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# Bridging the gap: the use of concepts from science and mathematics in design and technology at KS 3

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## Abstract

*National Curriculum documents note the importance of using science and mathematics in design and technology activity. However, the nature of the links between the subjects remains unclear in classroom practice. We will argue that rather than links between the subjects being obvious and exploited we can identify gaps between mathematical and science concepts as they are developed and used in the three subject areas. In order to build links between the subjects of design and technology, science and mathematics the potential gaps need to be recognised and understood by teachers. We suggest ways in which co-ordination between the subject areas could help to overcome some of these difficulties and in doing so enable students to see their learning in science and mathematics in context and enhance both practical skills and problem solving in design and technology.*

## Introduction

The requirements of the National Curriculum note the importance of using science and mathematics in design and technology activity: 'pupils should be given the opportunities to apply skills, knowledge and understanding from the programmes of study of other subjects where appropriate including art, mathematics and science' (DfE/WO 1995). There is, however, no articulation of what appropriate use might mean or how teachers are to support it. The House of Commons Education Committee report into science and technology in schools recognised a dysfunction between the two subjects in the National Curriculum and recommended more effective links between them (House of Commons Education Committee 1995). The nature of the links remains unclear and, in particular, there is little evidence from classroom research which can inform teachers about the ways in which scientific and mathematical understanding can be brought to bear on the different facets of design and technology tasks or the influence that the context exerts on pupils' ability to use their knowledge.

We will argue that if links are to be developed effectively it is necessary to identify gaps in conceptual knowledge between the subjects. In this paper we identify such gaps and suggest ways of bridging them.

We draw on two studies. (McCormick *et al.* *Problem solving in Technology education: a case of situated cognition?* funded by the UK Economic and Social Research Council grant number R00023445 and Evens and McCormick. *Mathematics by Design: an investigation into Key Stage 3* funded by the Design Council). Both use case study data from design and technology (D&T) classrooms in which all the lessons of a D&T activity were video recorded with a detailed focus on the work of 2 - 4 pupils. We have reported aspects of these studies previously (McCormick, Murphy, Hennessy and Davidson 1996; Levinson, Murphy and McCormick 1997; Evens and McCormick 1997). Our development of the idea of a gap between science and D&T was the subject of a presentation at the Association for Science Education annual conference 1998 and will be reported further in Spence (forthcoming) and Davidson and Murphy (forthcoming).

## The gap

Our research has enabled us to identify a range of topics within science and mathematics which are frequently used in D&T. For simplicity we report on only three: orthographic projection for mathematics, and circuits and levers as two examples from science. The gap can be viewed in three different ways arising from: 'overlap' between subjects where the same concepts are taught

and used in different contexts; 'mismatch' in which concepts are needed in D&T before they have been taught in science or mathematics; 'differing purposes' for the use of a context as a learning experience.

### Overlap

Knowledge already taught in science or mathematics may be needed in a D&T activity, but pupils are often unable to draw on it effectively. The new context of D&T makes it difficult to use existing knowledge if the teacher does not elicit that knowledge and make explicit the importance of the changed context. We illustrate this here with the example of drawing an orthographic projection. It was observed in the *Maths by Design* case studies that D&T teachers in two different schools demonstrated this construction using a 45° line to project part of the drawing through a right angle. Using a 45° line to 'move' an object such as a line is seen geometrically, in a mathematics lesson as a *reflection* or as a *rotation*. In the D&T context the use of a diagonal was taught as a procedure and the set square was the tool designed for the job. The reason for using 45°, rather than any other angle, was not explained so some pupils drew the line in freehand or used the 30°: 60°: 90° set-square. In one study, where the full-scale drawing accompanied the making of a styrene model of the object, the incorrect angle resulted in several inaccurate drawings and some puzzlement when the model didn't fit on the drawing.

One difference in context between the two subjects arose from the use of language. One D&T teacher used very little mathematical language, for example, the parallel construction lines used to preserve distances were never referred to as parallel. Another used more precise language but assumed (not always correctly) that his pupils understood it. Overall the language used by the D&T teachers was less precise than that used by the mathematics teachers and was tied to the drawing tools rather than to the underlying mathematical concepts. In D&T the tools such as T-squares are designed to produce parallel lines, so the word doesn't need to be used.

Similarly set-squares provide perpendiculars and specific angles, again without these mathematical concepts being made specific. Research shows pupils have difficulties with these basic concepts (Evens & McCormick 1997).

The D&T teachers did not acknowledge that there could be a connection between the procedure they were teaching and the pupils' experience in Maths. One did not recognise that there was any mathematics in the project, the other, in talking about the effects of the 45° line, deliberately hid the mathematics by using phrases such as 'this will appear as if by magic', so that in neither case was the mathematics made explicit. By the same token mathematics teachers taught the concepts, but there were few meaningful contexts for their use.

In interviews the D&T teachers gave various reasons for not making the mathematics more explicit: they didn't recognise the mathematics; they assumed that pupils would already know and recognise the mathematics and use it in the different context; reference to mathematics would spoil the enjoyment or that it wasn't their place to teach it.

### Mismatch

For many design-and-make activities teachers must decide the extent to which they should explicitly teach the underlying scientific or mathematical concepts on which the operation of a technological system is based. They may not be able to draw on prior experience from science and mathematics since the concepts have not yet been taught because they are seen as too difficult or are part of the KS4 programme of study. One particular case study illustrates this dilemma very clearly.

Two Year 7 pupils were 'designing' and making a money collecting box for a charity. Using a working model of the mechanism supplied by the teacher, they adapted it to their specific idea, a woodpecker that repeatedly pecked after the money was dropped into the box. The mechanism the pupils used is shown in Figure 1.

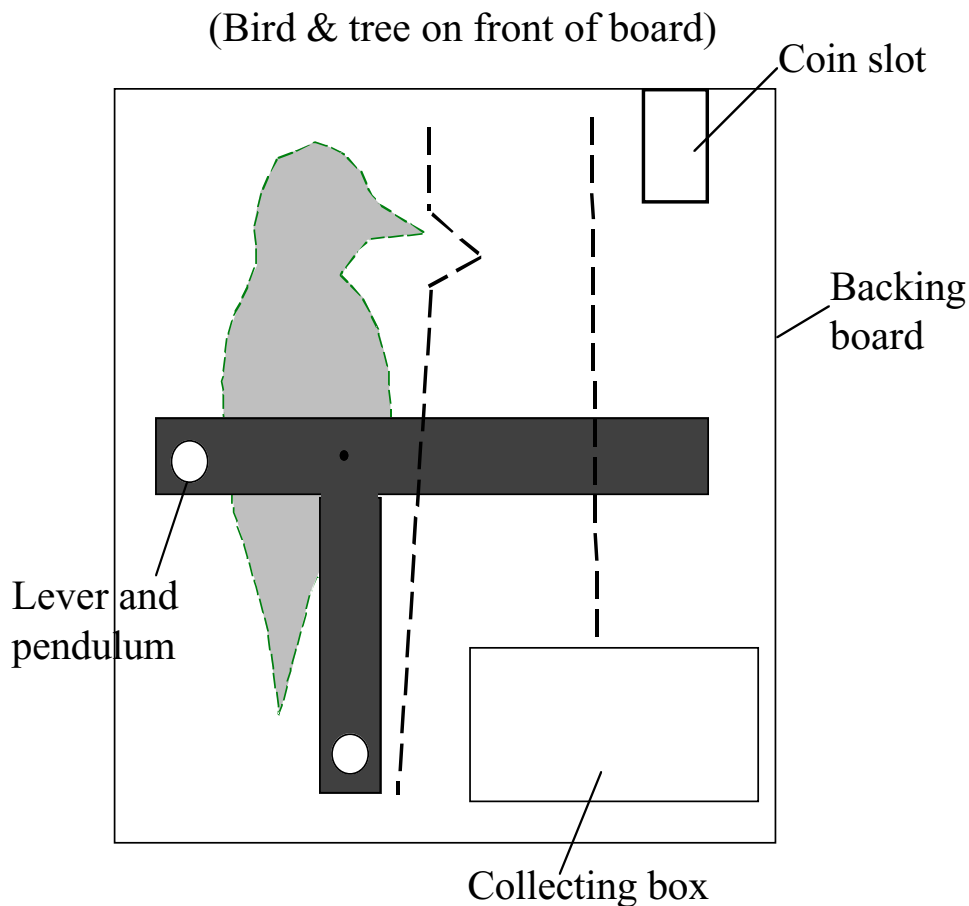


Figure 1 A diagram of the pupil's woodpecker mechanism

The 'design' element of the task was to ensure that coins of all sizes would provide sufficient pecking of the bird to encourage people to put money in the box.

The science concepts embedded in this activity include force, momentum, rate of change of momentum, equilibrium, turning moments, and period of oscillation of a pendulum. Such concepts exceed any that we would expect of a Year 7 pupil. Teaching about force and rotation is required in science KS 3, but momentum is not introduced until KS 4 and pendulums are not included at all. We might also question the extent to which the pupils needed to understand the scientific principles. Many technologists say they would not use science, but, what appears like 'trial and error', to design such a system. They would work through the effect of a coin dropping on the beam (A), and the need for it to drop 'far enough' to move the beam 'sufficiently', to swing the pendulum, etc.

The pupils did use trial and error. They only had a limited grasp of balancing beams, but developed a reasoning by continually trying out the coin drop and its effect, at first on a card model and then on the prototype. The teacher, in introducing the activity, referred to the need for careful balancing of the system and to the longer beam arm increasing the sensitivity of the effect of the falling coin. He assumed that the pupils had done some work in science on balancing beams. His approach was not systematic, in the sense that he introduced these ideas as part of a general examination of solutions used by earlier classes. He did remind the pupils at various points, but assumed that they understood the concept of a 'balanced beam'. We assume that the teacher did not consider that teaching the concepts was important for achieving a successful outcome and in this he was correct, which seems to us to be a major element of the dilemma. If successful outcomes can be achieved without the use

of existing, or introduction of new, scientific or mathematical concepts, what then is the link between D&T and these subjects? The fact that the mechanism is a system, where several concepts are inter-related only serves to complicate the teacher's job.

The whole experience could be seen as a missed opportunity. There was little evidence that the pupils had gained any new technological understanding about the operation of such a system nor did they understand that they had put their science knowledge to practical use. With a little more time spent in the early stages of the work the pupils could have explored how lengthening one arm of the beam increased its sensitivity and the consequent need to add a counterweight to balance the weight of the beam itself. (In science, beams have no weight!) Such an exploration would have been within their capability and the understanding developed would be valuable not only in technological terms but also to feed back to subsequent science investigations.

### Differing purposes

Although science, mathematics and D&T teachers may use similar contexts they may have different purposes for the use of these contexts as learning experiences.

During our observation of a D&T activity, in which Year 8 pupils designed and made a moisture sensor, we noted the treatment of an electric circuit was very different to that which a science teacher would have used (McCormick, Davidson and Levinson 1995). The teacher wished to introduce the idea of the sensor circuit as a system with an 'input', an 'output' and a 'process'. When the circuit was demonstrated the pupils appeared to have little difficulty in understanding the concept of output because it was graphically illustrated by a light or sound. However when the teacher asked what the input would be most pupils identified the battery. The teacher tried, using various examples of sensors, to develop the concept of an input signal, such as the presence or absence of water. That he was unsuccessful was apparent when, in answer to our questions at the end of the project, few pupils could suggest what the input for their

sensor was and of those who did reply most considered it to be the battery.

We are not surprised by this result, of which the teacher was unaware, since there is a conflict between what the pupils could have learned in science and the D&T teacher's approach. Science teachers would have talked to pupils about the circuit in terms of the battery as the source of the electric current, and the current as the producer of effects such as light. As part of work on energy conversion the pupils might have looked at a circuit, considering the forms of energy at various stages, for which the battery would have been the energy source.

In D&T, mathematics is used as a tool and therefore treated in a procedural way (to get something done), whereas in mathematics lessons the same topics are more likely to be explained conceptually. An orthographic projection is used in a D&T context to record design decisions and communicate information from designer to maker. If the drawing is incorrect there will be consequences for the end product. In mathematics, orthographic projections (sometimes referred to as 'plans and views') are used to practice skills of visualising and matching mathematical objects or as a vehicle for teaching 'scale'. Carrying out the activity is part of a theoretical task and is not always seen as having practical application.

Interviews with teachers highlighted differences between the teachers' approach to the subjects. A D&T teacher commented on the orthographic projection 'If they [the pupils] have the principle of the 3 views and everything is in the right place and it is to some sort of approximate scale ... I think 'great' they have understood the principle of a working drawing.' The mathematics teacher replied 'In this orthographic, with this projection ... we are trying to show them why it works. You are using it as a tool.'

The conflict of ideas that we illustrated from science is not present here, but it is clear that, the different purposes of the D&T and Mathematics teachers and the failure of each to acknowledge the purposes of the other, will

contribute to a gap in the understanding of the pupils.

### Closing the gap

It is simple to conclude that better co-ordination between departments could help to recognise the gaps which we have described and to build links between the subjects. We are aware of the difficulties which limits regular contacts between departments, let alone the co-ordination of topics. The use of sets to group pupils of different 'ability' in mathematics and science, but rarely in D&T, adds to these difficulties. Nevertheless we would argue that considerable potential for pupil learning is lost if such co-ordination at school level does not take place.

Co-ordination at the organisational level could be brought about by recording salient features on paper and through an exchange of records. Information could be exchanged in this way about:

- pupils identified by sets for mathematics and science, and the topics that each set could be expected to have met;
- the tasks that will be undertaken by D&T groups and the timing of these within the Key Stage.

However, more effective co-ordination would be achieved through face-to-face sharing of ideas between teachers from the three subjects. Ideally a joint analysis of D&T tasks should take place, which allows the teachers to recognise and explore how the use of knowledge varies between the subjects. Without such a task analysis it is unlikely that the difficulties we identified in both the 'mismatch' and 'different purposes' gap will be addressed effectively. Task analysis to identify the mathematics knowledge used in D&T tasks would show, as our research has done, that topics such as measurement, accuracy, scale and ratio are common to most design-and-make activities. With this knowledge mathematics teachers would be able to refer to practical applications of the theoretical concepts that they are developing. To do so would help both the pupils' understanding and appreciation of the importance of the concepts and give them a better chance of using their mathematics in the D&T context.

Task analysis will be insufficient to identify some of the differences in context between the subjects. Here visits to classrooms would be the ideal tool. For example, allowing mathematics and D&T teachers to see the different ways in which they handled the use of the 45° construction line in orthographic projection could lead to a useful dialogue about differences in language and even differences in pedagogy. However, this poses problems of time and of a lack of culture of sharing across departments. Despite this, in-service activities we have run with pairs of teachers of mathematics and D&T, for example, have proved that dialogue is fruitful.

We intend to explore the gaps and links between the use of knowledge in these subject areas more fully. A further study of mathematics in D&T is underway and that for science is at the planning stage.

We would however urge that schools should attempt to take some steps towards establishing a framework for co-ordination between science, mathematics and D&T departments. To do so would allow the teaching activities of each to enhance and support the other and widen and strengthen the learning opportunities for pupils.

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