Using Science In Design And Technology

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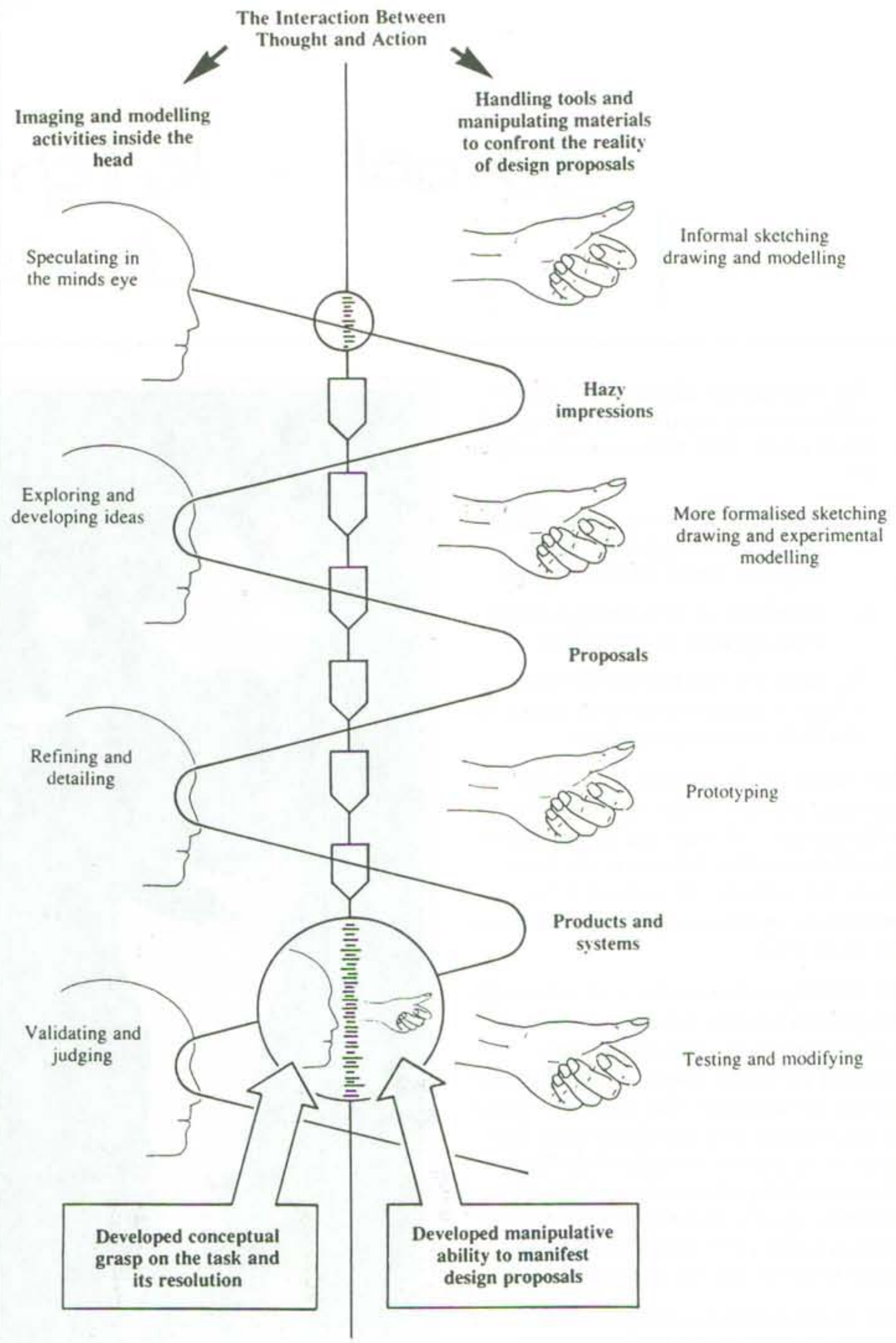
Modelling as central to D&T activity
The publication of Design and Technological Activity A Framework for Assessment[1] was a landmark in describing the developing concept of design and technological activity. The interaction between thought and action, mind and hand, summarised by the now familiar zigzag (see Fig.1) charted the progress of ideas from hazy impression to refined and detailed design proposals mirrored by successively more detailed models culminating in a completed (though not perfect) product. This description has as a central feature the act of modelling. It is all too easy to see the end result of the modelling activity, 'the models', as the most significant part of the activity. They are only significant to the extent that a) they help the pupil designer develop a clearer picture of that which he/she is designing and b) that they reveal to the teacher the mental processes of the pupil in coming to grips with the design task. While it may be convenient to classify the models in terms of their form (informal sketch, card mock up, 3D rendering etc) it is important that teachers and pupils see them for what they are in educational terms — insights into pupil thinking.

The use of science in D&T activity
Technology and school science an HMI enquiry[2] was severely critical of much of the technology education seen in the context of school science courses '...the science courses gave insufficient attention to the application of scientific knowledge in solving technological problems.' The terms of reference given to the Working Party for Technology in the National Curriculum[3] were quite explicit on the special relationship between Technology and science (and also mathematics). Some attempts were made in the Final Report[4] to develop and describe this but these were heavily criticised as little more than references to science attainment targets. This criticism was seen as serious 'because attainment targets at higher levels should involve the *application* of scientific and mathematical principles. This being

Figure 1: taken with permission from APU Design and Technological Activity A Framework for Assessment, London, HMSO, 1987.



necessary because the science curriculum does not tackle the crucial modelling problem of being able to express the complex features of the real world effectively (albeit approximately) in terms of the idealised models that science and mathematics require'[5]. The consultation documents[6] however justified the omission of specifically detailed links with mathematics and science as eventually occurred in the Orders for National Curriculum Technology[7] on the grounds that such detail is present in the Orders for Science and Mathematics. This of course does not meet the criticism that it is the application of the mathematics and science that needs to be detailed nor does it give any guidance to teachers and curriculum developers who might wish to deliberately include such applications in their approach to engaging pupils in design and technological activity.

So where should a teacher start in trying to identify the science that pupils might need to apply in tackling a design and technological task? Purists will argue that this is a false approach and that any such science and its application will emerge quite naturally on an as needed basis. I consider this view to be unhelpful for two reasons:

i. Many design and technology teachers will themselves be unsure of scientific principles and how they can be applied. Their first task will be to gain confidence for themselves in a relatively well structured situation where the science likely to be applied is apparent.

ii. It is known from several sources[2,8] that pupils do not readily apply scientific principles unless specifically required to do so and that they have developed a large range of avoidance strategies. Very often the careful preparation of the teacher in providing appropriate materials in a suitable form prevents pupils from needing to model scientifically as significant and important decisions have already been made for them.

A first place to look should be the National Curriculum Orders for Science[9] coupled with one, if not several, conversations with science teaching colleagues so that not only the appropriate attainment target — for example Attainment Target 10 Forces or Attainment Target 13 Energy — can be identified, but also the levels which are likely to be suitable for particular pupils. It will be unhelpful and probably counter productive if the design and technological tasks require scientific knowledge and understanding that is clearly beyond the scope, or outside the experience, of the pupils. This is not to say that in time, as pupils become accustomed to applying science for design and technology purposes they may not gain the confidence to venture successfully down new roads. I am deliberately erring on the side of caution in an attempt to set up a successful first experience so that confidence is built and a teacher readily tries again. It is also worth noting that having 'done' it in science does not necessarily mean that pupils will have retained the knowledge or fully grasped the concept and that a revisit through design and technology may well provide opportunities for pupils to reformulate their ideas and emerge with clearer understanding.

Coupled with this exploration of the science curriculum should be a look at familiar design and technology tasks; old chestnuts in fact. These have the advantage of using familiar materials, tools and techniques so that they are inherently manageable and probably well resourced although it might be necessary to resource them in a different way if pupils are to be put in a position where they quite naturally turn to scientific modelling. One such familiar task is that of designing and making a nut cracker.

Using science in designing a nut cracker

There are two approaches to thinking about how to crack a nut. The first is to ask 'How much force is required? This immediately raises the questions which may have their answer in pupils science experience — What is force? How can it be measured? What are its units? This is described in science Attainment Target 10 at level 5.

The second is to ask 'How much energy is required? Again this raises questions which might have answers in pupils science experience — What is energy? How can it be measured? What are its units?

This is described in science Attainment Target 13 at level 9. Both these approaches can be investigated for a range of nuts as follows:

To find the force required pupils can simply pile 100g masses on a nut until the nut cracks. This may be difficult as some nuts may require a huge pile of 100g masses. So it is worth using a simple lever system to act as a force multiplier. In fact this may turn out to be the basis of the nut cracker design. Clearly this will need to be done for several nuts and different types of nut. Pupils may need to design an investigation that several people can take part in simultaneously in order to get the range of data needed in the time available. It will be important for pupils to arrive at an answer that is in the units of force (newtons) and not mass (grammes).

To find the energy required pupils can drop 100g masses on a nut from ever increasing heights until the nut cracks. Pupils will need to ensure accuracy of strike without slowing down the mass; perhaps by dropping the mass down a tube just wider than the mass. The energy delivered to the nut is given by m x g x h where m = mass in kg, g = acceleration due to gravity 9.8 m/s/s (≈ 10), and h = height from which mass is dropped in m.

The answer is in newton metres or joules. As with measuring the force required pupils will need to test a range of nuts and may require a group of effort to produce a suitable bank of data.

Clearly pupils have the opportunity to use and develop investigational skills and to develop their understanding of force and energy through such activities. But this is only the beginning; having found out how much force or energy is needed (to some extent a technical specification for the artefact) they have to develop a system that will deliver this in a convenient manner.

Investigating ways to deliver the force

Conventional nut crackers use a second order lever as a force multiplier. It is quite possible for pupils to research the three different orders of lever and develop mathematical expressions for their ability to multiply force. Such expressions are models. If this is linked to the magnitude of force that the human hand can deliver then the length of levers necessary to deliver the required force can be calculated. Of course the force that the human hand can deliver without undue strain will vary quite considerably from individual to individual and there is the possibility of investigating this variation among the pupils in a class or finding out by reference to ergonomic data. Similarly the variation in span of grip may need to be investigated and taken into account. This range of data obtained by a mix of investigation, research and scientific calculation gives pupils the opportunity to develop a design proposal in which they can justify important features through resolving conflicting requirements such as in the case of a second order lever, length of lever required to achieve maximum force multiplication v limited size of gripping span. Of course innovative design — using a first order lever and body weight for the effort (leaning on one end) can resolve this conflict although it will almost certainly generate others.

Some commercially available nut crackers use a screw thread to obtain mechanical advantage. It is possible for pupils to investigate this and develop an expression (a model) for the force multiplication that takes place in a screw jack and consider this in the light of human hand performance possibilities.

Investigating ways to deliver the energy

A pile driver delivers energy to the pile by raising and then dropping a mass on the pile. This could form the basis for a nut cracker. Pupils can calculate for a range of masses the height they must be dropped through to deliver the appropriate energy. Considering what heights and what masses might be convenient provides an interesting exercise. Just what is 'convenient'? Immediately the mind is speculating with a nut cracking set in which there are a variety of masses and a winching device to lift them different heights for different nuts. And there is the intriguing possibility of turning this into a gambling situation where people bet on whether the nut will crack from a particular combination of mass and height.

Rather than raising vertically by winding-up the mass on the end of a string (say) pupils can consider delivering the energy by means of a swinging mass — a ballistic pendulum. Note it is the vertical distance the mass is moved through that governs how much energy is delivered. Note also that pupils can calculate how fast the pendulum bob or falling mass is travelling by equating potential energy gained through raising the mass with kinetic energy due to movement of mass:

$mgh = \frac{1}{2}mv^2$ where m is the mass the striker in kg, g = acceleration due to gravity 9.8 m/s/s (≈ 10), and h = height from which mass is dropped in m and v is the velocity of the striker in m/s.

As energy delivered is proportional to v^2 it is essential that any losses in velocity due to friction at the pivot are minimised.

It is possible to deliver the required energy by means of a spring (or even an elastic band). Stretching or compressing a spring will store energy in the spring which can then be transferred directly to the nut by means of a mass at the end of the spring. It is possible to measure the energy stored in the spring:

if 1 = change in length, m = mass causing the extension, energy stored in the spring is given by ½ x m x g x 1 where m is in kg, g is acceleration due to gravity and 1 is in m. Pupils may need to look again at Hooke's Law to understand this. An interesting account of the conversation between a physicist and a mathematician[10] reveals some important features to be taken into account when tackling this work. The introduction of a design technologist into the conversation provides an opportunity to give the investigation an intentional focus which will provide motivation in an otherwise perhaps academic and theoretical pursuit. Pupils will need to investigate a range of springs to discover how easy it is to store the necessary energy. There is no point in building a spring driven device that requires immense strength to operate!

Having developed a device that will deliver the necessary force or energy to crack nuts in a convenient manner pupils still have to DESIGN it so that it is pleasing to the eye and friendly in use. This will entail making decisions about the materials to be used and their form. The confusion in many pupils minds about the properties of materials was clearly revealed in APU Metals at Age 15[11]. The property words hard and strong were singled out as particularly difficult for pupils to distinguish and I imagine the introduction of stiffness to this scenario would just add to the confusion. Science Attainment Target 6, Types and uses of materials, puts the ability to compare materials on the basis of simple properties — strength, hardness, flexibility — and relating knowledge of these properties to the everyday use of materials at level 4 and the understanding of such properties — strength, hardness,

elasticity — at level 6. The ability to collect and use quantitative measurements of properties of materials to make judgements about the use of different materials is designated level 9. Clearly pupils are expected to consider materials at progressively more demanding levels as they progress through a science course and there is an opportunity in design and technological activity to establish specific requirements for the materials chosen in terms of what they must achieve or be able to withstand within the design proposal. There is a need for those parts that grip or strike the nut to be hard so that they do not wear away. The parts of the device that are under stress will need to be strong enough to withstand that stress without breaking or deforming and stiff enough to withstand that stress without over deflecting. It is possible to justify material type and form decisions by means of comparative tests involving forces of an appropriate size established through investigations outlined above. This will avoid those beautifully made nutcrackers, often from acrylic, that deflect so much that opposing second order levers touch before the force required to crack the nut is reached. Or similar designs made from thin section aluminium which deform rather than deflect because the applied force exceeds the elastic limit. It is possible to extend these comparisons to include mathematical modelling of the levers in terms of simple beam theory so that bending moments, stress due to bending and probable deflections can be calculated. This is clearly outside the scope of secondary school pupils but may be appropriate for sixth formers. It is within the remit of initial teacher education and inset courses for design and technology. This and the simpler aspects of using science described above provide a highly practical and purposeful way of engaging with scientific concepts and ideas that many design and technology teachers find difficult. They also develop the ability to model to the point where the features being modelled are those that cannot be seen an important development that moves us away from model as physical artefact, almost an end in itself, and towards model as an aid to, and revelation of, a pupil's thinking.

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