Important tools and methodologies in STEM subjects

The separately documented "Science Storylines" describe the level of scientific understanding that seems appropriate at SCQF level 6. This complementary note reviews the tools and methodologies that characterize scientific, mathematical and technological approaches to problem solving, investigation and projects. While there is a basic knowledge component in each methodology described, the main educational challenge is in general involves developing the specific skills required for its effective application. This survey incorporates what elsewhere might be described as "science and engineering practice."

1. Mathematics

This section supplements tools and skills that we and others have listed elsewhere under a heading of "core skills." In our own work we have reviewed these under the headings of

- numeracy:: assessing and manipulating data and quantity, and
- handling uncertainty and variability.

Those skills should be practised and reinforced in applications to science and engineering.

Important mathematics topic areas for focus at level 6 are:

- **Exponents**, notably within scientific notation, and logarithms, including addition and subtraction of logarithms, and use of logarithmic scales in graphs

- **Coordinate geometry**: use of Cartesian coordinates in two dimensions, basic manipulation of trigonometric functions; use of distance formula; eg positioning by triangulation

- **Vectors** in two and three dimensions, including addition and scalar and vector products, representation via components

- **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

- **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

- **Key tools from numeracy, algebra, proportion and graphs**

2. Engineering and technology

Some **appreciation of the nature, wide scope and importance of engineering** is perhaps the most important component, in addition to basic science and mathematics, for a school education

supporting progression to degrees and careers in 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 studies should give experience of at least some of the following characteristic engineering methodologies:

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

- **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

- **Materials selection** to meet required needs and to minimize costs: 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

- **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, scatter-grams, etc

- **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 on *Waste Electrical and Electronic Equipment*)

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 best viewed separately as one of the cores skills areas that should be addressed.

The following strands are of computer and information sciences are thought important within a general STEM education at SCQF level 6:

- **Roots of computer science in numeracy skills**: using symbols for quantities

- **The concept of information**: classes of information

- Specifying the steps in solving a general problem — **algorithms**

- **Basic introduction to programming** (using a simple high-level language

- **General ideas of how computers store, input, transform and output information**

- **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

4. Ideas about science

The scientific method

At this level, scientific methodology can in our view best be embedded as integral components of the package of **core skills** to be ensured. In our work this involves the STEM skills areas we identified as '**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 through hypothesis, model setting and attempted falsification, nor of Kuhn's analysis which suggests that science normally progresses by incremental extension in the range of applications addressed, a normal process that is occasionally punctuated by fundamental 'revolutions' in basic understanding.

Only one important idea should in our view be addressed under the "Ideas about Science" banner, namely:

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 everyone 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 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 emissions 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.