CHAPTER

3 Teaching science in the light of STEM

The nature and purpose of science education

In 2010, Wynne Harlen and a group of distinguished colleagues described ten principles of science education and, within these, identified three aims for science education:

- Understanding of a set of 'big ideas' in science which include ideas *of* science and ideas *about* science and its role in society.
- Acquiring scientific capabilities concerned with gathering and using evidence.
- Developing scientific attitudes.

These 'big ideas' are shown in Table 3.1. It is worth noting that one of the ideas *about* science acknowledges that the knowledge produced by science is used in some technologies to create products to serve human ends. This knowledge can, of course, be found in the ideas *of* science and immediately provides some justification for developing a curriculum relationship between science and design & technology.

TABLE 3.1 Fourteen big ideas in science.

Ideas of *science*	
1	All material in the Universe is made of very small particles.
2	Objects can affect other objects at a distance.
3	Changing the movement of an object requires a net force to be acting on it.
4	The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen.
5	The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.
6	The solar system is a very small part of one of millions of galaxies in the Universe.
7	Organisms are organised on a cellular basis.

(continued)

TABLE 3.1 (continued)

8	Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.
9	Genetic information is passed down from one generation of organisms to another.
10	The diversity of organisms, living and extinct, is the result of evolution.
Ideas about *science*	
11	Science assumes that for every effect there is one or more causes.
12	Scientific explanations, theories and models are those that best fit the facts known at a particular time.
13	The knowledge produced by science is used in some technologies to create products to serve human ends.
14	Applications of science often have ethical, social, economic and political implications.

Taken from Harlen (2010)

In his presidential address to the Association for Science Education in January 2012, Robin Millar made a compelling case for 'science for all'. Parts of his address were relevant to the idea of teaching science in the light of pupils' learning in design & technology. He quoted Jon Ogborn who signals that the economic argument, educating the next generation of scientists, has little worth in justifying science for all.

> A central fact about science is that it is actually done by a very small fraction of the population. The total of all scientists and engineers with graduate level qualifications is only a few percent of the whole population of an industrialized country. Thus the primary goal of a good science education cannot be to train this minority who will actually do science.
>
> (Ogborn, 2004, p. 70)

However, the voice from government, in the report of the Science and Learning Expert Group (2010) indicates that this minority will play a crucial role in the future of the UK:

> Global development means that the competition and market for the products of science, engineering and technology are greater than ever before. It is a truism to state that the future of the UK depends critically on the education of future generations. Science, Technology, Engineering and Mathematics (STEM) must be at the forefront of education in order for the UK to address some of the most important challenges facing society.
>
> (Science and Learning Expert Group, 2010)

Those concerned about the place of STEM in the curriculum have voiced concern about how the science curriculum appeals to pupils. The review by Sir Gareth Roberts 'SET for success' noted:

> widespread concern that science is taught in a way that does not appeal to many pupils and that the curriculum places too much emphasis on rote learning rather than relating theory to situations relevant to the pupil.
>
> (Roberts, 2002)

This provides a hint that relating science learning to the wider world in which it is applied could pay dividends.

However, there is a problem with much science understanding. It is counter-intuitive but a common-sense approach will almost certainly lead to ideas that aren't scientific. Learners have to contend with what Lewis Wolpert has called 'the unnatural nature of science'. This is compounded by the way in which pupils might respond personally to the nature of science, termed the 'affective challenge' by James Donnelly:

> Scientific knowledge offers a materialistic worldview which, in its substance, is devoid of humane reference, whatever might be said of its practices and its implications. Science is profoundly successful, on its own terms, and scientific knowledge profoundly authoritative. In consequence, creating scope for the individuality of pupils to come into play is difficult…these characteristics of science challenge pupils affectively and cognitively…It might even be said that they are somewhat at odds with the tenor of modern cultural life.
>
> (Donnelly, 2003, p. 19)

Robin Millar finds a telling quote from a student that supports this position. In science, 'there's no room to put anything of *you* into it'. Again there is the suggestion that enabling pupils to relate science learning to aspects of learning 'outside science' might pay dividends.

Science and design & technology in the light of STEM

David Layton, an acknowledged expert of in both science and design & technology education, played a key role in the conception of design & technology in the National Curriculum in England. He acknowledged the difficulty faced by science education. Writing as long ago as 1975: 'At the school level…the acquisition of scientific knowledge is inescapably tinged with dogmatism'. But 20 years later he used the following metaphorical question to explore the relationship between science and technology, 'Should science be seen as a cathedral, a quarry or a company store?' This has significant implications for the curriculum relationship between science and design & technology. In the 'cathedral' of science, the purpose of the endeavour is to explore and explain natural phenomena without much consideration of possible application or exploitation. The goal is understanding – 'worshiping science for its own sake'. This is a purist position. Of course, in reality there is a dynamic relationship between science and technology in which there is a spectrum of responses – from pure/fundamental science, driven by curiosity and speculation about the natural world without the thought of possible applications; through strategic science, yielding a reservoir of knowledge, out of which the as yet unidentified winning products and processes will occur; to applied science, related to a specific project and tied closely to a timetable with a practical outcome often specified by a client. Technologists, Layton argues, can rarely specify in advance what items in the cathedral will be most useful and so they treat it more as a 'quarry' to be visited and revisited, less as a place to marvel at the beauty of creation than to search out for items that might be of use. Note that in the middle ground Layton suggests the idea of the 'company store' – spaces where strategic investigations predominate. We would identify such spaces as research and development centres where, to quote Layton, 'the products of the cathedral are reorganised and remodelled to make them more accessible to practical users rather than worshippers'. So perhaps the science teacher wishing to teach in the light of pupils' learning in design & technology will need to view the knowledge, skill and understanding she teaches not only as a place of wonder and awe but also as a region into which her pupils can make forays of exploration for a variety of design & technological purposes – a space to be raided for that most precious of commodities – ideas that work.

Science and mathematics in the light of STEM

So far, this discussion has concentrated on the possible significance of a curriculum relationship between science and design & technology. We must now consider the relationship between mathematics and science. There is general agreement that mathematical thinking provides the ability to identify and describe patterns in a wide range of phenomena. Clearly, this ability will prove useful in science, particularly in the move from qualitative to quantitative thinking. Consideration of, for example, speed, velocity and acceleration, only becomes worthwhile and potentially useful once such phenomena can be described algebraically and the 'describing' formula can be used to justify, for example, speed limits with regard to road safety. Here again we have an example that takes the 'dogmatism' of science required for particular and precise definition and can be linked to the wider world and the personal interests and welfare of pupils. Such work could be extended in a variety of ways that make use of mathematics, including the derivation and interpretation of graphs to describe the motion of driven vehicles and the collation and interpretation of road safety statistics.

We have seen that the views of significant members of the science education community concerning the implementation of one science curriculum 'for all' have revealed how the very nature of science can cause tension. We have noted that there is the possibility of resolving this tension to some extent by relating science learning to its application in the wider world through developing curriculum relationships with mathematics and design & technology. However, it is important to consider the status of those engaged in this relationship. We discuss this issue in the following section.

A relationship among equals?

There is little doubt that science and mathematics are privileged subjects in terms of their curriculum status. Mathematics has long been regarded as an essential element in the education of all pupils. It has significant cultural status having been developed over centuries and providing the solution to some of history's most intractable problems. Jonathan Osborne, in his address at the 50-year celebration of the Nuffield Foundation, reminded the audience that this was not always the case for science education. At the end of the nineteenth century and beginning of the twentieth century some thought that the 'proper' education for an elite was deeply rooted in the Classics and humanities. This view was that science and technology were a necessary evil and that they did not offer proper training for the mind and that science had nothing to say about the human condition. It was believed that 'ordinary' people need only be educated in the three Rs. A particularly well known rebuttal of this anti-science education position came in 1959 from C. P. Snow, who argued that anyone who did not know and understand the implications of the Second Law Of Thermodynamics could hardly be considered educated. And now some 60 years later, science along with mathematics has an apparently unassailable opposition in the curriculum. But what of design & technology – a relative newcomer to the curriculum existing in England as a defined entity within the national curriculum only since 1990? Both Jonathan Osborne and Robin Millar are clear that science education has definite instructional goals. There are singular answers to particular questions. Millar (2012) sums this up well when he writes 'There is no merit in helping a learner to construct an idiosyncratic personal theory of matter or of motion (to take two examples) – it is the kinetic particle model and Newton's Laws that we want then to understand and be able to use' (p. 23).

Similarly, in mathematics teaching the educative goal is to some extent to impart agreed mathematical truths and procedures to enable mathematical thinking. This indicates a very real difference from design & technology where the values of both the designer and end user are integral to the process. Of course, there are clearly identified matters to be taught and learned in design & technology; properties of materials, ways to manipulate and join materials, ways to enable control and systems thinking for which there is an agreed understanding – but this is only half the story. Pupils then use this learning to develop products and systems to meet needs, wants and opportunities and it is perfectly possible, and indeed desirable, that the outcomes of this development produced by different pupils vary widely from one another. The extent to which particular developments meet needs, wants and opportunities is a matter of judgment and it is possible for quite different responses to be worthwhile. Hence design & technology does not suffer from the 'dogmatism' identified by David Layton. John Holman and Michael Reiss were very clear in their report to the Royal Society, 'S-T-E-M Working Together for Schools and Colleges', that it was important that any form of curriculum collaboration between science, mathematics and design & technology respected the legitimate differences between the subjects as well capitalising on areas of common interest. A difference of particular importance is the legitimacy of individual interpretations and responses in design & technology compared with the almost exact opposite in mathematics and science.

In the previous section we considered how difficulties in pursuing science for all caused by the nature of science itself might be resolved to some extent by forging curriculum relationships with design & technology and mathematics. In this section we have noted that within these relationships it is essential that legitimate differences between the subjects are both recognised and valued. In the following section we will provide examples of how science activities can be related to pupil learning in design & technology and mathematics, taking these issues into account.

Examples of teaching science in the light of STEM

It is important to illustrate that all areas of science can benefit from teaching in the light of learning in design & technology and mathematics. Hence the following examples cover the breadth of science. They take into account the importance of recognising and valuing legitimate differences in the subjects involved.

Example 1: The magnetic effects of electric currents

Teaching the magnetic effects of electric currents

Imagine a sequence of lessons concerned with teaching the effects of an electric current. You, as the teacher, could use iron filings and button compasses to show that as a direct electric current flows through a straight wire it generates a circular magnetic field around that wire. You could then challenge the pupils to explore what sorts of magnetic fields are formed when a coil of wire is used. With some guidance the pupils should be able to find out that the circular fields combine to give a field like that of a bar magnet. You could then challenge pupils to investigate the reverse possibilities with the question 'what effect does a magnetic field have on the electricity in a wire?' With some scaffolding their investigations you could show that a moving magnetic field causes an electric current to flow in a wire. You could place this learning in the 'cathedral' of science indicating that these breakthroughs was made by the great Danish scientist Hans Oersted and the great English scientist Michael Faraday in the first half of the nineteenth century.

In the early days of scientific investigation the prize sought was understanding with little thought of application. What we would now call 'blue sky research'. Yet the results of this understanding led to the development of solenoids, electric motors and dynamos. But it took over 50 years before these discoveries about the relationship between electricity and magnetism led to a powerful and useful electric motor. This is a clear example of Wynne Harlen's ideas *of* science – objects can affect other objects at a distance – and ideas *about* science – for every effect there is one or more causes and the knowledge produced by science is used in some technologies to create products to serve human ends. At this stage it would be worth reminding the class of the electric motors that they use in their design & technology lessons – small direct current motors containing permanent magnets. It would also be worth showing the class the internal structure of such a motor and giving them the opportunity to construct a simple electric motor for themselves (Gupta, 2014). Through these activities the pupils will begin to appreciate how the 'cathedral' can become the 'quarry' that can be mined for ideas of practical application. In this case, the understanding of the phenomena of electromagnetism being exploited to develop the electric motor.

Now it is worth the pupils considering how they might use their understanding of magnetism and electromagnetism in their design & technology lessons. The Design and Technology Association have developed visual materials that allow teachers and pupils to explore open starting points for their designing and making. These enable a class to explore a range of possible options without starting with a pre-defined product. Six starting points have been identified – playtime, keeping in touch, keeping secure, staying safe, thinking machines and other worlds. For example, let's say that a design & technology teacher is exploring playtime with the class. She could suggest that whatever is designed uses electromagnetism and or magnetism. This would provide a technical focus for the activity without overly limiting the variety of toys that the pupils might choose to develop. The simple electric motor the pupils have already constructed could be a starting point for some pupils. It is not powerful but does spin very quickly and could be made the basis for a wide range of amusing and intriguing visual effects. Here, we have an example which illustrates the moves from the 'non-negotiable precision' required by science to the flexible interpretation necessary in design & technology. A science teacher could deal with the teaching of electromagnetism through demonstration only, communicating explanations to be learned. By requiring pupils to carry out investigations and simple making, the activity moves to a place where pupils have to construct their own understanding. Using the understanding and the artefact, both 'constructed' by the pupils, in a designing and making task moves the pupils into situations where speculation is crucial – 'What if I do this? 'Can I do this?' 'Will this work' 'What about this?' The pupils are treating their science knowledge and understanding as a resource to be exploited, pushing it to the limits in their quest to produce an engaging toy. This almost playful pushing to the limits will in some cases require pupils to reformulate and increase their understanding.

With all electrical items powered by batteries there are opportunities to consider battery life. This requires the use of calculations which use data about the current that flows when the item is used. In this case of simple electric motor driven toys, some pupils will be able to measure current consumption and use this to calculate how long particular batteries or arrangements of batteries might last. This is not a trivial task and for pupils aged 11–14 this would almost certainly be seen as extension work for those who had shown an aptitude to using mathematics. Conversations between all the subject specialist teachers are important here to ensure that the relevant science concepts are used appropriately, that the mathematical manipulations are sound and that the circuits under consideration are appropriate.

Example 2: Floating and sinking

The work of Archimedes in the second century BC is perhaps one of the first historical examples of scientific activity that can be seen to occupy David Layton's 'company store'. Archimedes was set the task of determining whether a crown made for King Hiero had been made from pure gold as supplied by the king or whether silver had been added by the goldsmith. Using the principle of buoyancy – the loss of weight when an object is immersed in water – Archimedes was able to show that the goldsmith was dishonest and had adulterated the pure gold with silver.

Teaching buoyancy

Young pupils are introduced to the idea of buoyancy in the primary school by means of classifying materials as floaters or sinkers. This leads to the idea that some materials are more dense than others. It is not until they become older that they are asked to explain the mechanism that causes some materials to float and others sink. Here, they are required to consider the forces acting on the material and conduct experiments in which they weigh materials in air and immersed in water and compare the apparent loss of weight on immersion with the weight of the water displaced by the material. Ultimately, they come to a statement of Archimedes Principle: any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. This is a clear example of Wynne Harlen's ideas *about* science – for every effect there is one or more causes and scientific explanation best fitting the facts known at a particular time.

The science teacher can help pupils relate this principle to their everyday experiences of floating in the bath, the swimming pool or the sea. So given a table of the density of materials it becomes relatively easy to spot the pattern that if a material has a density greater than that of water (1g per cubic centimetre) then it will sink. It doesn't matter how much of the material is present – a single gram of lead will sink just as surely as a kilogram. The calculation of the density of different materials, involving weighing and the measurement or calculation of volume would be an appropriate mathematics activity and there is no reason why some of this investigation into why some materials sink and others float should not be carried out as a part of mathematics lessons as well as science lessons. Mathematics teachers appreciate the difficulty pupils experience in understanding compound measures and exploring density would provide a useful activity to support learning in this area.

Both the mathematics teacher and the science teacher can challenge pupils' understanding with the question, 'If iron and steel sink then how come ships made of iron and steel float?' Discussion can lead to the idea of shaping materials so that the shape can displace more than the volume of the material. This is easy to demonstrate in the design & technology workshop as follows. A disc of thin aluminium sheet when placed in water sinks. The disc can then be formed into a bowl by beating with a pear-shaped mallet in a dishing block and will then float when placed in water. This can be the starting point for a designing and making activity in design & technology in which pupils make water toys. These can include bath toys and small-scale replicas of yachts and powerboats. This links to Wynne Harlen's ideas *about* science – its use to create products. In all cases the way the toy floats will be dependent on both the material of the hull and the form of the hull. A hull made of solid wood will float very low in the water – it will be almost submerged. So in order to float in a realistic way the wood must not only be shaped to resemble a hull but also hollowed out to some extent. A hull made by vacuum forming thin sheet plastic over a hull-shaped solid block floats very high in the water, almost skimming along the surface. In this case additional weight needs to be added to reduce the buoyancy and achieve realistic floating. If the hull is to be made from sheet metal then it has to be formed from flat 'tin plate' into a hull shape. This is difficult to achieve without cutting the sheet into a net which is then folded up into a hull shape and soldered at the joins to prevent water leaking into the hull. The need to meet these making challenges in design & technology can be seen in the context of the learning about buoyancy that takes place in science lessons.

Example 3: Clean, accessible drinking water for all

'Chemistry for Tomorrow's World: A roadmap for the chemical science' produced by the Royal Society of Chemistry identifies 10 challenges for the chemical sciences. One of these is drinking water quality. Access to safe drinking water and adequate sanitation varies dramatically with geography and many regions already face severe scarcity. Current population forecasts suggest that an additional 784 million people worldwide will need to gain access to improved drinking water sources to meet the UN Millennium Development Goal target: to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. The World Health Organization estimates that safe water could prevent 1.4 million child deaths from diarrhoea each year. Technology breakthroughs required include:

energy efficient desalination processes; energy efficient point of use purification, for example, disinfection processes and novel membrane technologies; developing low-cost portable technologies for analysing and treating contaminated groundwater that are effective and appropriate for use by local populations in the developing world, such as for testing arsenic-contaminated groundwater. There are strong links here with Wynne Harlen's ideas about science – the knowledge produced by science is used in some technologies to create products to serve human ends.

Teaching purification

For the science teacher, teaching about the simple purification techniques such as filtration and distillation is the starting point to developing the knowledge and understanding required to tackle this global problem. Situating the teaching of this elementary science in the context of this problem would indicate clearly the importance of science knowledge and understanding in tackling the large problems faced by the world.

There is a growing movement to encourage designers to tackle the problems encountered in the developing world. Books such as *Design for the other 90 per cent* (2008), *Design like you give a damn* (2006) and *Design Revolution* (2009) are written to inform the general public about the way design can be a powerful means to improving the situation and to provoke a response from the design community. There is no reason why this approach cannot be extended to pupils in schools through the design & technology curriculum and build on the work carried out in science. Pupils could be challenged to develop simple filtration devices that 'clean' cloudy water and simple distillation devices to desalinate salt water. Such devices need only be developed into preliminary working prototypes that indicate their effectiveness. The pupils could then compare their designs with the devices developed by professional designers to identify differences and similarities, note where the basic science separation techniques were used, and enhance their appreciation of user-centred design and the importance of designs that empower people to improve their situation.

This learning of science in the light of learning in design & technology can also be extended to include mathematics quite simply. Asking pupils in mathematics lessons to estimate the amount of water they and their families use each day and compare this to that available to those living in developing countries would be a valuable learning activity. It could also lead to pupils considering the water shortages that might take place in the UK and the way such shortages are dealt with. This would inevitably lead to the question 'Where does our water come from?' which would take the learning science in the light of STEM full circle back to the science curriculum and the water cycle.

Example 4: The properties and applications of metals

Teaching metals

Consider the topic of 'metals'. The classification of some elements as metals or non-metals was an important step towards understanding the behaviour of these elements in chemical reactions. Most chemistry teachers will teach about metals: what they are like (their properties); where they come from (natural resources); how we get them (reduction of metal ores); what they are used for and why (properties related to use).

The design & technology curriculum is concerned with teaching what metals are like (properties); what they can be used for (properties related to use); how we can manipulate them (making skills) to design and make products that people need and want. Clearly, there is an overlap in teaching intention here and there is the possibility of capitalising on this through a collaborative scheme of work in which the science teaching about metals is tackled in the light of the learning that is taking place in design & technology. It will of course be important to engage with pupils in their daily lives and a simple 'homework' investigation of where there is metal at home and what is it used for will reveal its ubiquity – door handles, coat hooks, door knockers, casings for white goods, interiors of washing machines, filaments of light bulbs, electrical wiring, cooking utensils, cutlery, plumbing pipe work, mobile phone cases, etc. Pupils' attention can also be directed to the underlying structural framework of most modern buildings plus the chassis, body shell and moving parts of most cars and railway lines and the trains that run on them. Such a homework exercise can be divided between science and design & technology. Of course, the bigger picture must also be considered i.e., the amount of production and its impact, the use and disposal of metal and the multifarious ways that metal is utilised in the made world. To find and use data about this requires some understanding of statistics and the ability to question what such data means. Hence there is an interesting role for the mathematics teacher in this collaboration.

Chemistry teachers will teach about the reduction of metal ores through practical activities that are reliable and intriguing. In design & technology lessons the designing and making of simple body adornments is a relatively standard yet highly enjoyable exercise – copper rings, brooches, bangles, and bracelets are all possible. It could be possible to link the production of copper from its ores learned in a science lesson to the use made of copper in the manufacture of body adornment. One possible way is to start with the copper ore in a science 'lesson' and from this produce enough copper to be used in making copper rings and bangles. This is perhaps not amenable to the everyday timetable but as a STEM club activity, the production of copper from a small sack of green ore (malachite) by means of a home-made blast furnace would provide insight into industrial processes that produce the materials pupils use in their daily lives difficult to achieve in any other way.

Chemistry teachers may also teach about the electrolytic purification of crude copper that has been obtained by the reduction of copper ores. The electrolytic deposition of copper from a solution containing copper ions can also be used in design & technology lessons to decorate brass with designs made from copper. It is a relatively simple activity involving using the brass as the anode onto which copper will be deposited and masking areas of the brass so that electrolytic deposition takes place in the form of the desired decoration. Only a thin film of copper need be deposited to give a good effect. Once pupils have been taught about electrolysis in science it would be an interesting assessment of their learning to challenge them with decorating brass with copper as part of a sequence of design & technology lessons concerned with producing body adornment.

Example 5: Nutrition

Teaching digestion and respiration

Many science courses for pupils aged 11–14 years teach digestion and its relationship with respiration. The 'key idea' here is that in many foodstuffs the molecules are large, in the form of polymers, and that for these materials to become useful to the body the large molecules need to be broken down in order to be absorbed through the gut wall (small intestine) and enter the bloodstream. Once in the bloodstream they can be transported throughout the body. Often, but not always, the treatment of digestion is limited to the digestion of starch which breaks down to form glucose and that the glucose is then available as a source of energy to drive the chemical reactions on which the body depends and the use of muscles.

The formation of glucose from starch is often demonstrated through an experiment involving visking tubing, a semi-permeable membrane representing the gut wall. A starch solution is placed in some visking tubing sealed at one end and saliva is added. The tubing is lowered into water at body temperature. The pupils test for the presence of starch and glucose at regular intervals in small samples taken from within the visking tubing and the surrounding water. Care must be taken to avoid contamination between the solution inside the visking tubing and the surrounding water. Ideally, the test results should show the disappearance of starch from within the visking tubing and the appearance of glucose in the surrounding water. Students are given information about the size of starch molecules, glucose molecules and the perforations (holes) in the visking tubing and have to deduce the activity of the enzymes in the saliva in breaking down the large molecules of starch to much smaller molecules of glucose which can pass through the holes in the visking tubing which are too small to allow starch molecules to pass. This explanation is linked strongly to Wynne Harlen's idea *of* science – all material in the Universe is made of very small particles – but extended to include the idea that these very small particles can be of different sizes. It can be related to another of Wynne Harlen's ideas of science – organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms – by discussing with pupils where we might acquire starch in our diet in order to produce glucose.

It is at this point when the science teacher might consider reminding pupils of their work in food technology. Through discussion with stakeholders, Marion Rutland has identified the following conceptual framework as being essential for a modern food technology course:

1. Designing and making food products
2. Underpinned by an understanding of the science of food and cooking and nutrition
3. Incorporating an exploration of both existing, new and emerging food technologies
4. In the context of the sustainable development of food supplies locally, nationally and globally
5. Incorporating an appreciation of the roles of the consumer, the food industry and government agencies in influencing, monitoring, regulating and developing the food we eat.

Learning about digestion as described above links strongly to the second concept mentioned above (understanding of nutrition in particular) and also the fourth concept (concerning food supplies). So it should be relatively easy for the science teacher and the food technology teacher to collaborate around the teaching of digestion, where the food technology teacher continues the work of the science teacher but deals with sources of starch in various food stuffs, naturally occurring, processed and synthetic, and relates this to the labelling of food stuffs that now indicate their calorific value.

Calorific values are a cause of considerable conceptual confusion for pupils. Calorific values are derived by burning foods and measuring the heat produced. For many pupils the relation of this to the energy released during respiration of small molecules derived from such foods in our bodies is so counter intuitive that it seems to be completely mysterious. Pupils can of course calculate the heat released when potato crisps or breakfast cereals are burned but this is not a trivial task. This might take place in either the science or food technology classroom – perhaps even both. First, the material to be burned must be weighed. Then as it is burned the heat from the burning must be transferred to a measured amount of water. The temperature rise caused by the burning must be accurately measured. This temperature rise must be converted into the amount of calories that caused the temperature rise. This, plus the weight of material burned, must be used to calculate the heat released per gram. This involves a lot of calculations relying on sound arithmetic (or competent use of a calculator) and a strong understanding of ratio and proportion. So a conversation with the mathematics teacher would not be amiss here. Indeed the mathematics teacher might welcome the opportunity for pupils to be engaged in using mathematics for such a 'real world' purpose. The results obtained will probably not mirror those produced by professional food technologists and listed on food packaging. If the order of magnitude is similar then this is of great credit to the pupils. There are several sources of error over which they have little control given the equipment available in junior high schools. For example, some of the heat released will be absorbed by the atmosphere and some will be transferred to the container holding the water; measuring the temperature will be accurate only to one or two degrees; weighing the material to be burned will be accurate to only 0.1 gram. These inadequacies in experimental design can of course be discussed with the pupils in terms of Wynne Harlen's ideas *about* science – scientific explanations, theories and models are those that best fit the facts known at a particular time. Here the facts are being derived from experimental data and are used to support a scientific explanation of respiration of foodstuffs providing the body with energy. To achieve genuine understanding it is necessary to make the link between the measurement of calorific value of food by heat transfer and the energy made available to cells throughout the body through respiration of small molecules derived from the food by digestion which is expressed on food packaging. It is difficult to see how else this can be achieved other than by collaboration between the science, food technology and mathematics teachers. In food technology lessons pupils sometimes develop products for those with special dietary requirements and controlling calorie intake is often essential. Demystifying the energy content of various foodstuffs by enabling pupils to understand how such values are obtained gives an important scientific dimension to such activities.

Example 6: Genetic modification

Teaching genetics

Most school biology courses now describe and explain genetic modification (GM) and discuss possible costs and benefits of applying this knowledge to the development of genetically modified organisms particularly with regard to GM crops. Here we have examples of Wynne Harlen's ideas of science – genetic information is passed down from one generation of organisms to another and ideas about science – the knowledge produced by science is used in some technologies to create products to serve human ends and applications of science often have ethical, social, economic and political implications.

The production and use of GM crops is a topic that raises strong emotions. In 1999, the UK reaction against GM crops was so strong that supermarkets removed products containing or associated with GM crops from their shelves. The science writer Bernard Dixon provides an interesting account of the influences of many different stakeholders that led to this rejection citing, in particular, the circulation wars in the popular press leading to sensationalism which coupled with public ignorance led to an irrational fear of the new and emerging technology. The treatment in most science courses is now much more balanced giving voice to concerns by those who are apprehensive towards or against the use of GM crops, providing counter arguments and engaging pupils in discussion of the issues from different stakeholder perspectives. Such an approach is exemplified by the twenty-first century science biology course for pupils aged 14–16 years (Nuffield, York Twenty First Century Science, 2011). Hopefully, in the future such courses will lead to a general public who are better informed. However, as far as the UK is concerned the damage has been done and GM products are not available. Yet, the debate still continues so it is important for the science teacher to keep up to date with developments. For example, at the time of writing, the state of California is about to vote on Proposition 37 which would require the labelling of all foods containing GM ingredients and prohibit such foods from being marketed as 'natural'.

There appears to be little evidence that GM ingredients are intrinsically harmful to humans. GM can be used to develop pesticide resistance in crops, allowing farmers to use pesticides on such GM crops without harming the crops while preventing weeds from competing with the crops. But there is some evidence that this can lead to pests evolving resistance more rapidly. The situation is complex and proponents of GM argue that rather than preventing the use of GM, it should be extended to include a wider range of GM crops which could reduce the likelihood of resistance emerging by allowing farmers to switch the chemicals they use before pests evolve resistance. There are some, e.g., Greenpeace, who are philosophically opposed to the use of GM on the grounds that it is not natural and that natural plant breeding methods can and should be used. They have sited a developed strain of sweet potato that has four to six times the beta-carotene of an average sweet potato without recourse to genetic modification. Beta-carotene is a precursor to vitamin A in the body and important in preventing blindness in young children. A two-year project in Uganda involving 110,000 households demonstrated that eating the improved variety almost doubled the number of children who escaped vitamin A deficiency. This approach is in direct contrast to the Golden Rice project which has developed GM golden rice (golden in colour as opposed to the white) which contains significant amounts of beta-carotene. Ordinary rice contains no beta-carotene. The latest trials of golden rice using isotopic labelling indicated that just 100 to 150 grams of the rice – about half the children's daily intake – provided 60 per cent of the recommended daily intake of vitamin A. An editorial in the *New Scientist* magazine in 2012 called for multiple solutions to be adopted to combat preventable blindness; not just natural breeding, not just GM but both.

There are those who argue that natural breeding methods will be totally inadequate and it is only through significant investment and deployment of GM that the world food problem can be addressed. Mark Lynas, once a committed activist against GM, has now completely changed his position in response to consideration of planetary boundaries with particular regard to the nitrogen boundary. The natural mechanisms of the nitrogen cycle do not provide enough nitrogen in forms that can be used as fertiliser to support growing the food the world needs. The synthesis of ammonia and nitrates from nitrogen in the atmosphere has enabled the world to produce significant amounts of fertiliser that are used worldwide but at significant environmental cost. He argues that it will be essential to develop GM crops that are more efficient at utilising nitrogen thus reducing and even eliminating our dependency on synthetic fertilisers.

Where does all this leave the food technology teacher? Marion Rutland has argued that a modern food technology programme should involve a consideration of new and emerging food technologies and GM would seem an important example. Often in design & technology classes pupils are challenged with the question 'What would you use this or that technology for?' Clearly, if the technology in question is GM it is important that the food technology teacher is *au fait* with the learning that has taken place in science. Similarly, it is important that the science teacher who is teaching about GM knows that there is the possibility that pupils will be asked to consider its applications as a new and emerging technology in their food technology lessons. In considering GM in food technology, especially when speculating about possible uses, it is important that the speculation deals with what is feasible and that it is underpinned by current scientific understanding. Marion has also argued that in a modern food technology programme pupils should consider the sustainable development of food supplies locally, nationally and globally. Considering the role of GM crops would certainly enable pupils to engage with the global picture. And it is here that the use of mathematics will be significant in helping pupils understand the sheer scale of the GM problem: the projected growth in world population, the different foods needed to feed the increasing population, the extent of malnutrition in the world and resultant dietary related disease, the amount of fertiliser and pesticides that are needed to maintain the food production. The statistics used to track these issues and their interpretation to inform global food policy will provide a rich context for learning and using mathematics.

Example 7: Building your own laboratory equipment

Teaching experimental equipment

In attempts to modernise science curricula many teachers use data logging equipment. But such equipment is expensive and when finances are limited schools can only afford to purchase one or two of such items then their use is confined to demonstrations. Joshua Pearce, an associate professor at Michigan Tech in the US, has found a solution to this problem, one he applies to his own work in higher education and one that he feels is also appropriate for secondary (high) schools. Joshua advocates the use of a 3D printer to produce structural parts and the open source Arduino microcontroller to drive the 3D printer and provide data capture functionality. For schools in the UK the PICAXE microcontroller could be used to achieve the same result.

Joshua Pearce waxes lyrical about the benefits of using 3D printers in educational settings:

> The open-source microcontroller is key. The beauty of this tool is that it's very easy to learn. It makes it so simple to automate processes. Here's how it works. The Arduino chip – which retails for about $35 at RadioShack – can run any number of scientific instruments, among them a Geiger counter, an oscilloscope and a DNA sequencer. But it really shines when it operates 3D printers like the open-source RepRap. This microwave-sized contraption starts at about $500 and can actually make parts for itself. Once you have one RepRap, you can make an entire flock. My lab has five. 3D printers make stuff by laying down sub-millimetre-thick layers of plastic one after another in a specific pattern. This allows users to make devices to their own specifications, so they don't have to make do with what's available off the shelf. The Arduino controls the process, telling the printer to make anything from toy trains to a lab jack. Lab jacks raise and lower optical equipment and aren't radically different from the jacks that raise and lower your car, except that they are more precise. I received a quote for a $1,000 version, which inspired me to design my own. Using a RepRap, inexpensive plastic filament and a few nuts and bolts my students and I made one for under a buck. Then we posted the OpenSCAD code used to make the lab jack on Thingiverse, a web repository of designs where members of the 'maker community' can submit their designs for all kinds of objects and receive feedback. Immediately someone I'd never met said, 'This isn't going to work quite right, you need to do this'. We made a simple change, and now I have a lab jack that's superior to our original design. The Thingiverse community already has a whole line of open-source designs for over 30,000 'things', and everyday it's only getting better. Using open-source hardware has easily saved our research group thousands of dollars, and we are only getting warmed up. This will change the way things are done.
>
> (Pearce, 2012)

3D printers are becoming available to secondary schools in England and at the time of writing the Department for Education has initiated a small pilot study to explore their use in the design & technology curriculum. The use of microcontrollers, usually PICAXE, has become well established in some design & technology departments due to in-service training programmes that focus on the use of digital technologies. Hence, for a science teacher who wants her pupils to develop their own experiments there is the possibility of students using the learning in design & technology to devise and manufacture the necessary equipment. This would not be a trivial task. The science and design & technology teachers would need to discuss at some length the sorts of experiment that the pupils might wish to carry out, the equipment required and the programming of the microcontrollers necessary to enable sensors to collect the required data. In all probability the design & technology department would have computer assisted design (CAD) software that students could use to design structural parts and produce files that could be loaded directly into the 3D printer. This would eliminate the need to programme a microcontroller system to drive the 3D printer. In developing the structural parts for their experiment there is scope for considerable mathematical thinking that uses pupils' knowledge and understanding of both measurement and geometry. Achieving the correct size, shape and form for laboratory equipment such that the result can contain the electronics and required battery, allows access for battery replacement and microcontroller programming, connection of sensors is no mean feat. A three-way conversation between the science, design & technology and mathematics teachers would reveal the extent to which mathematics learning could be used to enhance and facilitate this task.

Action Programme 10 of the National STEM Programme in England was devoted to improving the quality of practical work in science. The body responsible for this aspect of the programme was SCORE (Science Community Representing Education). SCORE is a partnership between the Association for Science Education, the Biosciences Federation, the Institute of Biology, the Institute of Physics, the Royal Society, the Royal Society of Chemistry and the Science Council. SCORE acts under the auspices of the Royal Society. SCORE developed a framework for practical work in science and an accompanying professional development programme enabling teachers to discuss the framework and build it into their teaching. The framework identified a range of features present in high quality practical work including the following:

- Self-directed enquiry by individuals, or more commonly by groups, which promotes 'pupil ownership' of science and can be motivating and enjoyable.
- Investigations to encourage teamwork with members being given particular roles in the planning, implementing, interpreting and communication of the work.
- Extended enquiry or projects which encourage pupil autonomy and opportunities for decision making.
- Use of ICT for handing and presenting data and contemporary technical equipment to relate science techniques in school to modern practice.

Developing your own laboratory equipment in the way advocated by Joshua Pearce would meet the features identified by SCORE in high quality practical work and provides an inspirational example of teaching science in the light of STEM.

As we have seen from the examples above it is possible to teach some science topics in the light of STEM but one of the challenges is for teachers to be given an introduction to the possibilities. The following case study shows how physics teachers were able to respond positively once given this introduction.

Continuing professional development for physics teachers – a case study

In an attempt to address the issue of CPD, I worked with Peter Campbell in providing a professional development session for physics teachers concerning links between physics and design & technology. Peter is a highly experienced physics teacher and curriculum developer. In 2009, he was the course tutor for a 40-day physics in-service training course, part of the 'Science Additional Specialisms Programme' that helps practising chemistry and biology teachers to become effective physics teachers. As part of this course, one session posed the question, 'Is it worth physics teachers and design & technology teachers having a conversation about what they teach and how, with a view to improving pupils' learning experiences?' The half-day session began with a presentation clarifying the difference between science and technology and the place of design in technology. It also set the scene for considering the interaction between physics and design & technology in the secondary school curriculum. After the introduction the teachers tackled a range of practical activities. The activities were divided into two sets. The first set involved exploring phenomena, taking the position that a technology is a phenomenon that is captured and put to use. The second set involved considering how artefacts might be improved through re-design. The activities are summarised in Table 3.2. Peter answered a range of questions in response to the session and the activities.

In response to the question, 'Why might it be important for physics education to interact with design & technology education?' Peter answered:

> Physics is not an isolated discipline. It is important to make connections with other subjects explicit while teaching physics, because this can stimulate new interests for pupils or enhance their existing interests. Without help, few pupils manage to see such connections. Connecting physics to other curriculum subjects helps keep the physics curriculum broad. A school physics curriculum that focuses too narrowly on general principles and mathematical models will deter most pupils from engaging. Very few pupils, if any, will emulate Paul Dirac in a quest for the abstract. Those who leave school to continue their physics education, as aspiring engineers or physicists, do move progressively towards this goal. As well as being important for pupils, it is also important for the physics teacher to make connections with other subjects. The viewpoint of other subjects can give fresh insight into a physics topic. For example, understanding the mechanical properties of materials in physics is enhanced by engaging with design & technology perspectives such as manufacturing processes, cost, and availability.

In response to the question, 'In general, what do you think the experience gave the non-specialist physics teachers?' Peter commented:

The session exploring links to design & technology was the third in a series of 'eye-opening' sessions; music and art had been considered previously. Hence, to some extent the teachers were predisposed to consider connections in a favourable light. The principles used to formulate the nature of the activities were an important feature of the experience. In the world of pure science, research projects typically involve collecting huge data sets which are painstakingly analysed to draw conclusions (e.g., the COBE mission team's study of cosmic background radiation critically scrutinised their data for two years before finally publishing it in 1992). By contrast, these activities concentrated on either a) investigating a phenomenon to inform the design of an artefact that utilises the phenomenon or b) investigating an artefact to gain understanding to improve or modify the performance of the artefact.

TABLE 3.2 Practical activities to explore the relationship between physics and design & technology.

Exploring a phenomenon	
1	Exploring the Peltier effect
2	Exploring the behaviour of a small paper helicopter
3	Considering the properties of sheet material
4	Observing rolling cylinders
5	Investigating magnifying glasses
Engaging with designing	
6	Investigating paper crumple zones
7	Investigating a turning toy
8	Investigating a musical instrument
9	Investigating a wind energy conversion system
10	Investigating LEDs, lamps, super capacitors and rechargeable batteries

Peter's comments on the individual activities were as follows*:*

- Exploring the Peltier effect: 'For most of the teachers, this was a new phenomenon which they found intriguing. The fact that the device they used is available from a well-known supplier, at low cost, made the activity a practical possibility in their classroom. Taken together these two factors led to a high level of engagement.'
- Exploring the behaviour of a small paper helicopter: 'This was not a new activity for the teachers and it initially appeared deceptively simple. However, making observations and taking measurements proved a challenge. It required repeated observations, the use of scatter graphs to make sense of the observations and video capture with slowed-down playback to observe details of the phenomenon. This data collection challenge led to a high level of engagement.'

- Considering the properties of sheet material: 'This required the teachers to explore the potential of corrugated card as a structural medium. The activity unfortunately failed to engage the teachers. In retrospect, this was probably because the starter activity involved reading a case study about card furniture rather than practical engagement with structural forms. An exploration of flat pack to 3D structure might have been a more appropriate starting point.'
- Observing rolling cylinders: 'This required teachers to explore the behaviour of cylinders on a ramp, partially filled with liquids of different viscosities (water and glycerine) or different solids of different granularity (lead shot, ball bearings). For most of the teachers this was a new phenomenon, so engaging that they were only able to concentrate on explaining the phenomenon (which they found extremely challenging) and thus ignored possible applications. In retrospect, the introduction of some "real world" examples such as rolling barrels of beer during delivery to public houses might help move consideration from phenomenon to application.'
- Investigating magnifying glasses: 'This required teachers to explore a range of lenses to identify those features responsible for magnification. Most of the teachers could see that this had potential but were disappointed with the experience due to the very limited range of lenses available. To improve this would require some effort to source lenses not normally available in science departments.'
- Investigating paper crumple zones: 'This was not a new activity for some of the teachers but they still found it useful because new possibilities for quantifying the impact were made available. Also it provided an opportunity to discuss different approaches each of them had previously used. Going beyond a formal treatment and using practical contexts such as road safety can engage pupils in thinking about collisions generally.'
- Investigating a turning toy: 'This activity provided the opportunity for a very open-ended investigation that motivated questions and learning about movement. The use of an investigation to support learning instead of being used for assessment was new for many of the teachers and as such provoked interest.'
- Investigating a musical instrument: 'In this activity the teachers investigated the musical notes produced by vibrating cantilevers. The use of the oscilloscope to "see" the notes produced was novel but easily carried out due to their familiarity with the device. This is an example where physics can connect with more than one other subject, in this case music and design & technology.'
- Investigating a wind energy conversion system: 'Most teachers were familiar with this activity as the equipment was from a well-known curriculum project. The challenge was to get good data from the apparatus and to some extent this was marginalised by the over-structured approach of the support materials.
- Investigating LEDs, lamps, super capacitors and rechargeable batteries: 'This was a failure because the apparatus we provided made circuit wiring a formidable

challenge and the task was too wide-ranging. In the future, limiting the activity to investigating super capacitors would allow an approach similar to that of the Peltier effect.'

To gather the teachers' views on the session and to explore whether the overall experience was likely to lead to a change in practice the teachers completed a short questionnaire shown in Table 3.3:

TABLE 3.3 Teachers' questionnaire

Last term you took part in a range of activities designed to explore possible relationships between the teaching of physics and design & technology. It would be very useful if you could answer the following three questions:	
1	Did you enjoy the session? (Very much 1, 2, 3, 4, 5 Not at all) Please give reasons for your answer.
2	Did you find the session useful? (Very much 1, 2, 3, 4, 5 Not at all) Please give reasons for your answer.
3	In what ways has the session impacted on your practice? Please give examples.

Returned questionnaires revealed that the overwhelming majority enjoyed the session (11 answers at 1; 11 answers at 2; one answer at 4) and a large majority found the session useful (nine answers at 1; nine answers at 2; five answers at 3). In terms of impact on practice, however, the picture is mixed. Eleven indicated no change to practice with one indicating that previous attempts to establish links between science and design & technology had been resisted by design & technology, hence he was still reluctant to open discussions on the topic. The remainder, just over half, did indicate possible changes to practice. One teacher indicated that she planned to build the activities into an existing after school STEM club and another indicated that he would use some of the activities to start such a club at his school. Three teachers indicated that they had begun talks across the science and design & technology departments with a view to planning collaboration in general, collaborating during a STEM week which would include joint science, design & technology days. Two more teachers indicated that they were considering the introduction of integrated curricula that involved both science and design & technology. Two indicated the intention to change some of their physics practical sessions starting with 'artefact' investigations as opposed to the usual experiments to establish principles. One teacher indicated that he would start to build links by adding extension questions to science tasks which deliberately required pupils to make links between science and design & technology learning. One teacher indicated that he had established links which required pupils to build illustrative models of science learning as part of the design & technology curriculum, in his case 3D models of nuclear power stations. One teacher was rewriting the Year 7 schemes of work such that pupils would investigate properties in physics lessons and use the results to make decisions when designing and making a product in design & technology.

Given the limited success of some of the activities as revealed by Peter Campbell's comments and the small amount of time taken to explore the potential for links between physics and design & technology it is encouraging that such a large proportion of the teachers were prepared to make changes to their practice. Clearly, some next steps are required to show the effectiveness of such changes and establish such activities as permanent features within the curriculum in which science is taught in the light of learning that takes place in design & technology.

What might other continuing professional development sessions consider?

Imagine that you were asked to organise a similar session for other specialist science teachers. What might you include? If the session were for chemistry teachers it would be an interesting opportunity to focus on the role of chemistry in personal hygiene and appearance. A starting point could include looking at a range of cosmetic products – shampoos and conditioners, soaps, simple cosmetics such as lipstick, eye shadow and mascara and perhaps perfumes and aftershave lotion. The development of packaging for a variety of products has become a standard design & technology task in those courses that specialise in so-called 'graphic products'. Imagine the possibilities for linked learning if the products to be packaged had been previously explored in chemistry lessons with a view to understanding their composition and how they are made and how they work. There is the possibility of devising experiments to explore the performance of commercially available products in the light of advertising claims and information on the packaging. In some cases, e.g., lipstick, mascara and perfume it might be possible for the pupils to make the product which they then package. It would be important for the chemistry teachers to carry out the activities themselves, just as the physics teachers did in the case study above, and consider their feasibility. The results of such work might manifest themselves in collapsed timetable days organised by chemistry and design & technology teachers working together.

If the session were for biology teachers what might be considered? Systems thinking is used significantly in both biology and design & technology. The precise language used by biology teachers is likely be different from that used by design & technology teachers although they are describing identical concepts. The time at which the concepts are introduced may vary between the subjects and the features of progression may also differ. Here is an area that clearly merits some discussion. Biology is often concerned with the interplay of form and function, and designers often use living things to inspire and inform their designs. Here again is an area that it would be useful for biology teachers to discuss with design & technology teachers. Due to the nature and funding of the physics teacher course previously discussed it was not possible to invite design & technology teachers to attend but the presence of teachers from both biology and design & technology would almost inevitably lead to greater collaboration and changes in practice.

Now imagine a session in which biology, chemistry and physics teachers come together to discuss the way some of their older students use mathematics in their science lessons. The biology teacher might want some consideration of statistics so that his students could better understand the work of ecologists and also plan their own investigations into local biodiversity. The chemistry teacher might be keen for her students to become *au fait* with the idea of logarithms in order to become proficient at pH calculations. The physics teacher might be keen for his students to develop an understanding of calculus in order to explore rates of change in a variety of phenomena. For example, a group of good mathematics teachers could hold court to requests in the form of a questions and answers panel and suggest in their answers the sorts of collaborations that could be used to enable the teaching of science in the light of students' learning in mathematics.

As we have seen from the examples given in this chapter and the use of continuing professional development it is possible to enhance the teaching of science by taking into account pupils learning in design & technology and mathematics and teaching science in the light of STEM. In the following section we revisit the issue raised in the previous section, 'A relationship among equals?' There is a short discussion on the importance of giving equal weight to the perspectives offered by science, mathematics and design & technology within any relationship between the subjects.

Maintaining the integrity of learning in the interacting subjects

Each of the examples of teaching science in the light of STEM can be justified in terms of meeting an aspect of Wynne Harlen's ideas *of* science and *about* science. Hence, although the science teaching has been undertaken in the light of learning that has already or might take place in mathematics and design & technology it has not been compromised. The design & technology activities that were described in this chapter, as in all of the examples, link science learning to either design & making activities or to designing activities to which there are multifarious, as opposed to single correct answers. Hence, the particularly significant difference between science and design & technology has been respected and preserved. And in each example, science understanding has informed designing and making such that the utility of the science is exemplified without the science teaching becoming distorted. The nature of the mathematics activities is varied and includes simple measurement and estimation, the use of both arithmetic and algebraic calculations, the use of nets, understanding compound measures, using ratio and proportion and the interpretation of statistical data concerned with real world activity. All of these activities relate to topics that are prominent in most mathematics courses for pupils aged 11–16 years today. The mathematical perspective provided through making these links informs both science and design & technology and in some cases provides a mathematical window onto significant global problems. Hence, as with science, the utility of the mathematics is exemplified without mathematics teaching becoming distorted.

Conclusion

This chapter raises many questions. Does the nature of science really make it that difficult to teach because it is essentially 'outside students' individuality'? Is there room for a personal response to science within science for young people at school? One approach is to rely on creative pedagogy. The use of a blast furnace to create copper may appear intrinsically boring but if the response to learning about this and showing understanding is through creative writing then maybe it could actually be much more interesting. Asked to respond in such a manner we know of one student who wrote a short parody of a James Bond movie. 'My name is Bon, Car Bon. When things get hot I don't sweat, I just get stronger. That devil iron is no match for me when it comes to a contest over oxygen!' Of course many teachers do use creative pedagogy but the thrust of this chapter is that there is another very powerful weapon in teachers' armoury that can be used to combat some students' disillusion with science and to enhance the science curriculum for all. That is, science teaching should be carried out in the light of STEM where links with design & technology enable students to 'raid' science for useful ideas and links with mathematics can reveal the elegance of relationships within phenomena that can be described in no other way. We hope that the examples of teaching science in the light of STEM we developed here have shown what is possible. You might find some implausible or inappropriate for your particular situation; that is almost inevitable given the different circumstances in which schools and teachers find themselves.

Our hope is that you will be able to look at your own curriculum and see where you might teach science in the light of STEM to the advantage of your students. We firmly believe that professional development is an essential means for you to explore how you might teach science in the light of STEM. The experience of exploring practical activities and tricky concepts with a view to teaching science in the light of STEM is an important first step. Good ideas will come from the conversations you have with your colleagues.

Finally, we have had to wrestle with the issue of curriculum status. This is a particularly sensitive issue for design & technology in England at the moment with a government expert panel suggesting that the subject has 'weak epistemological roots' compared to other subjects more established in the curriculum. We believe that it is imperative to acknowledge the integrity of *each* subject, respect their ways of knowing and understanding and appreciate their different learning intentions.

Vera John Steiner has written about the dignified interdependence that underpins creative collaboration. We fully support her position with regard to the highly creative and collaborative endeavour of teaching science in the light of STEM. Hence, in teaching science in the light of STEM our advice is not to neglect the importance of regular conversations with colleagues from design & technology and mathematics.

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Note

1 In this seminal book David Layton argues that science education has now to serve the needs of technology education and act as a resource for the development of technological capability. This new role has implications for traditional science lessons as they will need to be reworked if the learning is to be useful in practical situations and related to design parameters.