from the European Union expressed concern about the numbers of students entering higher levels of education to study science and technology subjects in most OECD (Organisation for Economic Co-operation and Development) countries. The report recommend that, as a way of increasing numbers, countries should try to attract more women to study science and technology. This can be done in a number of ways but one would be to modify learning and teaching approaches to make the subjects more attractive to women. For example, women are generally more interested in people and medical aspects, whereas men tend to be more interested in 'things' and gadgets.

The report also says that curricula need to be reformed and special attention paid to 15 year olds. Students need to see the relevance of what they are taught to their own world. The report recommends that courses should have more attractive and relevant contents and that teaching should concentrate more on scientific concepts and methods rather than students retaining information only. The report also stresses the development of cross-disciplinary studies especially at tertiary level.

Another report[6] surveyed the views of young people on science topics. When asked about what interested them in listed science and technology topics, almost a half showed a high level of interest in new inventions, the earth and the environment, and the human body. Young men were more interested in new inventions and technologies and ICT, while young women were attracted by subjects such as the human body and medical discoveries.

These findings are in line with the interests of 14 year olds found in the ROSE (Relevance of Science Education) study.[7]

This ROSE survey was developed by an international group led by Professor Svein Sjøberg of the University of Oslo and has been conducted in over 40 countries. It is a 250 item

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[5] Global Science Forum, 'Encouraging student interest in science and technology studies', OECD, available at:
http://www.oecd-ilibrary.org/content/book/9789264040892-en
[6] 'Young people and science', Flash Eurobarometer#239, September 2008, available at:
http://ec.europa.eu/public_opinion/flash/fl_239_en.pdf
[7] Svein Sjøberg and Camilla Schreiner, 'The ROSE project: An overview and key findings', University of Oslo 2010, available at:
http://www.ils.uio.no/english/rose/network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf

questionnaire surveying school pupil attitudes, interests and experiences relevant to the study of science and technology. STEM-ED Scotland carried out the survey[8] in Scotland in 2006 obtaining responses from more than 2,700 students in 95 schools. The results were broadly in line with those obtained from other developed nations. The questionnaire contained a large section of 108 questions on what students found interesting in science.

When asked what they wished to learn about in science, there were marked differences in the responses of boys and girls. For girls, the priorities lay with topics related to the self and, more particularly, to health, mind and well-being. The responses of the boys reflected strong interests in destructive technologies and events, and in outer space. Topics such as 'Famous scientists' and 'How crude oil is converted into other materials' were among the least popular with both boys and girls.

While the ROSE survey focuses on 14 year olds it appears that interests do not subsequently alter much with age, and that the interests of men and women in relation to science continue to be different. The differing interests of men and women in science topics need to be taken into consideration when trying to motivate students and increase their interest in the sciences.

[8] 'The ROSE Survey in Scotland – An Initial Report', available at: **http://www.gla.ac.uk/media/media_51342_en.pdf**

2.2 Curriculum developments

We investigated various curriculum developments from the UK and around the world to see if they were relevant to our project, either because an appropriate STEM framework had already been devised or to see what ideas we could gather from inspection of different approaches to curriculum development. A few of the most interesting developments are given below.

2.2.1 UK developments

Two developments were of interest in the UK: the GCSE course Twenty First Century Science and the 14—19 Diplomas in Science and Engineering.

GCSE Twenty First Century Science

Twenty First Century Science grew from the recommendations of the 'Beyond 2000' report,[9] which argued that the compulsory science curriculum should be designed to develop the scientific literacy of future citizens. It also recommended that a separate but parallel course was needed to prepare students who wished to progress to a career in science.

Twenty First Century Science has been designed to cope with the whole student range and this has been done by offering all students a Science GCSE course which is designed to develop scientific literacy. Those who wish to further their studies to A-level can take one of two additional modules, Additional Science or Applied Science. The Additional Science course, when taken with the Science module, gives progression to A-levels in the sciences. This course emphasizes the fundamental concepts in science. The Applied Science option encourages students to develop their practical scientific capabilities and can lead to more advanced courses and careers in technical fields.

In Twenty First Century Science, to be scientifically literate, students need to have an understanding of the *Ideas about Science* and *Science Explanations*.

[9] 'Beyond 2000' report, available at: **http://www.kcl.ac.uk/content/1/c6/01/32/03/b2000.pdf**

Ideas about Science shows how science works and is organized under the following headings:

- Data and its limitations
- Correlation and cause
- Theories
- The scientific community
- Risk
- Making decisions about science and technology

Science Explanations helps students to make sense of their lives. It consists of the following topics:

Chemicals
Chemical change
Materials and their properties
The interdependence of living things
The chemical cycles of life
Cells as the basic units of living things
Maintenance of life
The gene theory of inheritance
The theory of evolution by natural selection
The germ theory of disease
Responding to stimuli
Energy sources and use
Radiation
Radioactivity
The Earth
The Solar System
The Universe

The GCSE Twenty First Century Science course consists of nine modules (shown below) and each module contains a map showing how the *Ideas about Science* and *Science Explanations* develop in the module story, and in related modules.

- B1 You and your genes
- C1 Air quality
- P1 Earth in the Universe
- B2 Keeping healthy
- C2 Material choices
- P2 Radiation and life
- B3 Life on Earth
- C3 Food matters
- P3 Radioactive material

The course has been designed to involve students in practical work and to debate ethical issues. Initially the course had mixed reviews and there were complaints that the subject had been 'dumbed down'. Recently a more comprehensive review was carried out and this gave more encouraging results. The survey showed that schools using the course saw an average increase of 30 per cent in the number of students taking AS-level biology, 24 per cent for chemistry, and 38 per cent for physics in 2008.

While this course concentrates on science literacy and gives links between the different sciences, by its very nature, it does not include any aspects of technology or engineering. It also appears to take a very non-mathematical view of the sciences. It is however being updated constantly.

14—19 Diplomas in Science and Engineering

The Diploma is a qualification for 14—19 year olds and has been available in schools and colleges since 2008. It is available at three levels: Foundation, Higher and Advanced. Diplomas were introduced by the last government to provide academic learning in a vocational context with the aim of motivating students who prefer a more work-related learning style. They cover subjects like engineering, construction, business, and travel and tourism but students must also pass a test of 'functional skills', covering numeracy and literacy.

The Diploma in Engineering sits alongside the traditional educational pathways of GCSEs and A-levels. It offers students an alternative route of study, blending classroom-based learning with work-related practical experience, allowing students to keep their options open.

Students studying the Diploma will understand how to apply theory and practice and be able to make informed decisions about their future. The qualification introduces students to some of the key themes of engineering and gives them an understanding of basic engineering principles.

The Diploma:

- equips students with essential skills to prepare them for work and continuing education
- is a challenging qualification valued both by industry and by education
- provides flexibility and choice and gives students a variety of study options.

Diploma students also develop a good standard of English, mathematics and ICT (information and communications technology), as well as other skills, such as teamwork and self-management. In Years 10 and 11 they will study other compulsory subjects such as science and physical education alongside their Diploma.

The Diploma in Engineering is popular with schools and colleges as well as with students, and new figures, recently published, show that students applying to university in summer 2010 via the Diploma route did as well as others in winning places. It has, however, been suggested that the present government may cut the funding required for these courses and this may mean that they can no longer be offered.

Science Diplomas were in the process of being developed during the period of the last government and there had been wide consultation with industry bodies and societies on the proposed content. Several critical comments were received about the Advanced Diploma, particularly from the Royal Society of Chemistry. Development of 'academic' Diplomas in science, modern languages and humanities has now been abandoned.

2.2.2 Developments in the US and Canada

Developments in the science curriculum in the US focus on scientific literacy and the search for one or more unifying themes. It is hoped that these unifying themes will aid student understanding and reduce the amount of factual material that needs to be acquired.

Three US developments were looked at:

- Physics First
- National Science Education Standards
- Benchmarks for Science Literacy

Achievement test results from the Third International Mathematics and Science Study (TIMSS) and the US National Assessment of Educational Progress (NAEP) suggested that the performance of US students in science was not strong in terms of either international or national standards. Yet the US is regarded as a world leader in standards-based and 'hands-on' science reform. William Schmidt of Michigan State University, and United States Research Coordinator for TIMSS, says that the major policy issue confronting the science community that addresses this apparent disconnect is the development of an organizing principle that would serve to limit the number of essential topics being taught. He argues that this organizing principle would weave the reduced set of topics into a sequence that is logical and that leads to an unfolding of a key story or stories in science that are intrinsically interesting to students and that provide the basis for understanding science and not just the memorization of isolated facts to be forgotten when school finishes. He came to this conclusion by looking at the science curricula from countries which had scored highly in TIMSS, such as Finland, Singapore, Japan and the Czech Republic. He found that they tended to introduce only a few topics early in primary school and then developed these progressively through the different stages of schooling at the same time as adding new topics.

This plea for a coherent science curriculum which is relevant to student interests and produces science-literate citizens is supported by many other people in the US and elsewhere.

Physics First

To improve science education, Schmidt and others believed that high schools needed to overhaul their current curricula. One such plan for reform was the Physics First curriculum, a strategic plan that reverses the order in which schools traditionally teach science.

Leon Lederman, a Nobel laureate and former director of Fermilab, was part of a group pushing science education reform called Project ARISE (American Renaissance in Science Education), who published a proposal aimed at reforming high school education through the Physics First curriculum. Not surprisingly, their plan heavily emphasizes the scientific method.

In the Physics First curriculum, high school students learn about the scientific process and explore real-world phenomena such as photosynthesis and gravity, giving them basic knowledge that will help them even if they do not pursue a career in the sciences. In addition to emphasizing the scientific process, as its name suggests, in the Physics First curriculum students learn physics before chemistry and biology. Lederman argued that true understanding of biology requires knowledge of chemistry, which in turn requires physics knowledge; he believes a physics-first curriculum fosters coherence in education, allowing students to build upon what they already know. This approach has been piloted in several schools but it has proved difficult to evaluate effectively.

National Science Education Standards

The search for a unifying concept in science has been taken up by other organizations in a bid to rationalize the science curriculum.

The US National Science Education Standards have been designed to produce a scientifically literate society. Founded on exemplary practice and research, the Standards describe a vision of the scientifically literate person and present criteria for science education that will allow that vision to become reality.

The National Science Education Standards outline what students need to know, understand, and be able to do, to be scientifically literate at different grade levels. The Standards rest on the premise that science is an active process. Learning science is something that students do, not something that is done to them. 'Hands-on' activities, while essential, are not enough. Students must have 'minds-on' experiences as well.

The Standards call for more than 'science as process', in which students learn such skills as observing, inferring and experimenting. Enquiry is central to science learning. When engaging in enquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills.

The course rationale has eight categories of content:

1 Unifying concepts and processes in science
2 Science as enquiry
3 Physical science
4 Life science
5 Earth and space science
6 Science and technology
7 Science in personal and social perspectives
8 History and nature of science

Conceptual and procedural schemes unify science disciplines and provide students with powerful ideas to help them understand the natural world. Unifying concepts and processes include:

- Systems, order, and organization
- Evidence, models, and explanations
- Change, constancy, and measurement
- Evolution and equilibrium
- Form and function

Categories 3—6 give details of what is covered in the sciences and also some aspects of technology. The standards are broken down into the different levels from kindergarten to Year 12.

It is hoped that by using unifying concepts students will see common themes which occur in different science areas.

Benchmarks for Science Literacy

The Benchmarks for Science Literacy, Project 2061, American Association for the Advancement of Science,[10] have identified very similar common themes to the National Science Education Standards, and the two schemes are very similar.

Mind maps

There is a website[11] called Hyperphysics, hosted by the Department of Physics and Astronomy at Georgia State University, which offers very useful concept maps in the sciences and mathematics. It shows the links between topics and develops these in a logical way. It also gives information on the different topics in 'hypercards'. Although the website is called Hyperphysics it also gives comprehensive mind maps for chemistry, biology, earth science and mathematics.

Science curriculum in Ontario, Canada

The school curriculum in Ontario, Canada, seemed to offer some interesting features as it links together technology and science and also provides links to mathematics.

The goal of the programme is to produce a scientifically and technologically literate person.

To help integrate scientific and technological knowledge with knowledge in other areas such as mathematics, fundamental concepts provide the framework. These fundamental concepts are: Matter, Energy, Systems and Interactions, Structure and Function, Sustainability and Stewardship, and Change and Continuity. 'Big ideas' are defined as the broad important understandings of science and technology, and in this model these

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[10] http://www.project2061.org/publications/bsl/default.htm
[11] http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

big ideas describe aspects of the fundamental concepts. The Science and Technology curriculum is organized in four strands: Life Systems, Structures and Mechanisms, Matter and Energy, Earth and Space Systems, and specified for grades 1—8. In each grade there is a table showing the fundamental concepts being looked at along with the big ideas. For example, in grade 8 for 'Understanding Life Systems — cells' the fundamental concepts being considered are Systems and Interactions, and Structure and Function. A sequence of ideas being developed is: cells are the basis of life; cells organize into tissues, into organ systems, and organ systems into organisms; healthy cells contribute to healthy organisms; systems are interdependent.

The approach here has similarities to US programmes in that they both look for common overarching themes as a means of integrating and holding big ideas together. What is not clear from any of these approaches is how effective they are.

2.2.3 Developments in other countries

Singapore

Students from Singapore perform well in international school surveys for science and so we investigated the curriculum that had been developed there.

The Singapore science curriculum is based on a spiral model where concepts introduced at the primary level are treated in increasing depth at the lower secondary level, and then at the upper secondary level.

The science syllabus is organized into six main themes: Diversity, Cycles, Energy, Interactions, Models and Systems, and Measurement.

There is also a Science as Enquiry framework, which is incorporated into the other themes. In the overview of the syllabus there is a table which lists the topics to be covered in each of the six themes. There is also a third column titled 'white space'. This 'white space ' takes up 15 per cent of curriculum time and is to enable the teacher to make learning more meaningful and enjoyable for their students.

This thematic approach is similar to those in the US and Canada but the themes chosen seem to give a better fit to the chosen science topics. In Models and Systems, models of cells and matter are given and plant and human systems are covered.

Finland

Finland is another country that performs well in TIMSS and PISA (Program for International Student Assessment); it has several unique features in its education system.

- According to the OECD, Finnish children spend the fewest number of hours in the classroom in the developed world. The principle here seems to be ‘Less is More’.

- Primary and secondary schooling is combined: the pupils don't have to change schools at age 12 so they avoid a potentially disruptive transition from one school to another. They also may keep the same teacher for a number of years.

- Children in Finland do not start main school until age seven. The idea is that before then they learn best when they are playing, and by the time they finally get to school they are keen to start learning.

Finnish parents can claim some credit for the impressive school results. There is a culture of reading with the children at home, and families have regular contact with their children's teachers.

Teaching is a prestigious career in Finland. Teachers are highly valued, and teaching standards are high.

The educational system's success in Finland seems to be partly cultural. Pupils study in a relaxed and informal atmosphere. There is an emphasis on relaxed schools, free from political prescriptions. This combination, it is believed, means that no child is left behind.

The Finnish government drew up a basic framework curriculum for compulsory education and this serves as the basis for school curricula, which are drawn up by local education authorities and individual schools. The guidelines contain only the general educational aims and basic contents. Consequently, the responsibility for teaching arrangements, exact course contents and the selection of teaching materials has been passed down to the local level, giving schools the opportunity to cooperate with each other, increase the educational resources needed in their respective areas and meet the students' individual needs.

The Finnish system seems ideal but its success may be due to cultural reasons rather than the school curriculum. However, the system empowers teachers and gives them a lot of freedom in what is actually taught and the method in which the curriculum is delivered.

It should be added that the Finnish government is as concerned as other OECD nations that young people seem to be turning away from studying science and technology, both in upper secondary and in higher education.

2.3 Opinions from industry and the universities in Scotland about STEM education

In the past we have sought the views of universities[12] and STEM related industries[13] in Scotland on what they are looking for in students entering higher education or employment. We consulted every university in Scotland and interviewed people in over 50 companies representing the STEM sector, in addition to consulting the views of Sector Skills Councils, professional societies and institutes. The views of the universities and the industrial sector were remarkably similar, although the universities were more specific in their views. These two surveys gave us a very comprehensive idea of what was required in the development of an educational framework for STEM subjects.

The university views are summarized below:

- The universities strongly favour a less crowded, less assessment driven and more flexible curriculum for all levels of science courses, aimed to liberate and enthuse both teachers and learners.
- Developing personal study and work attitudes is important and needs to be considered in curriculum design.
- Building key scientific skills should be a much stronger focus across the range of STEM subjects in school.
- Mathematics provides a vital underpinning to students wishing to study STEM subjects at university, and skills in mathematics should be developed and reinforced in the science curriculum.
- The science subjects at school are viewed as overloaded and lacking in obvious relevance to everyday life; the universities recommend clarified and driving aims for school science education.
- It is important to build understanding of the core principles of the sciences: more themed or applications-led approaches could be considered; more extended practical work and more in-depth and open-ended activities should be introduced.

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[12] 'The school to university transition in science, technology, engineering and mathematics subjects', STEM-ED Scotland, available at **http://www.gla.ac.uk/media/media_51344_en.pdf**

[13] 'Industry and the school curriculum across science, technology, engineering and mathematics', STEM-ED Scotland, 2007 available at **http://www.gla.ac.uk/media/media_51341_en.pdf**

The industry views are summarized below:

- The single most important concern of employers is to improve the attitudes of young people towards the world of work. Commitment to work, initiative, self-confidence, perseverance and a creative approach are seen as qualities that should be nurtured through school.
- Successful recruits need to engage readily with, and show respect for, work colleagues and supervisors, while also being prepared to take personal responsibility and independent action.
- There is considerable concern that the nature and significance of engineering, the importance of industry and the fulfilling and well-rewarded careers available are rarely appreciated and seem not to be reflected in careers advice.
- Next in priority is to enhance basic and transferable skills, notably of numeracy, literacy and both oral and written communication.
- Better developed technical and practical abilities are sought.
- Valuable employees require also to have well-developed problem-solving, team working and planning skills.
- Employers urge that every effort should be made to improve capabilities in basic mathematics.
- They are alarmed about decreasing trends in numbers studying sciences and about the very low exposure of engineering in schooling. They believe that all young people should gain some understanding of engineering and of the impact of science on life.
- Priority should be given to developing a breadth of understanding of basic knowledge and to an ability to apply this in new contexts.

2.4 What conclusions can we draw from this?

1 There seems to be worldwide concern about the numbers of young people who are not interested in pursuing a science/technology career, and there are several initiatives being undertaken to help remedy the situation.

2 Countries want their young people to be scientifically literate and have tailored school curricula to encourage this.

3 There is a move away from very factual based curricula with more emphasis being placed on the big ideas, and students being able to apply these ideas and concepts.

4 There are attempts in many countries to integrate subjects and topics to show inter-relationships. This has been done in a number of ways, but one of the most popular is using unifying concepts or themes.

5 There is an increasing emphasis on a skills-based curriculum as opposed to a solely knowledge-based one.

While most of the curricula examined were for students in school rather than in further education, the information gained from our review, in relation to our STEM skills project, is that any course we design should:

- be geared to motivate and inspire students
- emphasize the big ideas rather than be cluttered with a large amount of factual material
- be skills driven, with an emphasis on problem solving and the ability to apply knowledge in new contexts, developing organizational and planning skills and the ability to work as part of a team
- provide links between topics and integrate themes where possible
- build skills and knowledge in a progressive manner throughout the curriculum
- be relevant to the world today.

It is important to build understanding of the core principles of the STEM subjects: more themed or applications-led approaches could be considered; more extended practical work and more in-depth and open-ended activities should be introduced.

In short the framework must be designed to engage the learner, to highlight skills development on a broad front and to focus on the big ideas in STEM.

Chapter 3: The skills set to be nurtured

There are many ways of classifying skills. The approach taken here is designed to suit the context of developing capability for learning and working in STEM fields. While it is important to focus on and to emphasize skills as an educational thrust distinct from knowledge and understanding, there is in reality a degree of overlap. For instance, the elementary numeracy skill of addition depends on facile recall of ‘number facts’ (eg we recall from memory that 4 + 3 = 7 without having to ‘count out’ such a sum each time). Equally, skills of scientific analysis cannot be exercised without using an understanding of key scientific models and ideas.

STEM-ED Scotland’s earlier research projects with universities and with industry[14] both revealed a widely shared view that identified the issue of developing appropriate attitudes as of foremost importance, and as a prerequisite to progress on all other fronts. The consensus was that a range of operational and analytical skills were the next key priority, ahead of specific detailed knowledge.

In the published *Skills for Scotland: A Lifelong Skills Strategy*[15] there is a list of the skills regarded as relevant. The attitudinal and motivational issues that we identify and prioritize in our own work are effectively encompassed within this list under ‘personal and learning skills’, ‘employability skills’ and ‘the ability to work with others to achieve common goals’. In this work we adopt this wider interpretation of skills, to include attitudinal and motivational aspects.

Our project aims to address what is widely referred to as ‘the STEM skills gap’, and our proposed framework gives a very high profile to a wide range of ‘skills’, developed and deployed in a STEM context. This approach requires, first, engaging interest and, second, developing and applying an understanding of a range of key scientific and technical concepts and methodologies.

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[14] STEM-ED projects with (a) universities at **http://www.gla.ac.uk/media/media_51344_en.pdf** and (b) industry at **http://www.gla.ac.uk/media/media_51341_en.pdf**

[15] *Skills for Scotland: A Lifelong Skills Strategy*, 2007, p. 8: see **http://www.scotland.gov.uk/Publications/2007/09/06091114/0**

For STEM education we have found it useful to analyse skills development under the following nine headings:

S1 Learning, study, self-organization and task planning
S2 Interpersonal communication and team working
S3 Numeracy: assessing and manipulating data and quantity
S4 Critical and logical thinking
S5 Basic IT skills
S6 Handling uncertainty and variability
S7 Experimentation and prototype construction: design and execution
S8 Scientific analysis
S9 Entrepreneurial awareness

Different individuals will have different relative aptitudes. Success in science and engineering is driven by excellence, and it is as important to encourage the further enrichment of skills in which an individual has already shown relative strength as it is to bolster up their areas of relative weakness. It is not therefore sensible to regard skills training as appropriate only up to the point of achieving set minimum threshold levels under each skills heading. In science and industry workplaces, team collaboration is required, and different front-line skills are called for in different key operational roles.

Each of the skills areas is reviewed below. Given that our approach to STEM education gives high priority to building skills, it is important to indicate the levels of skills competence it is thought reasonable to achieve, in a way that demonstrates appropriate progression. To this end, under each skills strand, we list a series of 'indicative characteristic statements' describing capabilities judged appropriate for courses at SCQF levels 5, 6 and 7. The national SCQF specifications, intended to apply across all areas of education, give general statements describing the different types of context in which a given skill is demonstrated, typically referring to 'simple tasks' at level 5, 'more complex situations' at level 6 and 'contexts requiring pre-planning' at level 7. While our own statements demonstrate a similar progression to greater complexity we have not adopted the generalized wording. First, it is our **overall course** that is designed for a particular SCQF level. Second, our coherent emphasis on the matrix of skills relevant for STEM practice means that we should naturally aim to reach a higher level in the application of, for example, skills in numeracy and analytical analysis. Third and most important, the aims and programme for the exemplar course laid out in Chapter 6 are designed in the light of what we believe to be achievable for students who enter appropriately qualified at the preceding level.

Skills are enhanced by being practised, and skills development should be embedded within core subject learning: it constitutes a primary purpose of the whole educational process. We believe it is not productive formally to assess each skills category separately, in isolation. Courses should be designed with skills development clearly in mind, and to exercise all aspects during the programme of study. Learners should be encouraged to recognize the key importance of skills and to be conscious of progress and of areas of relative strength and weakness.

S1: Learning, study, self-organization and task planning

At root level, skills in this area are particularly dependent on attitudes and motives. Learning is best driven by 'thirst', implying interest and engagement. Deep learning is learning that can be applied and built on, into the long-term future, whereas surface learning is what is achieved when the primary motive is to regurgitate particular details or standard tasks at the next examination.

To embrace this area, course design should:

i. be geared, as far as possible, to excite interest and to be seen as relevant for the longer term
ii. include signposting (what is about to be studied, and why it is relevant to study it) and retrospective reflection (what has been learned, where this can be useful in future, and its wider significance)
iii. involve predominantly active learning, requiring information to be organized and tasks to be planned
iv. include formative feedback, involving self-evaluation (or sometimes team-based evaluation) and tutor reviews
v. involve the learner in self-constructed, carefully organized, and critically reviewed, summary documentation of key knowledge and techniques.

S1: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i	is fully engaged in tasks	exercises initiative in pursuing study tasks	
ii	recognizes relevance of existing knowledge to new contexts		is pro-active in identifying relevant previously acquired knowledge
iii	organizes relatively limited and well-signposted information; plans approach to well-defined tasks	seeks out, assesses the relevance of, and organizes effectively, more complex information	plans, sometimes with others, relatively complicated and open-ended tasks
iv	recognizes progress made in learning, and areas for improvement	notes and builds on relevant past understanding, when beginning study of a new topic	recognizes the likely value of learning achieved in supporting future study
v	produces coherently expressed conclusions from tasks completed		makes increasingly thorough critical reviews of conclusions from study

S2: Interpersonal communication and team working

Communication and team working are critical areas for practitioners that tend to be seriously under-played in courses dominated by preparing for traditional formal exams. It is important therefore to incorporate team investigations into a course. These exercises are useful also in developing scientific methodology and broadening understanding. In this context it is important to give explicit attention to the working mechanics of a team:

i. initially agreeing roles and planning the investigation process and schedule
ii. ensuring that the plan includes intermediate dialogue and review meetings
iii. nurturing positive interactions across the team, aiming for excellence in accomplishing the task
iv. at the end of a study, reflectively reviewing how the team has performed and how effectively each individual has contributed.

Team working is a very useful context in which to develop interpersonal communication skills, but it does not necessarily capture all important aspects. Also important to pay attention to more generally are:

v. communicating information effectively, orally or in writing, to a third party or group
vi. interpreting information or advice from a third party, and responding appropriately
vii. questioning, discussing and clarifying a topic with another party.

S2: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i—iv	participates in teamwork, paying attention to all four aspects — applied to relatively simple exercises, with significant briefing supporting the task; fronts a section of a team presentation coherently	progresses in skills levels towards the level 7 goals, with the tasks set designed to 'stretch' capabilities steadily	becomes steadily more competent in contributing, in different roles, to team tasks of increasing complexity; gains more experience of presentation, and responds cogently to questioning and in interview discussions with a tutor
v	*note that presentation and report writing skills are also referenced under S1(v), S4(ii), S7(vi) and S8(v): here we pick out a dispositional skill underlying most of the other aspects:* engages positively and sensitively with third parties in attempting to convey and explain information		
vi	follows clearly specified instructions successfully	asks relevant questions to clarify instructions or advice on tackling a task	works up a task specification provided in summary form, fleshing out intermediate steps
vii	asks for amplification when uncertain about an explanation given	contributes actively to a discussion, seeking to put together different aspects of a topic	probes the wider significance of information provided, and contributes to dialogue developing deeper or broader understanding

S3: Numeracy: assessing and manipulating data and quantity

Numeracy has been variously defined. In the Scottish *Curriculum for Excellence,* for schools, the term has been interpreted almost as a synonym for 'arithmetic'. Universities and employers would take a broader view, and in a science context in general this would seem more appropriate. In more detail we will regard 'numeracy' skills as embracing:

i. confidence in dealing with information on a quantitative basis
ii. facility and accuracy in arithmetical processes and in basic algebraic manipulations
iii. comfort in recognizing scale and the relative significance of dominant relative to more minor influences on behaviour; also comfort in applying arguments of scaling through proportion
iv. abilities in interpreting information and deriving key conclusions from data presented in tables or in graphs or diagrams; also ability to present data in suitable ways using these forms
v. comfort in using equations to model relationships and to make predictions
vi. basic familiarity with elementary geometry, angles and coordinates.

'Critical and logical thinking' and 'handling uncertainty and variability' are also important skills that could be classed within numeracy but which also deserve separate listing below.

Course design should ensure that all of the above strands are exercised. In the main this will result in the skills being strengthened, and applied with more confidence, through frequent use. Generally, numeracy will be presented within the context of science or engineering topics under review. It is important that there should be provision for enhanced individual support, where necessary. In most instances the main burden on such special support will be to build the learner's self-confidence in working with information systematically and carefully.

S3: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i	habitually looks to include quantitative information in studies across STEM; takes care consistently to quote the units when giving values for quantities	quotes values with the number of significant figures appropriate to the context; quotes values with an estimated uncertainty range as appropriate	uses these skills widely in the more complex curriculum context
ii	carries through the whole range of arithmetic operations with reasonable confidence; applies the rules of algebra when manipulating expressions and equations	through practice becomes both efficient and securely accurate in both arithmetic and algebraic manipulations	uses mature skills routinely, in the more complex contexts met in the disciplines being studied
iii	uses scientific notation comfortably; applies scaling involving direct proportion	accurately handles calculations involving quantities expressed in scientific notation, including handling of unit prefixes; handles cases involving multiple and complex proportion (where relationships involve inverse proportion or other powers)	uses mature skills routinely, in the more complex contexts met in the disciplines being studied
iv & v	identifies trends and anomalies in tabulated data or graphs; plots graphs of data suggestive of a linear relationship, and hand-draws best line of fit; solves pair of linear equations involving two unknowns	derives relationships fitting trends in data; constructs suitable graphs or tables to present data and inter-relationships clearly; can estimate the gradient of a tangent to a curve, and the area under a segment of a curve; makes estimates involving interpolation and	extends skills in these areas by applying them in more diverse and complex contexts, eg: • logarithmic plots • handling multiple equations in problem solving

	by SCQF level 5	by SCQF level 6	by SCQF level 7
		extrapolation, with some judgement of an error range; finds the equation for a hand-drawn straight-line graph; manipulates equations to change the subject and to cross substitute into other equations	
vi	uses ‘*x*, *y*’ Cartesian coordinates comfortably in applications (eg mapping); applies relationships between angles in triangles and involving intersecting or parallel lines; can relate the trigonometric functions sin, cos and tan to ratios of the sides of right-angled triangles, and to projections on to Cartesian axes; uses Pythagoras’ theorem via the 2D distance formula	reinforces these skills and develops them forward as described through the level 6 mathematics agenda, applied routinely to scientific and engineering contexts	carries the skills to more complex contexts, eg: • distance formula in 3D • polar coordinates

S4: Critical and logical thinking

Critical and logical thinking can be regarded as perhaps the single most fundamental intellectual tool that characterizes scientific and mathematical thinking. It underlies scientific analysis and is a key ingredient of problem solving. It can be described under a series of sub-headings:

i. extracting the sense of an argument or explanation expressed in a text source
ii. describing observations, explaining a concept or making an argument in a clear and well-organized way, orally or in writing
iii. applying logic to deduce conclusions from evidence, or in formal mathematical proofs
iv. identifying weaknesses and contradictions in arguments and explanations, and identifying where there might be significant missing information
v. carrying through standard mathematical manipulations for a set purpose, as in rearranging an equation to change its subject

Critical thinking skills are very important and should feature centrally in assessment: this requires reasonably extensive and relatively ‘open’ examination questions.

S4: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i—v	The major difference between the different levels will be in the sophistication of the studies and exercises undertaken. It should be a prime factor in setting the depth of study of topics and the complexity of tasks set, and also in designing assessment, that the level of demand on each aspect of these skills is appropriately exercised across a course.		
i	re-expresses the argument of the text studied in their own words	handles rather longer texts and applies some judgement to summarize the key points	writes or presents a clear précis summarizing the key points made
ii	writes clear reports of simple experiments, explaining the purpose, setting out observations, and deriving the conclusions	makes good contributions in a team context, towards building a well-argued joint report or presentation	produces well-structured more extensive reports, including references to source materials as appropriate and a critical assessment of conclusions
iii	identifies successive steps for solving an appropriate level of a multi-step problem	rehearses some examples of formal proofs in mathematics, including proof by induction (not intended for formal exam testing); shows a strategic approach to problem solving, founded on logical analysis	in contributing to scientific debate or discussion with others, makes arguments that are clearly rooted in a logical analysis of the issue at stake
iv	recognizes situations where more than one scientific explanation might apply	suggests studies that could add new information that might resolve a conflict between alternative explanations; identifies cases where unsound scientific conclusions may have been reached because of unjustified assumptions or factors overlooked; recognizes that scientific models may have a limited range of applicability (eg ideal vs real gases, Newton's laws vs motions within atoms and across space)	critically analyses conflicting accounts of a controversial area where different scientific explanations have been propounded
v	applies the numeracy skills levels described under S3(v) strategically in problem solving		

S5: Basic IT skills

Under this heading we group basic capabilities in using a family of standard IT packages as tools in other studies. Nowadays most learners acquire a large proportion of these skills outside of formal education, and if teamwork is undertaken, further reinforcement is likely through peer interaction. It is important, however, to be able to provide bespoke help where this is needed. This applies to:

i. basic computer operation, including file handling, directory organization and downloading
ii. basic word processing, internet searching, presentation software and emailing.

More structured attention is likely to be required in:

iii. use of a spreadsheet package, applying formulae and functions and generating plots
iv. use of specialized graphics packages where required (eg computer aided design (CAD), molecular modelling).

S5: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i & ii	has basic proficiency in all areas mentioned	uses skills as required	uses skills as required
iii	can use a spreadsheet in simple applications to tabulate, rearrange and sum data	can effect data manipulations involving a range of formulae, and produce standard charts and graphs	applies spreadsheet skills in more complex ways, eg deriving the equation for a linear regression fit to data
iv		can use relevant packages after receiving briefing (note that understanding the principles of data transfer between a computer and external equipment is covered in the computing and information science component of the course – see Section 5.3 below)	

S6: Handling uncertainty and variability

Historically this area has been much neglected in STEM education. Study has tended to focus almost exclusively on well-established areas, where the behaviour of a given system fits a simple model and is consistently reproduced accurately, so that for every problem or experiment studied there is a predictable and 'right' answer. It is generally recognized that experimental measurements are subject to errors depending on the equipment and techniques employed, but the traditional emphasis has been on what the 'true' result 'should' be. At the frontiers of science, and particularly in many of the complex issues that feature in public debate, modelling of the science is much more uncertain. Also, in very many new potential applications of science there are risks to be balanced against benefits. Statistical analysis is important in understanding the reliability of artefacts or the variability of characteristics across a population, and in analysing random experimental error.

Probability and statistics have traditionally been introduced relatively late in mathematics education, in a rather general and abstract context where they are often found rather difficult. There is an important job to be done here to introduce ideas of uncertainty and variability in the context of science and engineering applications, and to link this to treatment within mathematics. Aspects include:

i. basic examples involving random events and their probabilities
ii. examining risks from data such as rates of incidence of specific diseases or accidents
iii. ranking risks from severe through significant to negligible
iv. making judgements that require balancing risks against benefits
v. analysing reliability and breakdown data for manufactured equipment, and design issues
vi. recognizing the inherent variability within samples and in populations
vii. recognizing that experimental measurements are subject to random and systematic error
viii. understanding the basic idea of a statistical distribution, and ideas of mean, median, mode and standard deviation
ix. recognizing that scientific modelling of complex situations can carry inherent uncertainties (eg weather forecasting).

S6: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i—iv	accurately uses the concept of probability in simple contexts and recognizes that risk assessment involves consideration of the probability and the severity of the event's occurrence	carries through quantified risk assessment exercises for practical activities, and discuss risk versus benefit issues for a technology development	describes and defends a quantitative risk assessment exercise for an engineering project
v		contributes to a case study involving the reliability of a product	routinely considers reliability in a design exercise
vi—viii	recognizes the uncertainties inherent in studies of samples and in experimental measurements, and makes broad estimates of the impact of this on conclusions reached	includes error estimates where appropriate when reporting experimental results, using mean and standard deviation; **note crossover to ongoing Mathematics development (Section 5.1)**	carries through some basic tests of statistical significance (eg *t*-test); **note crossover to ongoing Mathematics development (Section 5.1)**
ix	contributes in a balanced way to a general discussion of the uncertainties in a given scientific prediction	participates in an objective way to a reasonably detailed analysis of alternative scientific predictions (eg in climate modelling)	routinely comments, in a technically sound way, on uncertainties when reporting conclusions

S7: Experimentation and prototype construction: design and execution

A good and varied experience of practical work, involving experimentation in the sciences and construction of physical models and graphic diagrams in engineering, needs to be a significant feature in STEM education at any level. Over a course, exercises should be designed to:

i. reinforce study by observing real-life scenarios in operation
ii. engage learners in some pre-planning and design for exercises
iii. give some appreciation of, and practice in applying, the technical and craft skills involved in careful execution of the task, aiming for maximum accuracy and precision
iv. require careful observation and recording of outcomes
v. involve a reflective review of the resulting conclusions, and their accuracy or reliability
vi. require report writing and critically review.

There is a place for practical demonstrations in science, and these can be very valuable for the first aspect above. However, direct learner experience must play a major part in addressing this skill area as a whole.

S7: Indicative characteristic statements about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i—vi	applies and progressively builds all of these skills areas in the course of study, with exercises becoming more complex and extensive in higher-level courses of study		

S8: Scientific analysis

This heading represents the distinctive methodology that characterizes scientific thinking, building on the numeracy, critical thinking and practical skills described above. It is convenient to distinguish five complementary sub-headings, which are applied sequentially in following through a scientific investigation or study. In engineering these basic skills underlie important systematic methodologies in project planning, process optimization, quality assurance, etc.

(i) Clarifying the scope and objective of a study, and setting its context

It is important to define the focus and scope of a study or investigation from the start, to have clear objectives and to review the context of the study in terms of what else is known. Information gathered during the exercise, or issues emerging during analysis, may necessitate a review: it is important to retain clarity of purpose at all stages.

(ii) Investigation: accruing and judging information

Skills involved in practical investigations have been reviewed above. In accruing information from published sources, skills needs to be developed in searching for and locating relevant sources, and in judging both the reliability and the relevance of the data obtained. There should always be an attempt to assess, and if possible to quantify, the accuracy of data, and the extent to which this affects the validity and accuracy of the eventual conclusions from the study.

(iii) Critical analysis and modelling: building on fundamentals

Outstanding scientists and engineers are noted for the clear and focused way they approach any new problem from first principles. Modelling constitutes the key organizer in scientific understanding. In any scientific analysis it is important to frame one's thinking in terms of the key concepts and ideas that are the subject of Chapter 4 below. This gives a context for addressing the issue or problem in hand, using the appropriate skills and methodologies.

(iv) Assessing conclusions appropriately, objectively and critically

This is an area that tends to be neglected in traditional approaches to the curriculum, in that for most situations addressed a definite and ‘correct’ answer is expected. Where more open-ended and student-centred investigations are pursued, the conclusions are often not definitive. Deficiencies and limitations of the study should be considered, and further work might be suggested that would test tentatively derived conclusions. Where alternative explanations might be possible, these should be mentioned. Where science reveals the feasibility and potential impact of applying a process or technology, a clear distinction should be recognized between the objective scientific analysis and the non-scientific subjective (and sometimes ethical) value judgements involved in any policy decision on implementation (as discussed more fully under ideas about science in Chapter 5). Where quantitative conclusions are drawn, there should be some discussion of accuracy.

(v) Report writing, presentation and discussion of conclusions

Reporting skills require to be developed through practice and feedback, including participating in reviewing presentations by peers. Important skills areas in reporting include:

- logical and clear exposition
- setting the work in its broader context
- a critical analysis of conclusions
- identification of where, given time, further work would be appropriate
- pitching the level and scale of the report to fit its planned purpose.

S8: Indicative characteristic statement about the learner, by level of course

	by SCQF level 5	by SCQF level 6	by SCQF level 7
i—v	applies all of these skills areas in the course of study, with the context becoming more complex, as dictated by the progressing demand of the curriculum topics and exercises in higher-level courses of study		

S9: Entrepreneurial awareness

In addition to deepening our understanding of the world, science, engineering and mathematics have enabled humanity to transform lifestyles, in terms of wealth, health, work, and social and leisure activities. In the modern world the relative prosperity of nations depends considerably on how effectively they can contribute to the innovation that drives economic success. Typically this requires talent in the timely and efficient application of scientific and engineering ideas to the creation of a new 'product' that will attract interest and demand. Similar talent is required on an on-going basis, to evolve the design and production of existing 'products' to keep up with new knowledge and evolving demands. The term 'product' here is intended to include artefacts, procedures and services.

The skills involved here are, first, in spotting relevant opportunities for innovation and, second, in the timely and effective realization of such an opportunity. Aiming to nurture these skills through education is a relatively recent development, in response to a recognition that, in the past, notable scientific breakthroughs achieved in the UK have frequently been exploited, with spin-off economic benefits, elsewhere.

At root these skills are by no means peculiar to the STEM disciplines; they are vital to the launch and operation of any successful business, and indeed to the management and delivery of efficient and effective public services. On the other hand STEM applications provide the key drivers for innovation, worldwide. In the current context the skills (and attitudes) to nurture are:

i. 'brain-storming' analysis of potential new applications built on scientific knowledge
ii. recognition of opportunities and constraints linked to Intellectual property rights
iii. general understanding of the significance of business issues, including finance and marketing
iv. recognition of the importance of applying skills in
    - analysis of uncertainty and risk (skills area S6 above)
    - project management (using methodologies discussed under Engineering in Section 5.2)
    - team working (skills area S2 above)
v. analysis of critical features in case studies of successful and unsuccessful STEM-rooted entrepreneurial ventures.

S9: Indicative characteristic statements about the learner, by level of course

<table>
<tr><th></th><th>by SCQF level 5</th><th>by SCQF level 6</th><th>by SCQF level 7</th></tr>
<tr><td>i—v</td><td>is aware that applications of STEM ideas and principles have transformed human life</td><td colspan="2">is aware of the importance of this area to economic and social advance and recognizes the significance of the factors identified under headings i—v

actively engages in discussions of case studies involving entrepreneurial innovation</td></tr>
</table>

Skills developed in the Units

The skills are progressively developed through the different cycles. A table showing the skills progression in the different Units is included in Section 6.2 below.

Chapter 4: Key explanatory models and storylines in the sciences

Science education progresses through building understanding of a range of key insights, ideas and models encapsulating the basic ‘substance’ of the sciences. These key explanatory models and storylines develop more sophistication and depth at higher levels of study: in Annex A we set out a version drafted with SCQF level 6 in mind. Emphatically, these storylines do not define a syllabus of items to be taught directly; they are intended to describe ‘a general understanding of the nature of the world about us’ that a learner might reasonably be expected to possess on completion of a broad course of study across STEM subjects up to SCQF level 6. They are expressed in general and descriptive terms.

These ‘storylines’ play a central role in the successful application of scientific analysis in any previously unfamiliar context of study. They represent a fundamental framework of ideas guiding investigation and underlying the detailed explanation of specific topics of current interest. They are an elaboration of what many commentators have referred to as the ‘big ideas of science’, often expressed as a short list of very terse phrases, such as ‘the particle model of matter’. We believe that significantly fuller descriptions are needed, and that these need to be phrased differently to characterize basic understanding at different levels of study. The version given here, pitched at SCQF level 6, thus marks the threshold for entry to university education in STEM subjects in Scotland.

Ideas from the storylines should regularly be referred to during the study of specific science topics, and they will be reinforced and often deepened in the course of study. The level of depth and rigour in the applications through which they are illuminated should reflect the analytical and mathematical thinking skills outlined in Chapter 3 above; conceptual understanding and skills are best advanced in synergy. We regard an exposition of the key science explanatory models and storylines as a core reference document for a course of the kind we are proposing, and for this reason we have presented it, in a stand-alone context, as Annex A.

4.1 Key conceptual strands in the sciences

It is useful at this point to give a much shorter summary checklist of 'key conceptual strands' embraced within the storylines. This is a concise way to highlight the range of ideas to be embraced. Again we must emphasize that this list, presented under a series of headings, should in no sense be viewed as a syllabus, let alone a sequential one. The storylines themselves, in Annex A, should be regarded as the principal reference source to describe the underlying 'picture of the world' upon which learners at this level should be able to anchor their studies of STEM topics. The storylines have been set out under science discipline headings, an approach not found appropriate for the balder list of conceptual strands below. These include:

- **Mass and matter**
  - atomic and molecular structure
  - periodic table, atomic masses
  - chemical bonding, including shape
  - reactions and stoichiometry, the mole
  - phases of matter and their properties
    - gas laws, conductivity (thermal and electrical)
  - intermolecular forces
    - temperature and phase changes
  - elementary particles

- **Energy**
  - forms of energy and energy transfer
  - heat and temperature including absolute temperature
  - energy storage and dissipation
  - energy states of atoms and molecules, transitions
  - extreme processes, interconversion of mass and energy

- **Chemical and biochemical processes**
  - bonding and energy
  - the molecules of life and metabolism
  - structures and function
    - interaction and reactivity
    - polarity, characteristics of functional groups
  - solutions and solvation
  - acids and bases, pH
  - redox reactions
  - chemical equilibrium
  - reaction rates and yields
  - biochemical steady states

- **Forces and motion**
  - forces of nature
  - laws of motion: velocity, acceleration, collisions
    - momentum, torque, rotational motion
    - vectors
  - electrostatic forces
  - cohesive and stress forces including pressure

- **The earth, solar system and universe**
  - structure and evolution of the universe
    - generation of the elements, stellar radiation
  - development and structure of the earth
  - seismic and cosmic processes and the earth
  - evolution of the biosphere
  - the atmosphere, weather and global warming
  - some basics of relativity — time dilation, curvature of space

- **The biosphere**
  - evolution of life
  - interdependences of organisms, ecosystems
  - agriculture and human population
  - biodiversity

- **The global environment**
  - processes and cycles
  - resources, human exploitation, sustainability

- **Wave motions**
  - general characteristics and propagation of waves
  - reflection, refraction and diffraction

- **Sound**
  - production and propagation, single and superimposed frequencies
  - sound and hearing, sound and music
  - sound recording and replay
  - ultrasound

- **Magnetism**

- **Electricity**
  - charge and current
  - ions and electrochemical processes
  - insulators, conductors, flows in circuits
  - semiconductors, superconductors
  - electrical signals, including via the nervous system
  - electromagnetic induction
  - electronics

- **Electromagnetic radiation**
  - the electromagnetic spectrum
  - frequency, wavelength, energy, photon
  - reflection, refraction, diffraction, absorption/emission
  - detection, including human vision, cameras and display devices
  - lasers

- **Organisms**
  - range and classification
  - constitution in terms of cells
  - physiology, organs
  - control and homeostasis
  - brain, nervous system and senses
  - diet and activity, sustaining health
  - infection and disease
  - nature and scope of interventions through modern medicine

- **Structure and operation of cells**
  - substructures
  - cell division
  - reproduction and heredity
  - genetics

4.2 Storyline priority themes for a course at SCQF level 6

The full list of storyline understandings, in Annex A, represents a platform that ideally should be established by the end of 12 years of formal education. The list is too long for all items to be directly addressed in one or even two years of a post-school return to study. We recommend that a full statement of the sort we have compiled should be presented as a general reference source and that, in the study of any topic during a course, specific attention should be given to highlighting how understanding is built on, and may have further deepened, relevant storyline ideas.

For the purposes of the specific course that we go on to outline in Chapter 6 below, shorter lists of appropriately representative 'priority concept area themes' are presented under each core science discipline.

PHYSICS

P1 Applications in electricity and electronics
P2 Study involving radiation (including lasers)
P3 Study of a wide range of materials properties
P4 Studies of forces, motion and energy
P5 Study involving spontaneous processes
P6 Study involving non-classical physics

CHEMISTRY

C1 The periodic table as a key explainer
C2 Understanding bonding and 3D structure of molecules, notably in organic/ biological and materials contexts
C3 Reactions, including mechanisms and yields
C4 Solution processes, including electrochemistry and reaction equilibrium
C5 Processes involving light absorption/emission

BIOSCIENCES

B1 Organization and operation of the cell, and the nature, roles and management of the key chemicals of life
B2 Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease
B3 Cell division, reproduction, heredity
B4 Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability
B6 Adaptation and evolution

EARTH SYSTEMS SCIENCE

G1 Study involving (human influenced) element cycle and environmental modelling

G2 Study implicating major seismic processes

G3 Study involving evolution of the earth, the solar system and the universe

G4 Study involving weather, climate and interplay with the biosphere

Chapter 5: Important tools, methodologies and practices in STEM subjects

The explanatory models and storylines of the previous section summarize a scientific understanding of the world. We now move on to summarize the tools and approaches that characterize scientific and technological approaches to problem solving and the pursuit of projects. While there is a basic knowledge component in each methodology, the main educational challenge is in developing the specific skills required for its effective application.

5.1 Mathematics

This section supplements the skills summarized in Chapter 3 under the sub-sections for

S3 Numeracy: assessing and manipulating data and quantity
S7 Handling uncertainty and variability

Skills introduced should be practised and reinforced in applications to science and engineering. Important topic areas for focus at level 6 are:

M1 Exponents, notably within scientific notation, and logarithms, including addition and subtraction of logarithms, and use of logarithmic scales in graphs
M2 Coordinate geometry, use of Cartesian coordinates in two dimensions, basic manipulation of trigonometric functions; use of distance formula; eg positioning by triangulation
M3 Vectors in two and three dimensions, including addition and scalar and vector products, representation via components
M4 Basic calculus (single independent variable), relevance to processes involving change or accumulation, and interpretation/estimation via line graphs; differentiation and integration of simple functions and expressions; the special significance in calculus of the number e and its series expansion, linked to the common occurrence of scientific relationships involving exponentials and natural logarithms
M5 Basic statistics including the ideas of a distribution of values across a sample or population, including imprecision in experimental measurement; calculation of mean, mode and standard deviation and application of at least one method of estimating statistical significance
M6 Key tools from numeracy, algebra, proportion and graphs

5.2 Engineering and technology

What is probably most important as a basis for progression to HE level study in engineering, in addition to a strong basic science and mathematics background, is some appreciation of the nature, wide scope and importance of engineering. All human artefacts, services and systems are 'engineered' at some point. This appreciation can be gained through participation in a range of studies that have an engineering dimension. These should give experience of at least some of the following characteristic engineering methodologies:

E1 Project planning and management
- importance of planning: examples of successful and unsuccessful large and small projects
- ten-step project planning

E2 Product design
- a problem-solving process covering initial brief, product design specification, concept design, detailed design, manufacturing and test, and sales
- includes looking at fitness for purpose, reliability, safety and efficiency in use, cost effectiveness, aesthetic impact, and environmental impact

E3 Materials selection to meet required needs and to minimize costs, including brief overviews of
- material structures (down to the atomic level)
- how these translate into various material properties (eg strength, friction, lubrication, etc)
- various types of materials and their associated costs
- end-of-life material disposal and recycling issues

E4 Process control methodologies
- why these are needed: introduction of process variability and how it is measured
- various statistical tools, including cause and effect, control charts, flow charts, histograms, pareto, process capability, run charts, scattergrams, etc

E5 Quality methodologies and sustainability issues
- the quality improvement cycle (plan, do, check, act), continuous improvement
- simple lean manufacturing techniques
- sustainability, including energy usage, end-of-life disposal and legislation (eg WEEE directive: Waste Electrical and Electronic Equipment)

Finally, some students may not have a clear concept of engineering as a discipline. A brief outline and some useful resources for communicating what an engineer is and does are given below, and this can be discussed at the start of relevant Units.

What is engineering?

The following description is quoted from the website 'What is Engineering?' at **http://cnx.org/content/m13680/latest/**

> Engineering is the practical application of science and mathematics to solve problems, and it is everywhere in the world around you. From the start to the end of each day, engineering technologies improve the ways that we communicate, work, travel, stay healthy and entertain ourselves.
>
> Engineers influence every aspect of modern life and it's likely that today you will have already relied on the expertise of one or more engineers. Perhaps you woke to a DAB clock radio, or used a train or a bus? Maybe you have listened to an iPod? Or watched television? Did you wash your hair today? Do you have a mobile phone in your pocket or trainers on your feet? These have all been designed, developed and manufactured by engineers.
>
> Engineers are problem-solvers who want to make things work more efficiently and quickly, and less expensively. From computer chips and satellites to medical devices and renewable energy technologies, engineering makes our modern life possible.

The above website gives further information and also discusses the difference between science and engineering.

There are different engineering disciplines, and engineers can work in many different environments. For more information about this, see **http://www.enginuity.org.uk/what_is_engineering.cfm**

A useful video clip entitled 'Is engineering right for me?' from the University of Buffalo in the USA can be found at **http://www.youtube.com/watch?v=vj-H_Mbfvu4**

It may also be helpful to know that there are three nationally (and internationally) recognized professional levels that can be worked towards: Engineering Technician (Eng Tech), Incorporated Engineer (IEng) and Chartered Engineer (CEng). Each of these levels can be achieved by various routes of study — going to university to study an engineering course is just one of the many options available. To find out how, see the 'Enginuity' website at: **http://www.enginuity.org.uk/routes_into_engineering/your_options.cfm**

5.3 Computing and information sciences

The key objective here is to establish a basic understanding of the nature and power of computing science as the discipline concerned with the development of skills and knowledge suitable for the design and implementation of new computer systems. This is distinct from ICT, which is concerned with the use of computing technology, and is covered separately in Chapter 3 as skill S5.

The following strands are thought important:

- CI1 Roots of computer science in numeracy skills: using symbols for quantities
- CI2 The concept of information: classes of information
- CI3 Solution specification for a general problem — algorithms
- CI4 Basic introduction to programming (using a simple high-level language, eg via justBASIC[16])
- CI5 General ideas of how computers store, input, transform and output information
- CI6 Analysing design issues in a range of applications (from in-built control devices in appliances to large scientific and technological information processing systems), eg DNA matching

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[16] 'justBASIC' is a suitable package for introducing programming at a simple level. It is available as freeware from **http://www.justbasic.com** and comes with good supporting information.

5.4 Ideas about science

The scientific method

For our purposes, scientific methodology will be adequately communicated in terms of the skills areas reviewed in Chapter 3, in relation to 'critical and logical thinking', 'scientific analysis', 'experimentation and prototype construction' and 'handling uncertainty and variability'. It is not suggested that there should be any generalized discussion of the historical evolution of science by hypothesis, model setting and attempted falsification, or of Kuhn's analysis of the progression of science, which suggests that it normally progresses by incremental extension in the range of applications, and occasionally by fundamental 'revolutions' in basic understanding.

Only one additional 'methodology' is added to the remit of the Framework, as below.

i. The boundary between objective scientific analysis and policy advocacy

A modern definition of 'science', from the UK's Science Council, runs: 'science is the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence'.[17] Engineering involves the creative application of scientific principles to achieve specific 'useful' outcomes. Technology variously refers to tools and artefacts designed on scientific principles, for useful purposes, or to the knowledge and craft skills required to exploit these. Science is value free, as are the processes of engineering and technology, though not the initial identification of a goal of application as 'useful'.

Science creates knowledge that extends human capability. Modern biosciences open the potential to overcome genetic diseases, to develop new crops and to clone individuals. Our understanding of nuclear science enables a range of medical technologies, the large-scale generation of electric power (from fission or fusion) and the production of nuclear bombs. Computing science enables the organization and rapid analysis of vast arrays of information, for a hugely diverse range of purposes. In every case, value judgements underlie the choice of applications that should be pursued, and it is for wider society, and governments, to agree which ends are 'useful' and to regulate and support activities accordingly. While 'science' is value free, 'scientists', like anyone else, are not.

Scientists can advise, with a fairly high degree of confidence, how much various changes in human activity could influence carbon dioxide concentrations in the atmosphere. They can also give an estimate, based on their best scientific judgement, as to the likely

[17] See **http://www.sciencecouncil.org/content/what-science**

impact on future climate change, though here all scientists will admit to some level of uncertainty in the details and scale of this impact, and a small minority judge that controlling emission may have almost no effect on climate. Ultimately it is for society as a whole to decide what actions should actually be taken. Individual scientists will have strong views on this, and will be able to highlight in some depth the probable and possible consequences of inaction. In the end the judgement reached can be based on science, but it is not in itself science.

In presenting science it is important to make very clear where the boundary lies between the conclusion based on scientific analysis of the evidence and the judgement required as to what action ‘should’ be taken.

Chapter 6: An exemplar course — *Access to STEM*

In Chapters 1 to 5 we have described a new model of approach to STEM education at sub-degree levels, consistent with modern perspectives. This chapter fleshes out a detailed implementation of the model.

We have chosen to do this for a general course, *Access to STEM*, which would pave the way for learners returning to study post-school, who might aim to enter relevant first-year university degree (or college Higher National) courses in Scotland, following one full-time year of study in college. There is existing provision for this purpose, developed through the Scottish Wider Access Programme, running under the title *Access to Science and Technology.*

The design is guided by the framework approach previously outlined in Chapter 1.

(a) Engage interest and commitment to STEM studies:

- take a fundamental learner-active approach
  set challenges designed to be achievable but non-trivial
- select topics and objectives for study that are varied in nature and likely to be found interesting and often intriguing
- reflect on gains achieved in skills and core understanding
- highlight connections between ideas developed in different contexts

(b) Progressively and systematically strengthen skills required for effective practice:

- aim to practise and advance all of the skills areas listed in Chapter 3
- emphasize progression of skills capability across the board, rather than focus on a raft of required minimum thresholds for each skills sub-heading

(c) Introduce and steadily deepen understanding of the main explanatory concepts, models and storylines of the sciences:

- it is not feasible to deal directly with all of the key models and storylines listed in Annex A
- learners will carry some awareness across these ideas from earlier schooling, though their fundamental nature and wide applicability may not have previously been understood
- Annex A should be used as a reference resource for the course, and explicitly revisited from time to time
- topics in the course should address all of the concept areas listed in Section 4.2 for physics, chemistry, biosciences and earth systems science

(d) Develop the techniques and methodologies that are the tools of the trade for the different STEM areas:

- these identify strands in mathematics, engineering, computing science and ‘Ideas about Science’ that should be addressed appropriately for SCQF level 6

(e) Select and schedule a sequence of specific applications to be studied:

- given the number and range of skills, concepts and techniques to be encompassed, and the learner-active style of course envisaged, this took some thought

We considered adopting a problem-based learning approach (PBL). This has been used successfully in higher education where skills development and the practical application of core knowledge are the driving educational priorities. Such an approach has been widely pursued for degree courses in medicine, in nursing and (to a lesser extent) in engineering. Typically each problem set is quite a large exercise. We concluded that it would be very difficult to meet our full range of requirements in this way.

What we settled on instead was to design the course in Units, where each Unit has a scientific, engineering or mathematical key theme. Within each Unit, the key theme is explored typically though investigation of a range of smaller problems or applications, arranged to build an overall coherent package. Few of the Units can be regarded as fitting exclusively inside a specific discipline; the lead theme may appear to do so, but the applications generally broaden the Unit perspective.

The exercise was deliberately approached from a ‘green field’ point of view, not necessarily constrained by the way that college courses in Scotland are generally structured at present. We judged that quite a large number of Units would be required to give the richness of experience we were aiming for. In a full-time course of study it would be natural to study a moderate number of Units together, as one ‘cycle’ within the whole course. The full course would consist of a moderate number of cycles, studied sequentially through the year.

We decided on a structure involving 25 Units, with five cycles, each consisting of five Units taken contemporaneously. This allowed for a good balance to be maintained across the STEM disciplines throughout, and for connections across Units to be recognized at all stages.

We believe we have succeeded in designing a rather good exemplar course on this basis. The Unit titles describe the lead themes, and are as listed in Table 6.1 below. The structure of these Units is described in more detail in Section 6.1 below, and the content of the Units is outlined in Section 6.3. A full description of the 25 Units is given in Annex B of this report.

Table 6.1 The 25 Units of the full *Access to STEM* course

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Numeracy	Energy sustainability	Calculus	Statistics	Information systems
Atoms and molecules	Reactivity	Eukaryotic cells	Materials	The universe
Forces, motion, energy	Electricity	Radiation	Prosthetics	Nanotechnology
Earth processes	Equations and graphs	The human organism	Industrial chemical processes	Genetics
Ecosystems	Study of a domestic appliance	Investigation of a large infrastructure project	Commercial case studies	Analysis of a commercial application

As explained above, we were intent on designing a course from first principles and did not necessarily want to be constrained by standard structural design conventions currently operating in Scotland's colleges. We recognized that some adjustments might in practice have to be made to ease actual implementation. In the event that issue caused us to reassess our proposals in a way that we think is beneficial.

College courses in Scotland, up to SCQF level 6, are organized using a standard Unit size corresponding notionally to 40 hours. Each Unit carries 6 credit points, and a set of 20 Units fills up a full-time year of study (carrying 120 credit points). Individual subject 'courses' taken in upper secondary schools at these levels are similarly 'unitized' as bundles of four Units each (one of which is typically devoted to preparation for and sitting the final exam). A school-based learner typically studies five such subject courses in a year: again giving a total of 120 credit points for SCQF credit transfer purposes (5 courses × 4 Units × 6 points each). The most obvious way in which we could have adapted the 25 'Units' in Table 6.1 to the standard Scottish models would have been to bundle each cycle of 5 into a 'quadruple SQA Unit' analogously to how the Scottish school 'Higher' courses are arranged. However, on consideration, we decided on a rather different solution.

In practice most learners 'returning' to education at a college, in order to study STEM subjects, do not proceed straight into a SCQF level 6 Access to HE course. Most take some studies first at SCQF level 5. The first cycle of Units listed in Table 6.1 can be seen in many ways as preparing the ground for the later cycles; they 'brush up' on some core skills and concept areas that underpin a great deal of what follows. A learner who has strong prior achievements in physics, chemistry and mathematics in the school National 5 courses should in principle be able (perhaps after a brief introductory bridging course) to enter directly into cycle 2 of our *Access to STEM* course. Our 25 Unit structure was designed to embrace the full sets of skills, concepts and techniques identified through our analysis in earlier chapters. We concluded that this could be better presented if we arranged for the first cycle of Units to be set at SCQF level 5, leaving cycles 2—5 to constitute a full-time one-year course at SCQF level 6. This solution has the significant additional benefit that all of our Units can be classified as standard Scottish Units.

The first-cycle Units could in practice be taken in a number of different ways. They could be studied as part of a full year or a part year of study at SCQF level 5, or as a stand-alone part-time course in its own right as a formal bridging course prior to entering the level 6 *Access to STEM* programme. For well-qualified entrants, these Units could be taken in a much truncated form as a 'taster and refresher' short course prior to starting the full-time programme. More is written about this in Chapter 7.

6.1 Structure of the Units

The STEM-ED Scotland progamme is a skills-led framework for developing individuals' capabilities in science, technology, engineering and mathematics. It has been designed to engage students of mixed ability and diverse interests in active participation in their learning. It takes tutors and students beyond the standard curriculum and allows them scope to select from a content menu that develops the different discipline strands in harmony and with mutual reinforcement. It emphasizes skills development and a broad understanding of the key concepts that are required by employers and universities alike. These key conceptual strands represent the 'big ideas of science' — a fundamental framework of ideas, which we have described fully as a series of 'storylines' in Chapter 4.

In the introductory notes for each Unit, information is provided on its storylines and also the skills it develops. Every Unit is subdivided into a number of topic areas, and Unit notes provide an outline of content, teaching notes and resources for each of these. Within each Unit, lecturers and students may choose to concentrate on particular areas of interest. In most Units it is envisaged that individual students will undertake different tasks and report back to the rest of the class, so that no student will be expected to tackle directly all of the content in a Unit. The content of the *Numeracy* Unit in the first cycle, however, is so basic and important for many other Units that failure to cover all aspects may put students at a disadvantage.

6.2 Mapping skills and concept development, and connections

Within the Unit notes, clear guidance is provided on which other Units provide useful prior knowledge and which will provide application, consolidation or extension. These links illustrate the real links between subjects that have historically been regarded as discrete and taught accordingly, and so allow the student to understand STEM education as a coherent whole as well as providing new routes to develop generic problem-solving skills. To facilitate such links each Unit has three tables: one to give the key concepts and storylines associated with the Unit; one to give links from the Unit to other parts of the programme; one to show skills development within the Unit. The level of skills is progressively developed throughout the five cycles. This is indicated in Table 6.2, which shows how the skills level is developed (from SCQF level 5 to level 7) as students progress through the 25 Units.

Enquiry-based learning develops important transferable skills and enables students to gain experience in facing the types of problems encountered by practising engineers and scientists. Independent learning is an important skill for any student to develop and is recommended for a significant part of most Units. Useful resources for this purpose, including websites, are given where appropriate. Wikipedia and similar generic web-based resources are helpful but students should be cautioned about content that has not been subjected to any kind of review process before publication.

The assessment criteria are given for each Unit. The final Unit, *Analysis of a commercial application*, brings together a lot of the work done in previous Units, and its assessment will play an important role in the overall grade attained for the course.

Table 6.2 Skills development throughout the Units (from SCQF level 5 to level 7)

	S1 Learning, study, self-organization and task planning	S2 Interpersonal communication and team working	S3 Numeracy: assessing and manipulating data and quantity	S4 Critical and logical thinking	S5 Basic IT skills	S6 Handling uncertainty and variability	S7 Experimentation and prototype construction: design and execution	S8 Scientific analysis	S9 Entrepreneurial awareness
Numeracy	5	5	6		5	5			
Atoms and molecules	5	5	6	5	5	5	5	5	
Forces, motion, energy	5	5	5		5	5	5		
Earth processes	5	5	5	5	5	5	5	5	
Ecosystems	5	5	5			5			
Energy sustainability	6	6	6	6	6		6	6	
Reactivity	5							5	5
Electricity	5	5	5						5
Equations and graphs	6	6	6	6	6				
Study of a domestic appliance	5	5	5		5		5		5
Calculus	6	6	6	6	6	6	7	6	
Eukaryotic cells	6	6	6	6	6		6	6	
Radiation	6	6	6	6	6	6	6	6	
The human organism	6	6						6	
Investigation of a large infrastructure project	6	6	6	6	6			6	
Statistics	6	6	6	6	6	6	6	6	

	S1 Learning, study, self-organization and task planning	S2 Interpersonal communication and team working	S3 Numeracy: assessing and manipulating data and quantity	S4 Critical and logical thinking	S5 Basic IT skills	S6 Handling uncertainty and variability	S7 Experimentation and prototype construction: design and execution	S8 Scientific analysis	S9 Entrepreneurial awareness
Materials	6	6	6	7	6	6	6	6	6
Prosthetics	6	6	6		6		6		6
Industrial chemical processes	6	6	6	6	6		6	6	
Commercial case studies	7	7		7	6				7
Information systems	7	6	6	7	7		7	7	
The universe	7	7	7				7		
Nanotechnology	7	7	6	7	6	7	7	7	7
Genetics	7	7		7	6	7			
Analysis of a commercial application	7	7	7	7	7	7	7	7	7

Storylines covered in Units

The table below indicates the distribution of the important storylines through the 25 Units. The row headings (P1—P6, C1—C5, etc) refer to the storylines and methodologies mentioned in Chapters 4 and 5; the column headings (1a etc) link to the Unit titles, with the number relating to the cycle (1 first cycle, 2 second cycle, etc) and the letter relating to the rows of Table 6.1 (a is the first row, b the second row, etc). For example 1a is the *Numeracy* Unit and 5d is the *Genetics* Unit.

Table 6.3 Storylines covered in the Units

	1a	1b	1c	1d	1e	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	4a	4b	4c	4d	4e	5a	5b	5c	5d	5e*
P1				X		X		X		X	X		X		X		X	X	X				X		
P2			X	X		X					X		X												
P3				X		X						X	X		X	X	X	X		X			X		
P4				X		X			X		X	X		X	X					X					
P5			X			X										X		X							
P6						X											X						X		
C1		X		X		X	X										X		X						
C2		X		X			X					X	X				X	X	X				X	X	
C3						X	X		X		X					X	X		X						
C4		X				X		X		X									X				X		
C5				X									X				X						X		
B1				X								X		X										X	
B2													X	X		X							X	X	
B3												X		X										X	
B4				X	X				X		X				X					X				X	
B5					X																			X	
G1				X		X																			
G2																X						X			
G3																						X			
G4			X		X										X	X						X			
M1	X								X		X		X						X						
M2	X								X				X		X										
M3			X												X										
M4			X		X						X				X										
M5															X	X				X			X		
M6	X	X		X		X			X				X					X	X				X		
E1											X				X					X	X				
E2			X												X	X		X	X	X	X				
E3															X			X		X					
E4															X				X	X	X				

	1a	1b	1c	1d	1e	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	4a	4b	4c	4d	4e	5a	5b	5c	5d	5e*
E5															X	X				X					
CI1	X																								
CI2																									
CI3																					X				
CI4																					X				
CI5																					X				
CI6																		X			X				

* Unit 5e, *Analysis of a commercial application*, does not directly relate to any of the key concepts/storylines. As this is the final Unit in the programme it will draw on the concepts and storylines relevant to the area chosen for study.

6.3 The Units at SCQF levels 5 and 6

Descriptors for the 25 Units are given in Annex B, but a brief summary of the outcomes of each Unit is given in the table below. The Units are in five cycles, and each cycle builds on the skills and knowledge gained in the previous cycle. The order or way in which Units are tackled in a given cycle is immaterial: they can be run simultaneously or in any other suitable way. At the end of each cycle there will be time allocated to review progress, to reflect on what has been learned, to look at how skills are being developed and to set future targets.

The content of the Units is not meant to be too prescriptive and much of the work is project based. The descriptors do not say how Units should be delivered but they contain ideas and examples of possible projects. It will be up to the lecturer to decide what the most appropriate approach for a particular class is.

Cycle	Unit title	Brief summary of outcomes
1	Numeracy	▪ use SI units and understand the meaning of prefixes ▪ manipulate and use numerical data in a number of scientific and engineering contexts - fractions and ratios - precision, accuracy and significant figures - interconversion of fractions, percentages and decimals - calculator use - BODMAS ▪ understand and use indices, exponents, scientific notation and logarithms ▪ understand formulae and equations - rearrange equations - limitation (eg of $V = IR$) ▪ plot and interpret graphs (including slope and area underneath) - rate of change and equations of motion - shape of $y = mx + c$ and $y = x^2$ ▪ carry out data handling - mean - significant figures ▪ present data in various formats appropriate to end use ▪ use elementary geometry, trigonometry and algebra - functions - Pythagoras - practical applications - solving equations - factors

Cycle	Unit title	Brief summary of outcomes
1	Atoms and molecules	▪ relate atomic and electronic structure to the properties of elements - electron arrangement - periodic table - energy levels in atoms ▪ relate the shapes, bonding and properties of chemical compounds to electronic structure - ionic and covalent bonds - VSEPR (valence shell electron pair repulsion) - introduction to hybridization ▪ understand the factors involved in chemical reactions - balancing equations - the mole and Avogadro's number - reaction types ▪ understand the nature of reactions in solution - acids and bases, neutralization - redox reactions
1	Forces, motion, energy	▪ understand the significance of Newton's laws and carry out calculations using the equations of motion - inertia - $F = ma$ - action—reaction ▪ understand the concept of gravity and carry out simple calculations - g and G - mass and weight ▪ carry out calculations relating to potential and kinetic energy and to energy balances ▪ appreciate the reasons for some bridge failures and how these failures could have been avoided ▪ resolve vectors ▪ understand how energy is transferred in living and non-living systems ▪ understand the physical causes of some weather phenomena
1	Earth processes	▪ understand the human impact on the biosphere - biogeochemical cycles - global warming ▪ understand how both direct and indirect energy from the sun is used - photosynthesis - solar energy ▪ appreciate material and energy flows in an ecosystem - energy flow - food webs ▪ relate human food and energy use in a quantitative manner - energy-giving foods

Cycle	Unit title	Brief summary of outcomes
		- energy use in the body - conversion of food to energy ▪ understand the impact of agricultural practices on the environment, in support of the human population - factors affecting growth of human population - developments in agriculture - fertilizers and pesticides - sustainability of farming methods ▪ understand the impact of fossil and biofuels on the environment - methods of reducing emissions, clean coal technology - production of fuels from crops
1	Ecosystems	▪ understand soil ▪ understand vegetation ▪ understand fauna ▪ understand biomes and interdependence - biodiversity ▪ understand the human impact on the biosphere - C, N and H_2 cycles - pollution and waste management - sustainability ▪ understand evolution - Mendel, Darwin and Wallace - DNA mutation - effect of plate tectonics ▪ understand how both direct and indirect energy from the sun is used ▪ appreciate material and energy flows in an ecosystem ▪ relate human food and energy use in a quantitative manner ▪ understand the impact of agricultural practices on the environment, in support of the human population - spread of populations - predator/prey - spread of infections ▪ understand the impact of fossil and biofuels on the environment
2	Energy sustainability	▪ investigate global energy use and trends ▪ review energy use in the home - units of power - average consumption per household - increasing efficiency ▪ review methods of energy production - coal, oil and gas - nuclear and renewables ▪ investigate energy use in transport - reducing carbon dioxide emissions in cars, dual fuel - batteries and hydrogen fuel cells

Cycle	Unit title	Brief summary of outcomes
		- emissions from planes ▪ investigate an application of energy use in industry ▪ investigate an ethical issue related to energy use or energy production
2	Reactivity	▪ use the periodic table to predict molecular shapes and to predict the electrometric forces between atoms and thus forecast the reactivity of different molecules ▪ describe multiple bonding from a valence bond (VB) and a molecular orbital (MO) viewpoint ▪ describe simple reaction mechanisms ▪ use the IUPAC (International Union of Pure and Applied Chemistry) naming system ▪ understand organic functional groups ▪ understand isomerism - structural, geometric, optical - nomenclature - conformational analysis ▪ understand molecules of biological importance - polymerization - structure and function - 3D structure ▪ understand the principles and processes of drug design - active sites - lock and key - step from discovery to clinical use
2	Electricity	▪ use and understand the fundamental relationships in electricity - terminology and units - Faraday's laws - material properties (conductors/insulators) - circuits ▪ explain and describe the phenomena associated with static electricity - laws - gold leaf electroscope - Van der Graaf generator ▪ describe the effects arising from electromagnetism and also describe their uses - lines of force - magnetic flux density - induction - electricity generation ▪ explain the theory of transducers and measurement devices ▪ describe the practical applications of transducers and measurement devices ▪ be aware of the dangers of electricity to human organisms

Cycle	Unit title	Brief summary of outcomes
		and of the necessary precautions ▪ explain the theory and applications of electrochemistry - oxidation/reduction - balancing redox equations - cells - standard potentials - Nernst equation - cells and batteries - corrosion - electroplating ▪ application of Faraday's laws
2	Equations and graphs	▪ use graphical techniques ▪ use vectors in calculations ▪ use and apply algebraic techniques ▪ understand how to manipulate trigonometric expressions and apply trigonometric techniques ▪ use mathematical modelling techniques to solve a real-world problem ▪ apply all above techniques to a wide range of applications
2	Study of a domestic appliance	▪ describe the function and design and manufacturing characteristics of a component in a domestic appliance ▪ use simple finite analysis to determine the factors governing the design characteristics, including fitness for purpose ▪ use a CAD modelling approach to design ▪ determine the forces on the drum bearing during operation ▪ understand the chemistry of corrosion protection and the criteria determining the properties of protective enamels ▪ produce flow charts of the basic control loops, and design and test simple control circuits ▪ acquire the entrepreneurial skills to ensure that the machine satisfies the customer requirements both functionally and aesthetically ▪ understand the environmental considerations in the design of the detergent, energy consumption and machine scrapping ▪ carry out a number of calculations relating to machine operation
3	Calculus	▪ carry out the basic mathematical techniques of integration and differentiation ▪ apply these techniques to the solution of scientific and engineering problems ▪ perform experiments related to the areas studied

Cycle	Unit title	Brief summary of outcomes
3	Eukaryotic cells	▪ describe cell structure and function - constituents of cells - role of DNA and RNA in protein synthesis ▪ have some knowledge of DNA technology - use in forensics - gene therapy ▪ describe cellular respiration - role of ATP ▪ explain methods of cell reproduction ▪ have some knowledge of basic microbiology
3	Radiation	▪ appreciate the different types of electromagnetic radiation in the spectrum and identify typical use ▪ Investigate the properties of radiation - reflection, refraction, lenses - interference and diffraction ▪ investigate the interaction of radiation with matter - emission and absorption - IR and UV spectroscopy - lasers - medical uses
3	The human organism	▪ describe the structure and function of the main human cells - mitosis - cell structure and function - cell products ▪ describe the causes and treatment of various human diseases - types and causes - prevention, transmission and treatment - natural immunity ▪ relate the use of energy to nutritional requirements ▪ carry out energy balance calculations ▪ relate the use of energy to cardiovascular and respiratory functions ▪ describe the structure and function of at least three human body systems ▪ perform practical exercises
3	Investigation of a large scale infrastructure	▪ take an overview of the Glendoe hydro project ▪ understand methods of project planning and management ▪ appreciate the principles of project design ▪ apply scientific principles to materials selection ▪ appreciate project/process control methodologies ▪ research quality methodologies, including sustainability issues ▪ formulate and present conclusions of the case study

Cycle	Unit title	Brief summary of outcomes
4	Statistics	▪ understand the basic idea of a statistical distribution, ideas of mean, median, mode and standard deviation, and recognize variability within samples and in populations ▪ handle basic examples involving random events and their probability ▪ identify random and systematic errors that occur in experimental measurements and show how these can be quantified ▪ examine the parameters considered in the scientific modelling of a complex situation and identify the inherent uncertainties ▪ analyse reliability and breakdown data for manufactured equipment and design issues ▪ perform quantified risk assessment exercises for practical activities ▪ discuss risk versus benefit issues for a technology development
4	Materials	▪ understand the structure, properties and uses of metals and alloys ▪ understand the structure, properties and uses of polymers - addition and substitution polymerization - natural and man-made polymers ▪ understand the structure, properties and uses of smart materials - liquid crystal displays - quantum tunnelling composites ▪ understand the structure, properties and uses of semiconductors and superconductors ▪ understand the sustainable use of materials (disposal and recycling)
4	Prosthetics	▪ select materials for a particular device for a particular user ▪ relate structure to function for a number of materials ▪ use CAD/CAM as a design tool ▪ understand methods of manufacturing for prosthetics ▪ use cybernetics, and design and test control systems ▪ carry out biomechanical calculations and analysis ▪ use mathematical modelling ▪ use diagnostic imaging ▪ have a knowledge of materials - types, advantages and disadvantages - structure, properties and function ▪ fulfil customer expectations ▪ analyse body systems, eg upper/lower extremities, in terms of the forces encountered in different environments

Cycle	Unit title	Brief summary of outcomes
4	Industrial chemical processes	▪ relate the influence of enthalpy changes to industrial chemical reactions ▪ understand and apply the principles of chemical equilibrium to industrial chemical reactions ▪ apply the principles of acid-base and redox equilibria to industrial chemical reactions or to drug delivery ▪ understand the importance of reaction mechanism and reaction rate in industrial processes ▪ have a knowledge of 'green chemistry' - atom efficiency - multistage synthesis and efficiency - recycling
4	Commercial case studies	▪ research the history of a company ▪ identify the key business opportunity and how it is different from anything else that currently existed in the product/market area ▪ identify the product manufactured ▪ identify the key business methodologies to its products ▪ identify the risks that the founders took during the formation of their companies ▪ identify how funding capital to drive forward company development was found ▪ investigate how important to the success of this company the original founder was ▪ explain the future plans for the company
5	Information systems	▪ use technology for learning (eg on-line research) ▪ apply scientific knowledge and understanding to a case study ▪ learn independently and/or as part of a small team ▪ prepare written reports, suitably referenced, and make oral presentations to peers ▪ analyse and discuss high-level programming issues in the design of specific devices and scientific or engineering information handling and processing systems ▪ appreciate the nature of some of the intellectual challenges inherent in applying computing science
5	The universe	▪ describe elementary aspects of the physics underlying weather phenomena ▪ perform calculations to derive planetary orbits ▪ understand cosmology - *g* and *G* - Kepler's laws - tides - differences between planets ▪ describe the life cycle of a star ▪ understand the mechanism by which the sun generates

Cycle	Unit title	Brief summary of outcomes
		energy ▪ explain the consequences arising from application of special relativity - Michelson—Morley - constancy of *c* - time dilation - mass increase - Doppler effect - space travel - time travel ▪ explain the formation of the earth and natural phenomena - plate tectonics and their effects - carbon dating - ocean currents - climate variation - radiation from space - sun spots, comets, and asteroids ▪ describe the formation of the universe - big bang (red shift) - age and size - black holes - quasars
5	Nanotechnology	▪ understand the uses and properties of nanomaterials - fullerenes - quantum dots - medical and industrial uses ▪ understand the methods of manufacture of nanomaterials - colloidal solutions - nanolithography and molecular assemblies ▪ know and debate the benefits and risks involved in the use of nanomaterials
5	Genetics	▪ understand the principles of molecular genetics - DNA synthesis - genetic code ▪ explain the patterns of inheritance - Mendel's laws - codominance - lethal alleles ▪ know a range of applications of genetic technology - gene products - new phenotypes - gene therapy - cloning
5	Analysis of a commercial application	▪ investigate a previously unknown area of knowledge; research, absorbing and understanding information, and present these new facts to peers

Cycle	Unit title	Brief summary of outcomes
		▪ use this information to make sound commercial decisions ▪ take part in discussions and defend or support a course of action (eg selecting the manufacturing process or manufacturing site) ▪ take part in presentations and discussions concerning ethical, environmental and political issues

Chapter 7: Application of the new approach at other levels

The new approach, based on our analysis of modern priorities and perspectives, has been expounded quite fully for SCQF level 6. We regarded this, the threshold level for progression to higher education, as the most appropriate initial testing ground for our new model. We have categorized the key skills, articulated the core explanatory models and storylines for the sciences, and reviewed important tools and methodologies in mathematics, engineering and computing science, all in a manner judged appropriate for this stage. Based on that platform we have completed the substantial task of describing a fully specified exemplar one-year full-time course that in our view could serve as a very good preparation for entry to the first year of any STEM degree programme at a Scottish university. This gives a radical alternative approach to the 'Access to HE' courses currently offered in STEM areas.

Building a New Educational Framework to Address the STEM Skills Gap is of course a broader enterprise. We believe the principles we have adopted can be applied at both lower and higher levels, with appropriate adaptation in detail.

Our project remit is referenced to post-school education, covering learners who left school at age 16 or above, and who vary greatly in their levels of formal prior qualifications. Often, several years may have elapsed before 'returning' to further education. In considering STEM provision for education and training below SCQF level 6 it is important to recognize the differences in context compared with initial schooling. Learners entering further education do so voluntarily, at a more mature age, and following their own motivation to progress. There is no need to mirror the entire school experience through a series of steps in STEM education, progressing from SCQF level 1 through to level 6. Below level 6 we believe that all relevant STEM programmes of substantial extent can most suitably be set at level 5, with no specific requirements for prior entry qualifications in STEM subjects.

Of course, some student returners are not yet ready to study at level 5. For them, in our view, general study skills, career motivation and planning, basic numeracy and literacy are the initial educational priorities. It is important that the contexts of such learning are motivational, and interest-raising short 'taster experiences' of STEM applications can play a valuable role in this regard, while also potentially triggering interest in subsequent entry to a level 5 STEM programme. We would not argue for any more substantial STEM provision at level 4 or below, except perhaps for bespoke short basic operator-level training courses commissioned by particular employers.

In Section 7.1 below we review how the new model approach can be applied to STEM programmes pitched at level 5.

For higher levels, at SCQF level 7 and above, programmes necessarily diverge, with an increasing concentration on a specific, relatively narrow subject specialization. This is inevitable if learners are to attain the depth of understanding required at level 10 (the honours degree), which is in turn the basis for working at professional level, whether in research or in industry. We do, however, believe that there is a great deal of scope, and much potential advantage, in reviewing present practice from the point of view of the perspectives that have driven our work at a lower level. The disciplines do meet together again at nearly all of the main research frontiers. Industry too increasingly relies on coherently harnessing knowledge and skills derived from different STEM specialisms. Public policy development in technical areas often hinges on balancing expert analyses covering different aspects of an issue.

Thinking through how to evolve the very many different degree and Higher National programmes is far beyond the scope and competence of a single project team. However, we do discuss these issues in a little more detail in Section 7.2 below, with a particular emphasis on SCQF level 7. We believe that our level 6 proposals should provide a stronger platform from which to enter degree-level studies, and we discuss general ways in which first-year programmes could be adapted to take advantage of this.

7.1 STEM programmes at SCQF level 5

Some programmes at level 5 may be fundamentally **specific** in purpose, to meet closely defined requirements for the learner's employer, or for guaranteed entry into a specific job role. In these cases a primary requirement for the course will be to provide training in specific job-role operations.

Other programmes may be described as **general**, preparing either for progression to further STEM study at SCQF level 6, or as preparation for entry to technical level employment in a STEM related context. In these cases no single specific final educational qualification or job is uniquely identified or guaranteed.

We would argue that all general courses should be designed to support both further progression in education and entry to employment as potential progression routes. There is a strong labour market need for well-oriented recruits to enter employment at this level. Preparation for educational progression is important even for those entering work, and this will often be realized through apprenticeship programmes. We would then argue that the principles of our new framework remain valid for course design. The priorities remain:

- to engage interest and active participation
- to build broadly across the relevant skills range
- to strengthen understanding of core concepts and characteristic methodologies across a relatively broad and interdisciplinary front
- to provide an introduction to the skills required to meet the National Occupational Standards as specified by the various sector skills councils (eg SEMTA: the Sector Skills Council for Science, Engineering and Manufacturing Technologies)
- to provide an opportunity for students to regularly reflect on their progress to date and to set targets for future skills acquisition.

Applications studied should typically have a more practical emphasis, with a proportion illustrating the range, challenge and value of technician-level work, and developing skills supporting entry to careers at this level.

For specific courses we would hope to encourage dialogue with the interested employer (or employer group) to adopt at least some Units of study following our new model. Broadening the breadth and depth of understanding of their recruits, and developing skill in a transferable context should have substantial longer-term benefits, as technology and product development change practice and as they seek 'growth' in their staff's ability to contribute ever more effectively to the evolving needs of their business.

For level 6 our exemplar *Access to STEM* course represented a full-time, one-year programme. While this could clearly be taken on a part-time basis over two years, it is fundamentally a single large package supporting entry to HE. By contrast, at level 5, different learners and different purposes will suit courses of various lengths, some part-time, some 'block release' or single term, ranging through to full-time. A full-time year at SCQF level 5 may be particularly important for learners returning to education after quite a few years, with few or no certificated qualifications from school. Other returners, with significantly better, but perhaps 'rusty', prior qualifications might usefully benefit from a much shorter bridging course prior to enrolling on the level 6 *Access to STEM* programme. A further class of possible learners who would benefit from this programme are those either on apprenticeship or wishing to take up a scientific or engineering apprenticeship.

In Section 7.1.1 below we first sketch a possible shape for a full-year general level 5 course, designed from a 'green field' point of view. Then, in Section 7.1.2, we review a broad range of shorter programmes, including a number of ways in which some course elements based on the new model might be usefully blended with some of the existing provision at this level in Scotland.

7.1.1 Applying the 'green field' model at SCQF level 5

The skills building process can reasonably be regarded as the most important aim in course design at this level. For those entering employment to begin training for technician roles, the skills agenda represents the overwhelming pre-education priority as expressed by most employers. All of the strands of the skills analysis presented in Chapter 3 should be addressed, and learners should be explicitly aware of their strengths and weaknesses, and their progress, in each area. We have already set out 'characteristic statements about the learner' in Chapter 3, for each of levels 5, 6 and 7. In developing an appropriate course, it is important to ensure that the application topics investigated across different Units are approached in such a way that the full range of skills are exercised and stretched.

The 'Key concepts and storylines' of science in principle require to be expressed in quite different language and depth to capture the expected range and depth of understanding at different levels. If we were addressing education at upper primary school level, or early secondary, substantially different descriptions would be required, as would also be the case if an analysis were attempted at graduate level. On the other hand we are here dealing with an immediately adjacent level to level 6, for which the description in Annex A was developed. We believe it is advantageous to keep that version as the reference account, set at the threshold for entry to HE. Clearly then, on completion of study at level 5, there will be some storylines that may not have been addressed at all (perhaps, for instance, those related to non-classical physics), and there will be others that will have only partially been explored. What matters, we suggest, is that the level 5 course will leave learners 'on track' so that full coverage should be accessible after one further year of study at level 6.

Similar considerations apply to the depth of treatment of the tools and methodologies in mathematics, engineering and computing science. For instance, we would not expect calculus to be formally addressed at level 5.

Taking our *Access to STEM* course as the level 6 target, educational progression requires only that the five Units set at level 5 in Section 6.1 are satisfactorily completed. These were:

Level 5 Unit 1a	Numeracy
Level 5 Unit 1b	Atoms and molecules
Level 5 Unit 1c	Forces, motion, energy
Level 5 Unit 1d	Earth processes
Level 5 Unit 1e	Ecosystems

For a fuller course, focused less exclusively on hasty educational progression, there should be an emphasis on practical applications relevant at this level. This could develop general skills relevant across a wide range of technician-level work roles. The following suggestions are illustrative possibilities:

Level 5 Unit 2a	Electronics — designing circuits for practical applications, including use of logic components
Level 5 Unit 2b	Chemical laboratory analysis for an industrial context, issues of precision, quality and process control
Level 5 Unit 2c	A study involving forensic skills, with a biological focus: eg DNA analysis and relationship matching
Level 5 Unit 2d	A competitive group project involving design and schedule planning, eg bridge building
Level 5 Unit 2e	A study involving computer interfacing with monitoring equipment, recording, processing and reporting readings, and adjusting instrument settings as appropriate

A further strand could be more directly workplace oriented, enhancing work readiness for those going into employment in technical roles, for example:

Level 5 Unit 3a	An investigation of a wide range of STEM careers and career development pathways, including case studies of individual entrepreneurs
Level 5 Unit 3b	A general review of health and safety across a range of work settings
Level 5 Unit 3c	A short work placement
Level 5 Unit 3d	A group review, comparing the work placement experiences of each group member, leading to individual aspirational career plans
Level 5 Unit 3e	Studies of the significance of team working in industry contexts, following work protocols, and communication between those with different roles
Level 5 Unit 4a	Health and safety in the laboratory and in the workplace; this could include risk assessment and the interaction between the human organism and eg electricity, chemicals, radioactivity
Level 5 Unit 4b	Perhaps linked to Unit 2a, some practical work on diagnosis and ` repair of equipment, portable appliance testing, calibration, etc
Level 5 Unit 4c	General laboratory management, staff, stocktaking; equipment and consumable sourcing and purchasing

The above illustrative possibilities are presented as indicative of the sort of approach that might be followed in a 'green field' context, drawing only from our skills and concept-led approach. In this project we do not develop this thinking any further. Instead, we go on to discuss ways to link elements of our new approach to existing college-based provision in Scotland.

7.1.2 Shorter courses at level 5, and courses blended with current provision

The five core Units required before entry to the SCQF Level 6 course can be delivered in a number of ways depending on circumstances. It may be that a short full-time course can be run with the five Units being delivered before the summer break so that students are qualified to start the SCQF Level 6 course in the autumn. The five Units could also be run over one session on a day release basis.

For beginners with no recent experience in studying STEM subjects, a longer time may be needed to help students progress in the five Units.

For students who are more interested in science at level 5 the five Units plus the four Units in the Skills for Work Laboratory Science course will give a good blend of practical work and the basic concepts.

The four Units in the Laboratory Science course, which is at Intermediate 2 (SCQF Level 5), are:

Laboratory Science: Careers using Laboratory Science	1 Unit credit
Laboratory Science: Working in a Laboratory	1 Unit credit
Laboratory Science: Practical Skills	1 Unit credit
Laboratory Science: Practical Investigation	1 Unit credit

Completion of the Laboratory Science course qualifies students to progress to other NC courses and to employment.

For students more interested in engineering aspects there are two other Skills for Work courses which are relevant, namely Engineering Skills and also Energy. The Energy course fits in very well with our level 6 course with its emphasis on alternative forms of energy.

Energy: An Introduction	1 Unit credit
Energy: Domestic Wind Turbine Systems	1 Unit credit
Energy: Domestic Solar Hot Water Systems	1 Unit credit
Energy: Employability and Careers	½ Unit credit

Optional Units are:

Energy and the Individual	½ Unit credit
Energy: Oil/Gas Extraction	½ Unit credit
Energy: Conventional Production Technologies and the Grid	½ Unit credit

7.2 Some general comments on reviewing provision at level 7

For higher levels, at SCQF level 7 and above, programmes necessarily diverge, with an increasing concentration on a specific and narrower subject specialization. This is essential if learners are to achieve the depth of expertise required to function with initiative in research or in a modern industrial setting. We do, however, believe that there is significant scope, and much potential advantage, in reviewing present practice from the point of view of the perspectives that have driven our work at a lower level.

The disciplines do meet together again at nearly all of the main research frontiers, as for instance in biomedicine, nanotechnology, environmental science, renewable energy and space exploration. Industry too increasingly relies on harnessing knowledge and skills derived from different STEM specialisms. Specialists need to be aware of one another's strengths, and have a sufficient level of understanding of where their input is essential, and how, working together, they can most effectively advance their overall enterprise.

Thinking through how the very many different degree and Higher National programmes might be evolved is far beyond the scope and competence of this project team. We do believe that our level 6 proposals should provide a stronger platform from which to enter degree-level studies, and the whole motivation behind the new approach derives from the clear priorities identified by academics and industrialists in the course of our earlier studies.[18]

A first point to recognize is that our *Access to STEM* programme will have been taken by only a small minority of entrants to a particular degree or HN programme. It would not in the shorter term be appropriate to assume that the broader skills and more strategic and reflective approach to learning that our course should cultivate are fully shared by students entering straight from schools. The *Curriculum for Excellence* reforms are, however, designed to take them some way down this path.

Therefore our comments here are made on this basis:

> *So we believe that priorities are to engage students in active and deep learning, that skills development is a top priority, and we want learners to be able to think from core principles, to recognize the scope of application, and where there are connections with ideas from other fields. Are our courses ideally designed to meet these ends?*

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[18] See **http://www.gla.ac.uk/stem/projects** to access reports under 'University views' and 'Industry views'.

We hope experience of the distinctive outlook and skills of students from our programme will reinforce the motivation to carry out such an analysis.

The notes that follow suggest a number of questions and issues that might help provoke a reappraisal of courses as currently offered.

- First, a caveat seems appropriate: some of the following points will read a little like: 'let's return to the educational practices of the halcyon days of the past!' This is not the intention. Over recent decades higher education courses have come under progressively much more careful and structured review. Their impact on and success with the learner is nowadays in general more carefully analysed, and changes are quite quickly implemented to improve outcomes. But our thrust derives from new thinking. Detailed knowledge has become too vast for any learner to have instant recall of it all and, thankfully, new information technologies make it easier to retrieve details that have become hazy. Skills of thinking through a new problem or scenario are at a premium. The STEM subjects are evolving fast, and new frontiers are opened regularly. Graduates need to be prepared to adapt to radical change throughout their future careers.

- A characteristic feature of Scottish higher education historically was its breadth. During a degree students were required to study a number of subjects not directly associated with their main discipline. Such breadth has significantly reduced in recent decades. Usually there remains a rich range of module choices open, but these are typically very tightly clustered around the main specialism, which itself will often, and necessarily, be more narrowly defined. To some degree at least it might be appropriate to consider whether it would be better to encourage broader perspectives in the choice of subsidiary subject courses. Our researches demonstrated a strong consensus to build pan-STEM perspectives through schooling. How can some element of this be sustained through HE?

- Drives to identify clearly the aims of each examined subject or module have led to an emphasis on carefully articulated learning outcomes. These are often written in very tightly specific forms, often mapped rather directly to prescribed continuous assessment tasks and even to individual exam questions. It could be useful to review the ways in which this process is applied. Can learning outcomes be ensured to serve the larger educational purposes in broader skills development and strategic analysis?

- There have been drives in many cases to make examination questions more tightly specified. The twin strands of argument supporting this are to make tasks clearer to the student, and make marking a more objective and incontestable process. The bigger purpose is for learners to be able to apply their knowledge and skills in new contexts, to carry out in-depth analysis, and to notice how knowledge from one area can be usefully applied elsewhere. Often essays are set with a detailed specification of points and issues to be addressed. Often problems that are set are relatively short and closely related to standard forms previously rehearsed in detail. Should assessment processes be reviewed to ensure that they consistently reinforce the priority attached to building in-depth analysis and open-ended competences? Asking this question is one thing, addressing it can be quite challenging.

- There is a rich variety of imaginative learning and teaching strategies practised within HE, and the development of these has been much facilitated through shared experiences promoted by the HE Academies. This gives a good starting point for a review. Are the delivery mechanisms employed across a degree programme fully tuned to support the skills development prioritized? Are learner-active strategies used to full effect? How might problem-based-learning thrusts and enquiry-led studies best be balanced with more directed studies?

We are aware that course teams in many situations are regularly considering issues such as those raised above. What we tentatively suggest is that there might be value in opening up such an analysis jointly, at a level reviewing the whole range of STEM provision offered within an institution, set in a context taking explicit account of modern perspectives on the priorities that should drive degree education across STEM subjects.

Chapter 8: Towards implementation

The preceding chapters of this report have given a full account of the work done to articulate and to exemplify the fundamental object of our project, namely a 'new educational framework for the twenty-first century to address the STEM skills gap'. This last chapter describes the first stages in a process of dissemination of our conclusions, and early opportunities that have been suggested for implementation. We have deliberately focused on taking dissemination efforts forward in parallel with identifying explicit opportunities for implementation. Pursuing actual delivery of courses using the new model is necessarily a much slower process than simply presenting our conclusions to various audiences, but it is the crucial step if our work is to have ongoing impact.

During the model development stage we took opportunities to air our emerging ideas at a number of forums. This included giving progress reports at twice annual meetings of STEM-ED Scotland Partners, and also those of the Deans of Science & Engineering in Scotland. In addition, a presentation was given at the November 2009 annual conference of the Scottish Educational Research Association (SERA) and short inputs to two meetings of the Scottish Wider Access Programme (SWAP).

We were able to open much fuller and more substantive discussions with others only after the full shape and detail of our major exemplar programme, the *Access to STEM* course, was drafted in a sufficiently complete form that it could be shown to meet the criteria we had set for it. That stage was reached in mid May 2010. The progress made up to the beginning of November 2010 is summarized below. Effectively, this gives a snapshot of the state of play in relation to dissemination and implementation up to that point, which is when a completed final draft of this report was required so that it could be published before the end of December 2010. We are planning to continue to take this process forward over the coming months, and we will present a short supplementary report to the Scottish Funding Council at the end of March 2011, on the further progress achieved.

The main reason why implementation of our new model will take time to complete is that the course design, the learning and teaching approach it adopts, and the nature of the learning outcomes sought, constitute a sea change compared with current practice. Along with many of the people we have discussed our proposals with, we are confident that the new approach offers considerable benefits. However, there are bound to be lessons to learn from early experience. Simply to validate and then immediately to offer the new *Access to STEM* course in its entirety would be to take significant risks with a whole cohort of students. Hence we are aiming to encourage an incremental and progressive approach to adoption:

- We hope to find opportunities to offer small-scale pilots first, with a single new-style Unit embedded as a small modification within a larger existing programme.
- We hope to test at an intermediate level, with a cluster of new Units offering a more substantial modification of an existing programme.
- We then hope to implement the full *Access to STEM* programme.
- In the course of this process we are naturally beginning to identify other STEM programmes, mainly at SCQF level 5, where we can suggest purpose-designed new Units in our new model style.
- We hope to be able to offer support for early implementers in terms of detailed implementation, and in CPD-type support.
- We would hope that, from the first pilot applications onwards, clear feedback should be obtained on the outcomes, from learners themselves, from the lecturers involved and, subsequently, from lecturers on courses that learners go on to study.

Summary of the process May to November 2010

Groups engaged (see Glossary of acronyms at end of this chapter)

- SWAP (West): Several helpful meetings have been held with Kenny Anderson, Andrew Quinn and Lisa Marsili of SWAP (West).
- SQA: Several meetings have been held with different groups of people within SQA with the aim of gaining course approval. A summary of the meetings is given below.
- FE: Initial college contacts have been made, particularly with Stow College.
- Glasgow Caledonian University: discussions have been held about the possibility of incorporating one of our Units into the *Preparation for HE* summer school.
- Scottish Engineering: Susan Andrews Policy and Lifelong Learning Executive has shown interest in the project.
- Scottish Food and Drink Federation: Discussions have been held with the Director and Education Officer.
- Other STEM-ED Scotland Partners: Learning and Teaching Scotland representative Alyson Dobson thought that our work was ‘in line with *CfE* developments’.
- The Deans of Science and Engineering group are supportively aware of our project.

Dialogue process with SQA

Unit and course approval is needed if colleges are to engage with us in the implementation of our project and we have held numerous discussions with them over the past year. These discussions have been mainly very positive and we continue to make progress. A summary of meetings held and progress made is given below.

Preliminary meeting with HN Qualification Manager

- We were encouraged to contact the Product Marketing Manager.
- Interest was shown in the Nanotechnology Unit for inclusion in the NQ Applied Science programme.

Initial meeting with Chief Executive and Head of Marketing

- Our ideas were very positively received and seen as fully in tune with *CfE.*
- It was recommended that our course 'Should be taken to the relevant QDTs'.
- In principle our level 6 course was relevant for schools.
- There was seen to be potential value in our Units for teacher CPD/initial training.

Meeting with NQ and HN Qualification Managers

- There was strong support for our model, but the QDT process is too constrained for such an approach to be considered in general at this stage.
- There was potential for a candidate stand-alone Unit for National 5 Numeracy.
- There were possible progression links to (interdisciplinary) National 4 Science, which is currently being developed by SQA.
- Suggestions put to the officer leading the Mathematics QDT may influence how applications of mathematics might be approached in the National 4 and National 5 courses for schools.
- Also some parallels to our approach are being considered for the National 4 interdisciplinary Science course.

Meeting with Product Marketing Manager

- There could be support and guidance for staged implementation plan with initial pilots.
- There was recognition that some novelty will be involved in assessment design.
- Submission of the programme to the New Product Board is planned for November 2010.
- If successful, there would be further submission to main SQA Board.

Future meetings being pursued

- There is an arrangement to present at the next SWAP East meeting (spring 2011).
- Further progress with SWAP West: see single Unit programme below.
- FE (Dundee, Cardonald, Kilmarnock, North Glasgow, Reid Kerr).
- Forum sought to present to a wide college audience (there is an offer of support on identifying and fixing this up from an officer of Scotland's Colleges).
- Wider dissemination event — there is support in identifying an opportunity offered by SFC, and an approach is also being pursued with the Scottish Government Lifelong Learning Division.

Possible uptake of single Units to gauge impact of model

From preliminary meetings we have had there has been initial interest in the following Units:

- **Numeracy** for a pre-apprenticeship engineering course (course under way)
- **The human organism** for the *Access to Nursing* course
- **Energy sustainability** for *Preparation for HE* course and SWAP students support day (GCU)
- **Ecosystems** for *Access to Primary Education* course
- **Analysis of a commercial application** for students from Libya
- Potential interest in **Nanotechnology** as a general Unit
- **Study of a domestic appliance** for *Access to Engineering* students

Testing the impact of clusters of Units (subject to SQA approval)

It may be possible to introduce a cluster of six of our units into *Access to Science and Technology* courses by keeping the 12-Unit SQA NQ in *Applied Science* and adding our new style Units.

Implementation of the full *Access to STEM* course

This will require all 25 Units and the level 7 course to be fully approved by SQA before uptake of the course is possible in any college.

Glossary of acronyms

CfE	*Curriculum for Excellence*
CPD	Continuing Professional Development
FE	Further Education
GCU	Glasgow Caledonian University
HE	Higher Education
HN	Higher National
LTS	Learning and Teaching Scotland
NQ	National Qualification
QDT	Qualifications Design Team
SCQF	Scottish Credit and Qualifications Framework
SFC	Scottish Funding Council
SQA	Scottish Qualifications Authority
SWAP (East)	Scottish Wider Access Programme (East of Scotland)
SWAP (West)	Scottish Wider Access Programme (West of Scotland)