

Strategic Decisions: Ambitions, Feasibility and Context.

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Abstract

The main aim of this paper is to identify some of the main issues which call for strategic decisions in the early stages of designing new materials. I do this by giving short accounts of four different innovations in which I have been personally involved, and then, in summary, comment on how these indicate both the complex interplay of five issues – research basis, curriculum, assessment, pedagogy, and sustainability – and how, according to the contexts, some might be left alone and others are crucial. It is argued that both successful implementation and long-term impact are crucially dependent on teacher change.

Introduction

Any production of new materials for education must be driven by a desire to change. The scope of that change can span a spectrum from the radical, e.g to completely reorganise the structures and systems of schooling, to the almost trivial, to e.g. produce a more attractive textbook similar to that of publisher A to be marketed as a rival by publisher B. Thus, one of the questions which I want to address here is “How far can you go?” i.e. how far should the move towards innovation be tempered by practicality. The answer will require a review of the relevant constraints and affordances. The list of issues to be considered is formidable. Two of them, the power to attract resources to design and produce and disseminate, and the resource of expert people to do the work, I shall only consider marginally. Another, that of leverage, i.e capacity to attract publishers, to convince those who control teachers, the power to convince teachers to use the material, the likelihood that teachers may be able to use them to good effect (aka ‘the teacher-proof material’ syndrome), will be more salient in the discussion.

What I take to be obvious is that any new materials are but one component in a systemic reform, and the many features of the context in which the materials will be planted and nourished have to be appraised in the initial planning of the work. There are obvious examples of the risks of neglecting the context: the teaching approach required to use the materials may turn out to be too challenging for most teachers, or statutory requirements of high-stakes testing might not reward the aspects of learning which the materials were planned to promote.

In this paper, I shall develop a view that the strategic approach to design of educational

material should focus on five main issues, namely research, curriculum (C), assessment (A) pedagogy (aka instruction) (P), and sustainability.

The close inter-relationship of three of these, C, A and P, requires a preliminary analysis. The curriculum, whether centrally prescribed, or implicit in the practice and culture represented in textbooks, is seen as a list of things to be taught, and which the teacher may 'deliver' by a pedagogy that he/she thinks appropriate. In most systems, assessment becomes the lens through which the curriculum is interpreted; this interpretation may depend on the appraisal of the aims of the curriculum that the test-system and its controllers adopt for their work. Such an interpretation may be benign, in that their instruments reflect and reward powers to understand and apply, or malign because it reflects a view of the curriculum as a collection of things to be known, with assessment recording mere recall, thereby constraining the pedagogy to 'teach-to-the-test', rather than to the original curriculum aims. The strategic choice for the designer of new materials is to anticipate how they will fit into the existing equilibrium between C, A, and P, or perhaps to seek to change this to create a more favourable environment.

I propose to explore this framework in the spirit of 'notes towards a theory of' rather than in one of defence of a definitive theory. I shall pursue this exploration by discussing four cases of innovation, in which I have been personally involved, in order to show how they illustrate the differing priorities of the five issues. My main reason for choosing these examples is that the differences between them are such that they might illuminate the diverse complexity of the issues, and at the same time I know them intimately because I was involved in all of them.

Because this paper aims to consider the strategy rather than the details of design implementation, it will not discuss design at the level of the actual design of the various artefacts produced, such as printed pages. Whilst effective design at this level is a necessary condition for eventual quality, it is not a sufficient one, and it cannot redeem a design for which the strategy has serious flaws.

Research-based materials: developing primary school science.

This work started from a concern that this area was weak despite several past attempts to give it a strong base. An underlying reason was that development was trapped between two inadequate approaches ([Black, 1980](#)). One was to conceptualise primary science as a diluted version of high-school science, whilst the other was to propose activities which might engage young children in general reasoning skills, but developing thereby a content-free 'process' science. As Wastnedge put it 'At present we must concern ourselves more with how children learn than with what they learn' ([2001 p.50](#)).

To escape this trap, the vision was to design activities which would challenge children's thinking and help them to develop some of the elementary insights which might serve as a basis for high-school science. To inform this vision, a research project was set up to explore the ideas about the natural world which children might already have. An example would be in the study of light, where children might first identify the various

sources from which light comes, and then, through activities with torches (flashlights) and mirrors try, as they draw pictures of what is happening, to explore the different ways in which light may be represented on paper. The most ambitious of the targets was to help children realise that we see only by the effect in our eyes of the light which enters them from outside ([Osborne et al.1993](#)). The outcome was a set of data, evidence about the effectiveness of interventions based on them, and proposals for the elementary levels of conceptual development which might serve as a basis for the future learning of science ([Black and Harlen, 1993](#)).

On the basis of this work, funding and support from publishers was secured for writing and trialling new materials with selected teachers. Whilst the weakness of the science education of most primary teachers was a well-known problem, here, the nature of the activities and concepts was such that the new training in science which was needed was modest. The sole proviso was that when children raised unexpected questions which they were not equipped to answer, which would be bound to happen, teachers would have to admit this but perhaps use such questions as issues for discussion - e.g. asking “How could we test that idea?”.

The outcome was two sets of booklets, one for ages 5 to 7 and one for ages 8 to 11, with 11 for teachers and 11 for pupils in each set. At the time when these materials were being written, the future national curriculum was just coming over the horizon in England, and high stakes external tests were not established. The guides for teachers ([Nuffield Primary Science 1993](#)) were able to include links to the first version of the national curriculum for science, and second editions referred in more detail to the revised 1995 version. Built in to the activities set out in the teachers’ guides were suggestions for pupils to express their ideas in drawings and writing ([Figure 1](#)), and the guides contained samples of such work to help teachers judge such products in relation to the national curriculum levels of achievement. Thus, for example, the booklet on materials for 5-7 year olds included a page presenting a well-known children’s story about a ginger-bread house, at a simple reading level and with coloured pictures, but then asking children what would happen to this house if it were to rain. This was followed by a closer look at a real house ([Figure 2](#)).

When it was clear that the 1998 national curriculum was to be revised again, further development of the publications was halted, because of the uncertainty about the outcome. New statutory written tests, to which the materials were not aligned, were externally set and marked, the status of the assessments by teachers of any practical work was down-graded, and the addition, in the late 1990s, of a new stress on literacy and numeracy, with national prescriptions for teaching methods and testing goals for these topics, all served to undermine the priority given to science education ([Harlen, 2007](#)). Thus the innovation did not survive, and no comparable project has emerged to serve the changed context. Yet a recent review of materials for teachers about young pupils’ misconceptions in science, advised:

Probably the most valuable source is the Nuffield Primary Science Teachers’ guides ([Dabell et al. 2006, p.137](#))

Figure 1: Nuffield Primary Science 5-7 - Extract from Teachers' Guide

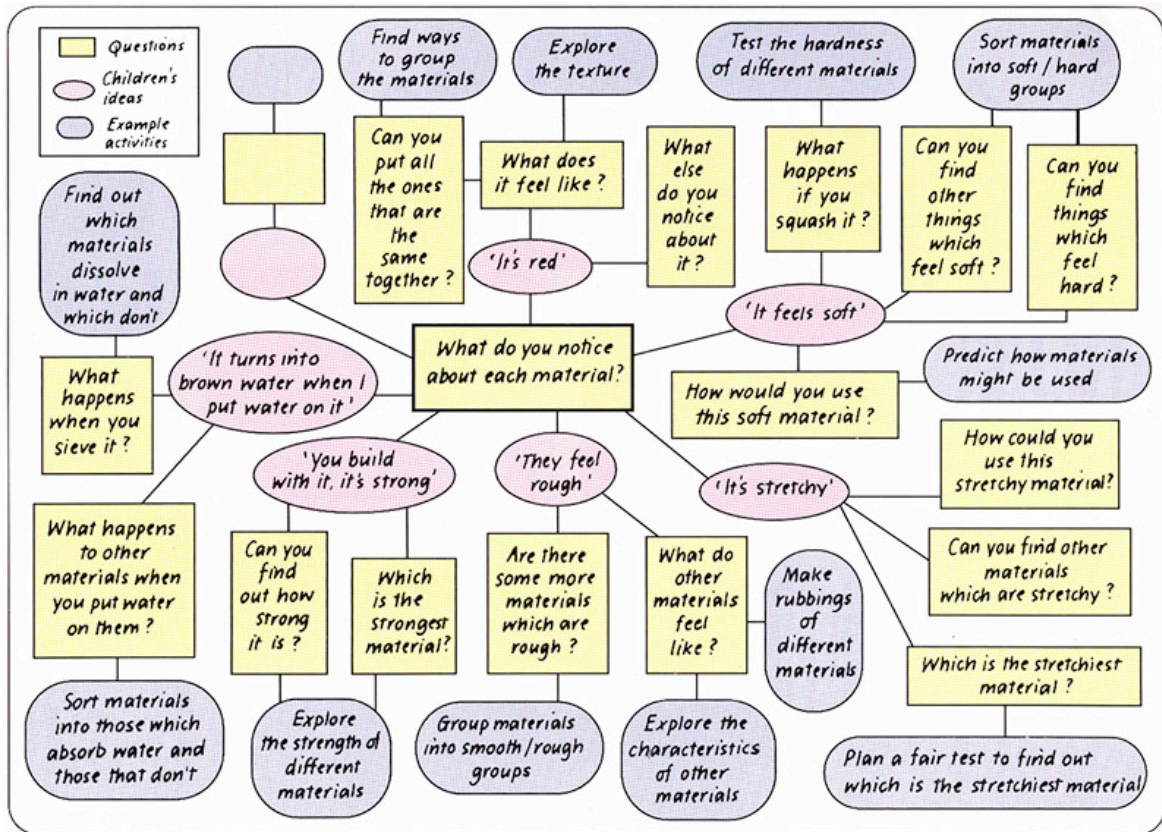
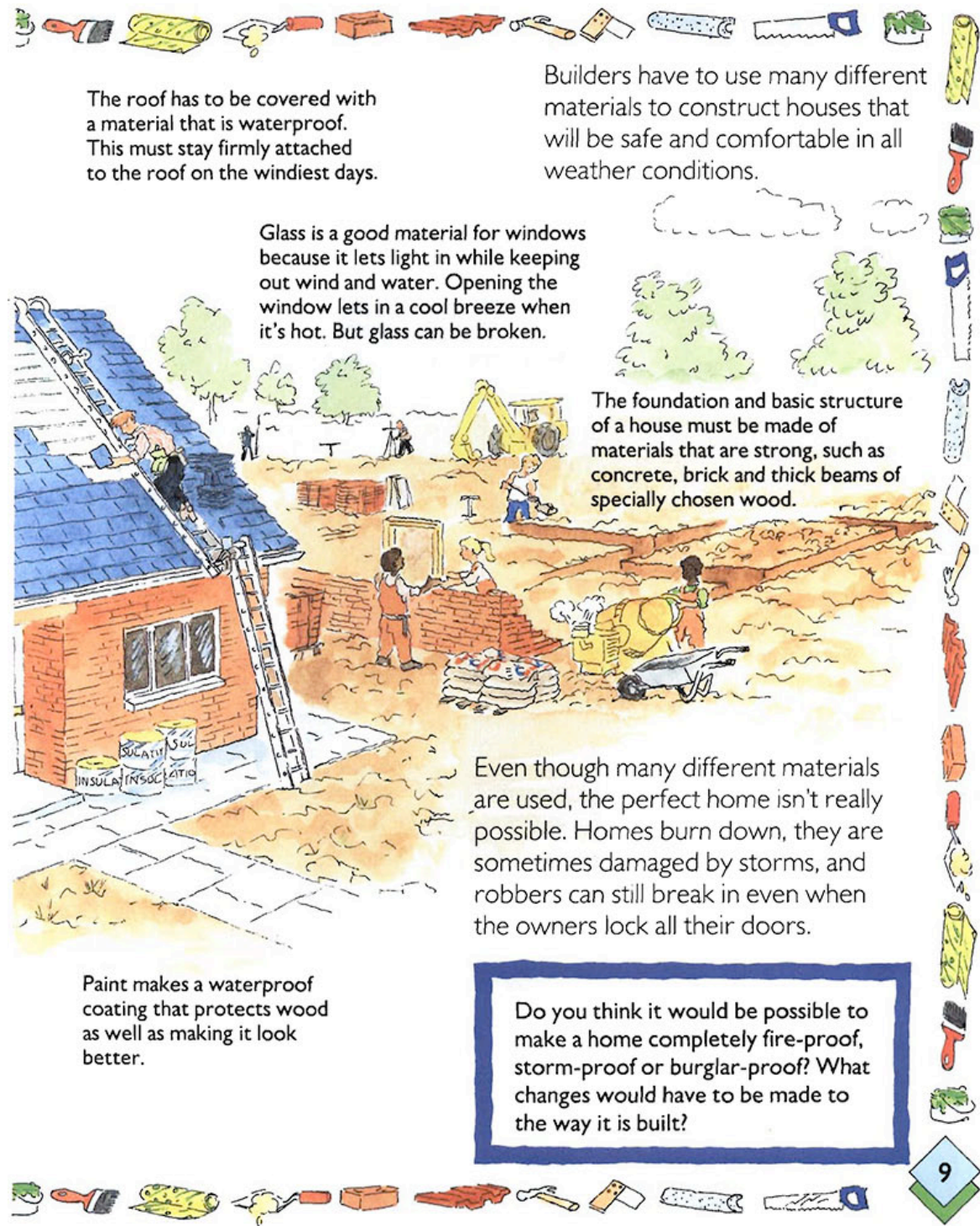


Figure 2: Nuffield Primary Science 5-7 - Extract from Pupils' Guide



The roof has to be covered with a material that is waterproof. This must stay firmly attached to the roof on the windiest days.

Builders have to use many different materials to construct houses that will be safe and comfortable in all weather conditions.

Glass is a good material for windows because it lets light in while keeping out wind and water. Opening the window lets in a cool breeze when it's hot. But glass can be broken.

The foundation and basic structure of a house must be made of materials that are strong, such as concrete, brick and thick beams of specially chosen wood.

Even though many different materials are used, the perfect home isn't really possible. Homes burn down, they are sometimes damaged by storms, and robbers can still break in even when the owners lock all their doors.

Paint makes a waterproof coating that protects wood as well as making it look better.

Do you think it would be possible to make a home completely fire-proof, storm-proof or burglar-proof? What changes would have to be made to the way it is built?

Inventing a new subject - Design and Technology in England's national curriculum.

This field of study has been represented by a patchwork of subjects in the school curriculum, and its definition varies widely between different national systems (Black, 1998). An integrating rationale for the field was proposed by Black and Harrison (1985) who argued that technology was a field of practical action aimed at meeting human needs, and would require inputs from a variety of resources rather than those provided by any one school subject. The diversity of relevant subjects, such as home economics, craft design and technology, art and design, engineering studies, and so on, meant that this vision had implications for curriculum planning. Two projects then explored ways in which several models of cross-curricular work might be implemented in schools (Black et al. 1988; Murray et al. 1994).

The 1998 national curriculum designated Design and Technology as a single compulsory subject, but the inherent problems with this new subject are illustrated by the fact that it was not until 1995, after six years of confusion, that an acceptable specification for the national curriculum was settled (Barlex, 1998).

During this period, a Nuffield Project was designing and producing materials for teachers, which both came to help teachers and also helped the formulation of the new statutory specification. Central to this subject was the concept of practical capability, with two dimensions expressed by the Project as follows:

Capable pupils can design what they are going to make and make what they are going to design

The aim was that pupils would be led to think about the made world and about how they might intervene to change it.

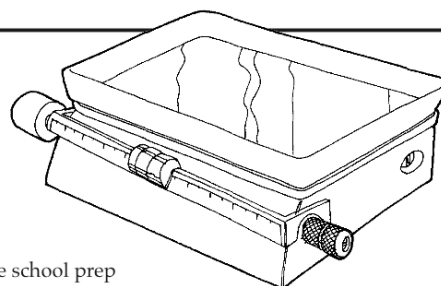
Very few teachers had any experience of this new approach and the reports of the national inspectorate about the early implementation were very critical. Our analysis was that the requirement – that hitherto independent teachers were to teach this co-ordinated subject – raised problems about collaboration, ownership, status and consistency, problems about how to realise its unifying aim in a set of concrete activities, and problems about whether and how printed curriculum materials could help a style of learning which should focus on practical activity.

The solution was a set of novel materials. At the core were two ring-binder files. One contained specifications of 'Capability Tasks' – 24 in all for the first three secondary years (Figure 3a, Figure 3b). Ideas were collected from many sources, a criterion being that any task would have to call for and help develop practical 'design and make' skills, and to require techniques of as high a level of sophistication as schools could reasonably manage. Each task had to be open to a variety of solutions so that there would be opportunity for students to develop creativity. A typical task might require students to design and make a "cool" hat for a teenager, or a buffet meal for a small party, or a work station for a pupil's bedroom.

Figure 3a: Sample of capability task

Focusing on resistant materials and mechanisms

Better weighing



The detail

Sample brief

Design and make a weighing machine that can be used in the school prep room to weigh small animals.

Sample specification

What the product has to do:

- measure and display the weight of small animals;
- operate in the mass range 0-500 g;
- be accurate to within 10 g.

What the product should look like:

- be appropriate to the purpose;
- suit the location where it will be used;
- be attractive to the user.

Other features:

- ensure that the animals suffer minimal distress;
- be easy to read.

Starter sketches

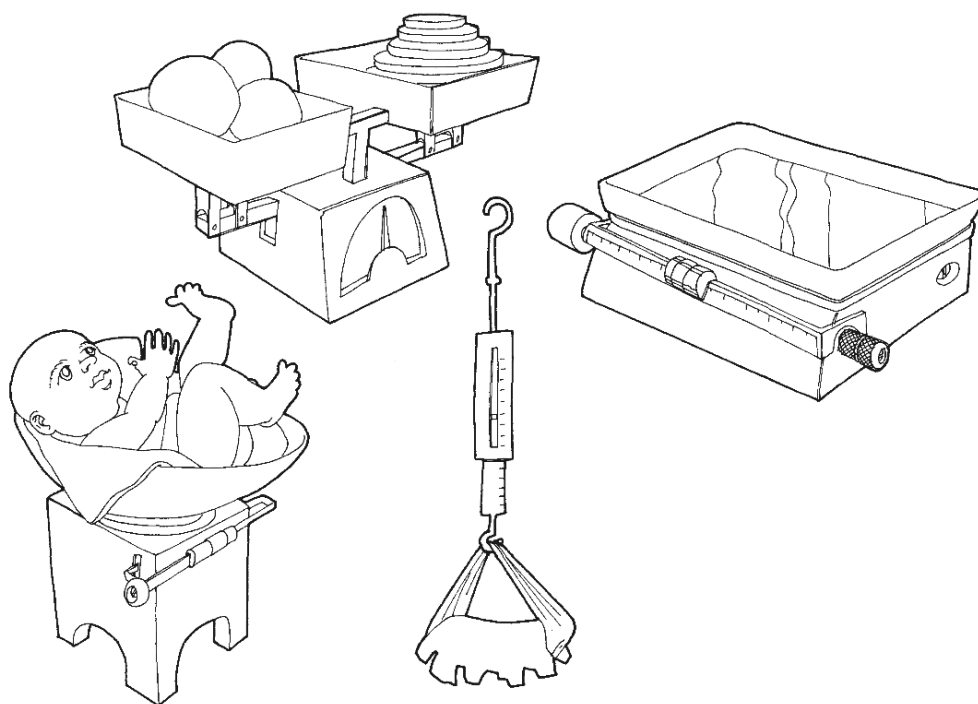


Figure 3b: Sample of capability task**better weighing****Nuffield teacher talk**

'OK, you want the weighing machine for the babies and small children in the nursery. What range will it need to weigh over? What do I mean by range? Well, what's the heaviest child likely to weigh compared with the smallest child? That'll be the range that your machine will have to be able to measure. You don't know. OK. How could you find out? Use the old bathroom scales that we've got. Then you'll have to find a spring that changes well across that range.'

'So you want to use a spring that gets squashed by the weight. What'll happen if the spring is very stiff and difficult to squash? It'll be good for measuring heavy weights but not light weights. Can you explain why? That's right, a small weight won't squash it enough to give a reading.'

'I can see that the spring will be stretched when you put the letters on but I'm not sure how you'll know what a particular stretch means. And you've found a spring that stretches OK over the likely weights of letters and small parcels. This is good. But you need to know the

exact weight of a letter or packet to know how much the postage is. Can you remember what calibrate means? That's it – to use known weights to find out how much the spring stretches for a particular weight. So now you can calibrate your spring.'

'I know your science teacher says weight is a force and that you measure force in newtons. And she's right, but I don't think anyone will understand your weighing machine if it measures in newtons. Can you work out how to convert newtons into kilograms?'

'The tricky bit is making sure that you can attach the spring. If you look in the sample box, you'll see that most of the tension springs have a loop or hook at each end. You can use that to attach your spring. Is the place where you attach each end important? You're not sure. Well, think like this. The bit that moves is a lever pulling against the spring. If the spring is attached here, near the fulcrum, will it be harder or easier to stretch it than if it's attached here, far from the fulcrum? Try it and see.'

Resource Tasks**General design**

For the first Capability Task in Year 9:

SRT 6 *Writing a fuller specification*

SRT 31 *Graphs*

SRT 39 *Evaluating outcomes – Is it appropriated?*

For the second Capability Task in Year 9:

SRT 7 *Research*

SRT 20 *Harmony and scale*

SRT 27 *Modelling with CAD*

Focus area design

SRT 33 *Using system diagrams*
(if not already tackled in Year 8)

SRT 34 *Understanding system interfaces*
(if not already tackled in Year 8)

SRT 35 *Understanding feedback*
(if not already tackled in Year 8)

SRT 36 *Using/low charts*
(if not already tackled in Year 8)

Communication

CRT 5 *Drawing orthographic views 1*

CRT 6 *Drawing orthographic views 2*

CRT 7 *Assembly and exploded views*

Making

RMRT 9 *Designing containers to be made by vacuum forming* (unless tackled in Year 8)

RMRT 10 *Mass producing a simple product*
(unless tackled in Year 8)

Technical

MCRT 1 *Changing types of movement*
(unless tackled in Year 7 or 8)

MCRT 2 *Changing axis and direction of rotation*
(unless tackled in Year 7 or 8)

MCRT 3 *Changing force, speed and distance*
(unless tackled in Year 8)

MCRT 5 *Understanding levers* (unless tackled in Year 8)

MCRT 6 *Springs in the office*

MCRT 7 *Understanding screw threads*

MCRT 8 *Assembling mechanisms*

MCRT 9 *Introducing mechanisms design*

MCRT 10 *Making your own mechanisms*

Commercial

RMRT 4 *Taking care of products*

Case Studies

Weighing, downloadable from the website www.secondarydandt.org

ICT opportunities

Use the Internet to find out about the law as applied to weights and measures. Try putting 'trading standards +UK +weights +measures' in the search engine. Look directly at www.hants.org.uk/regulatory/tradesta/.

Use DTP software to produce an instruction manual. Use CAD software to produce diagrams for an instruction manual. Use CAD software to design the layout of visual display systems. Use CAD/CAM for the manufacture of standard parts.

This collection of tasks was large enough to allow teachers and students to exercise choice. However, it needed other supporting materials to tackle the problem that, given freedom to choose, pupils would not even think of using techniques of which they were ignorant. The solution was a second file ring-binder file containing 144 'Resource Tasks' for the first three secondary years ([Figure 4](#)). Each task presented a realistic problem, so specified that certain techniques had to be used, and so would be learnt in the context of a particular product serving well defined purposes. Any such task could be tackled before, or in an intermission during, any Capability Task which might require it. This two-level approach worked well - and it became a requirement when it was eventually adopted in a revision of the National Curriculum.

However, further under-pinning was required. Any student might need specific information about, for example, properties (of metals, wood, plastics, fabrics and foodstuffs); techniques of cutting, shaping, joining, and treating different materials; techniques for electronic or pneumatic control systems; advice about various approaches to design; advice about product evaluation, and so on. A suitable resource had to be accessible to pupils from age 11 upwards. The potential range of content was enormous, but affordability and accessibility called for a text of limited length. Brevity and intelligibility were attained by very smart use of diagrams and tables, with a minimum of text in simple language ([Figure 5a](#), [Figure 5b](#)). Given the novelty of the subject for teachers it seemed essential to address pupils directly, without providing a conventional text-book: so this Student's Book explained to pupils how the activities – Capability and Resource tasks and the materials in the book, – aligned with the requirements of the National Curriculum.

A second book, the Student's Study Guide, was in two main parts. One was a set of Case Studies of fourteen examples of design and technology developments, describing for each the design, manufacture, marketing, selling and impact of the product. The other gave guidance to pupils about the nature of the subject, about how to use resources from other school subjects, about what it means to 'get better' at the subject, leading to advice about how to assess one's own progress. The strategic aim here was to help develop pupils' autonomy in becoming learners of design and technology.

The final component was a Teachers' Guide, which served as an explanation of the philosophy of the subject on which the materials were based, together with a navigation guide – with enough details for new users. With the help of an extensive scheme of in-service training, the publications achieved status and success. About 2,000 copies of the two task files were sold, suggesting that, since only one copy of each was needed per school, a third of all secondary schools had bought them. The Student's Book has sold over 50,000 copies and is the only publication still in print, whilst the Student's Study Guide has sold about 20,000 copies. The two files and all of the other materials, apart from the Student's Book, are freely available on the web ([Nuffield Design and Technology, 2008](#)).

A detailed description and evaluation of the material was published by Givens and Barlex ([2001](#)): one of their findings was that only the most successful schools saw the need for, and made use of, the Student's Study Guide. A most significant problem was

that the four main constituent areas, namely Food, Textiles, Resistant Materials and Systems and Control, were usually taught by four different teachers, with pupils rotating between them in a carousel model, so that a coherent system of progression in the subject was hard to achieve despite the emphasis on these aspects in the Student's Study Guide and the Teacher's Guide.

Figure 4: Sample of resource task

Electrical control



Designing a simple alarm circuit

What to do

- 1 Look at each of the situations in the boxes below.
- 2 For each one design an alarm circuit that could be used to prevent the difficulties shown. To help you do this:
 - ◆ draw a system diagram that describes what the device will do; Label the input signal and the output signal.
 - ◆ use the Sensing with Electronics Chooser Chart to help you to decide how you will detect the input signal;
 - ◆ use the Sensing with Electronics Chooser Chart to help you to decide how you will produce the output signal;
 - ◆ use the Sensing with Electronics Chooser Chart to help you to decide what processing elements your circuit needs.
- 3 Model your circuit using an electronics kit. Check that it operates in the way that you expect.

Student's Book:

Sensors and processors pages 227–30

Sensing with Electronics Chooser Charts pages 236–7

Time available:

60 minutes

You will learn:

How to design a simple sensing system.

You will need:

Low-voltage direct-current power supply

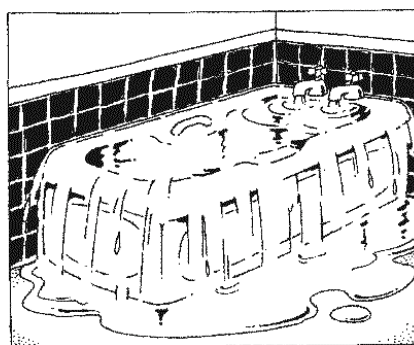
Switches

Access to these components in easy-to-assemble kit form

A range of sensors: light-dependent resistor, thermometer, bimetallic strip, moisture sensor

A processor, e.g. a transistor

Output devices: buzzer, bell, lamp, LED



What to write

- ◆ Draw the final system diagram for each alarm system.
- ◆ Draw a circuit diagram for each of the alarm systems you have designed. Add notes to the diagram explaining how the circuit works.

Figure 5a: Chooser chart from Student's Book (1/2)

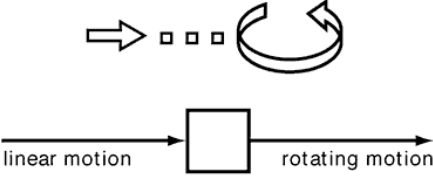
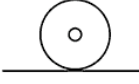
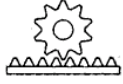

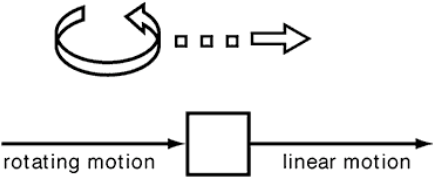
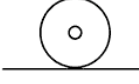
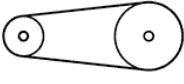

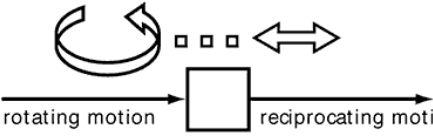
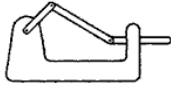

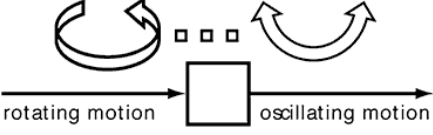
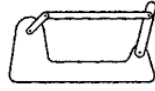


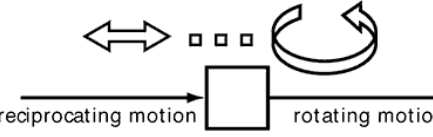

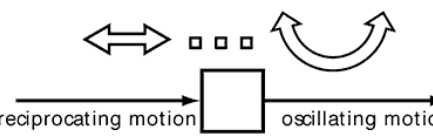
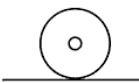

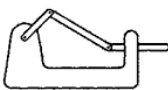
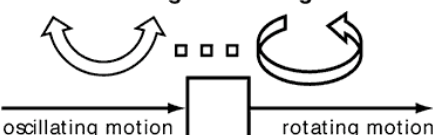
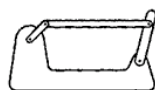

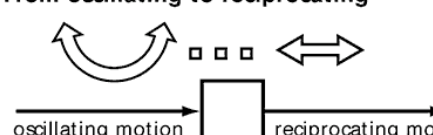
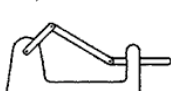

<i>To change the type of movement</i>	<i>You can use:</i>		
<p>From linear to rotating</p>  <p>linear motion → [] → rotating motion</p>	<p>wheel and axle</p> 	<p>rack and pinion</p> 	<p>screw thread</p> 
<p>From rotating to linear</p>  <p>rotating motion → [] → linear motion</p>	<p>wheel and axle</p> 	<p>belt and pulley</p> 	<p>screw thread</p> 
<p>From rotating to reciprocating</p>  <p>rotating motion → [] → reciprocating motion</p>	<p>crank, link and slider</p> 	<p>cam and slide follower</p> 	
<p>From rotating to oscillating</p>  <p>rotating motion → [] → oscillating motion</p>	<p>crank, link and lever</p> 	<p>cam and lever follower</p> 	<p>peg and slot</p> 
<p>From reciprocating to rotating</p>  <p>reciprocating motion → [] → rotating motion</p>	<p>crank, link and slider</p> 		
<p>From reciprocating to oscillating</p>  <p>reciprocating motion → [] → oscillating motion</p>	<p>wheel and axle</p> 	<p>rack and pinion</p> 	<p>crank, link and slider</p> 
<p>From oscillating to rotating</p>  <p>oscillating motion → [] → rotating motion</p>	<p>crank, link and lever</p> 	<p>peg and slot</p> 	
<p>From oscillating to reciprocating</p>  <p>oscillating motion → [] → reciprocating motion</p>	<p>crank, link and slider</p> 	<p>cam and slide follower</p> 	

Figure 5b: Chooser chart from Student's Book (2/2)

To change the direction of movement <i>You can use:</i>	
<p>From clockwise to anticlockwise</p> <p>clockwise motion anticlockwise motion</p>	<p>gears</p> <p>belt and pulley</p>
<p>From left to right</p> <p>leftward motion rightward motion</p>	<p>levers</p> <p>linked levers</p> <p>rope and pulley</p>
<p>From left to right</p> <p>horizontal motion vertical motion</p>	<p>levers</p> <p>linked levers</p> <p>rope and pulley</p>
To change the axis of rotation <i>You can use:</i>	
<p>From rotary motion to rotary motion with axis at different angles</p> <p>rotary motion rotary motion with axis at different angles</p>	<p>bevel gears</p> <p>flexible couplings</p> <p>worm and wheel</p> <p>belt and pulley</p>
To increase output force and decrease speed <i>You can use:</i>	
<p>With parts rotating or oscillating</p> <p>force larger force</p> <p>speed lower speed</p> <p>gears</p> <p>bevel gears</p> <p>worm and wheel</p> <p>wheel and axle</p> <p>belt and pulley</p> <p>chain and sprocket</p> <p>input output input output</p>	<p>With parts reciprocating or moving in a straight line</p> <p>rope and pulley</p> <p>levers</p> <p>linked levers</p>
To increase output speed and decrease force <i>You can use:</i>	
<p>With parts rotating or oscillating</p> <p>force smaller force</p> <p>speed smaller speed</p> <p>gears</p> <p>bevel gears</p> <p>belt and pulley</p> <p>chain and sprocket</p> <p>input output input output</p>	<p>With parts reciprocating or moving in a straight line</p> <p>levers</p> <p>linked levers</p>

Nuffield A-level Physics: systemic reform in a friendly environment.

The origin of this project lay in concerns, both in the U.K. and the U.S.A., about the state of science education ([Jenkins, 1979](#)), and about cold-war threats linked to the shortage of scientists ([Rudolph, 2002](#)). Such pressures encouraged the Nuffield Foundation to set up reform projects, first in the science courses for all secondary pupils, and later for the A-level sciences. (After age 16, students in England aiming at university entry spent a further two years in advanced *A-level* courses, in specialised study of only three subjects).

The aims of the course were outlined as follows :

The construction of a course is itself a piece of engineering, a job to be done despite inadequate knowledge of how some of the basic components in the learning process work. We have conceived the task as one of weaving topics together to make a connected story which makes sense and arouses interest in its own right, which has discernible themes and connects these in fruitful ways, and which at the same time serves these deeper aims of learning in the future, of understanding physics, of understanding how physics works, of learning to inquire oneself, and of seeing applied and social implications.
p.303, Black and Ogborn, 1970

This challenged the existing norms of both curriculum, pedagogy and examinations. The course was designed as a sequence of ten topics, each drawing on the work of its predecessors, with the final topic serving as a grand finale, drawing together many of the concepts developed in the earlier topics. This was physicists' physics, reflecting, in its web of connections, one of the most compelling features of the subject. Other topics led in different directions, principally to explore technological and social effects of physics.

One key feature was the need to introduce topics not previously studied at A-level. This called for 'pedagogic transformation', i.e. ways to present ideas, previously considered too demanding at this level, to make them both authentic and intelligible. For example, a new way to teach the second law of thermodynamics involved consulting the different approaches in many sources ([Ogborn, 1978](#)), then setting up a new approach, requiring new methods and visual aids ([Black & Ogborn, 1978](#); Black et al. [1971, 1972](#)), then checking with several university physicists that the approach was authentic.

For the pedagogy, a core aim was that students should become independent learners. So the final publications did not include pupil textbooks, a feature which worried publishers and many teachers. There were detailed guides for teachers ([Figure 7](#)), and small booklets for students of background reading ([Figure 6](#)) and of questions ([Figure 8](#)).

Teachers were asked to provide a range of existing textbooks for students to consult, the aim being to help students to become less dependent on a sole textbook. Much of

their learning was laboratory-based, with experiments designed to provoke discussion rather than to 'prove' established results. In one topic, different groups conducted one each of a suite of experiments, and then reported to a plenary in which all could draw together the full picture. All were required to do two small independent investigations, each taking two to three weeks, with the second being teacher-assessed to contribute about 10% of the A-level examination.

Both the integrity of the course and the interests of the students called for development of a new A-level examination. To validly reflect and support the aims of the course, a tailor-made set of six instruments was developed as follows :

- a multiple choice test;
- a test with a set of short, structured questions each calling for a set of short answers;
- a test offering a choice of essay-type questions;
- a passage about a topic not in the course, with questions assessing understanding of it;
- a practical test composed of about eight tasks using laboratory equipment;
- a report on an individual open-ended experimental project, assessed by the teacher.

Entry to university depended on the results of A-level examinations and acceptability of the results of this examination had to be secured in negotiations to establish that it would lead to a qualification which would be recognised and accepted beyond schools, notably by university admissions officers ([Black & Ogborn, 1977](#)).

There were numerous other aspects to the engineering, e.g involving schools who would trial the course, equipment manufacturers, publishers, teacher trainers, school district authorities, and the funding agency. One example will illustrate the complexity of the advanced planning required: trials of the new approaches in schools could not start until any novel equipment was available, so manufacturers had to make it – so they needed to see working prototypes a year ahead of the trials, which prototypes had first to be developed and tested: thus decisions about and development of such equipment had to be settled at a time when the course was no more than a set of aims with mere outlines of the material to be written.

The success of the course depended on meeting all of these the multiple requirements. However, a key feature of the context was the team's freedom when the curriculum was not seen as an area for government control – the innovators were free to innovate, and succeeded or failed by their power to attract voluntary participation. Governments in the UK allowed more freedom for work at this level, in part because of their concerns about poor recruitment to those advanced studies which lead to qualifications in science and engineering.

The materials were revised and re-printed after a few years, and at this point it was decided, under pressure from publishers and schools, to produce a pupil textbook. The new materials had significant effects on the development of many conventional

syllabuses and text-books. The course and its special examination continued for over 25 years until a quite new course, Advancing Physics (Ogborn, 2003) replaced it.

Figure 6: From 20-page article entitled “Electrostatics and the engineer” in students' background reader

of its volume by having multiple live parts which could compensate for the lower specific forces afforded by electrostatic fields.

From the standpoint of engineering, however, such proposals seem rather questionable. Arrays of thin discs or sectors, alternately stationary and rotating at high speed, are likely to vibrate, rub, or even foul each other. For these reasons, unlike capacitors or storage batteries, electrostatic generators cannot take full advantage of interleaved parts.

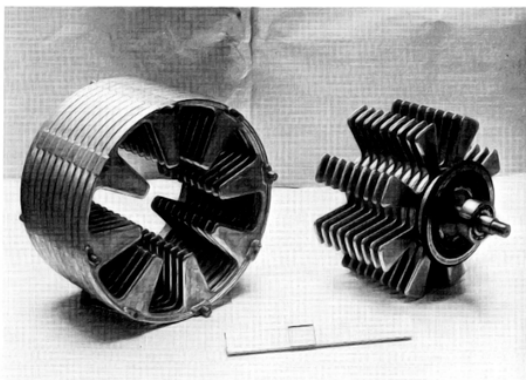


Figure 4
Stator and rotor of a variable capacitance electrostatic generator. Vacuum-insulated machines of this type are being evaluated as a source of high voltage power for spacecraft.

At any rate, the most realistic approach is to dispense with insulants in the rotor assembly altogether by having something like a rotating capacitor on a shaft supported by stationary insulators. Such a machine, worked in high vacuum, has been proposed as a possible voltage source for spacecraft ion rockets, since it is the only type of generator

capable of working indefinitely under extremes of temperature and radiation. As far as terrestrial power units are concerned, perhaps a more successful line of attack may spring from present research on high permittivity liquids.

These might eventually endow electrostatic engineering with the exact counterpart of the magnetic cores of conventional machines.

Industrial applications

Applications of electrostatics are so numerous that it would be impossible to list them all. For example, in a small Japanese tea factory I was shown an ingenious separator that picks up the dried leaves and rejects the worthless stems and wooden fragments. It was engineered locally and has never, to my knowledge, been mentioned in any review.

Electrostatics is the only universal way of directly using electrical energy for the displacement, acceleration, or sorting of matter. Electricity has been otherwise merely a means of transmitting energy from a remote prime mover, needing clumsy and inefficient energy conversion at the receiving end of the link.

The first major application of electrostatics was the precipitation of dusts, fly-ash, and fumes. Electrostatic precipitation now plays an outstanding role in reducing air pollution. Every modern thermal power station has huge precipitators which eliminate 95 to 99 per cent of the fly-ash discharged to the stack. Pulverized fuel firing, which made low grade coal suitable for large power plants, also made electrostatic precipitation necessary because the unburnable 20 to 40 per cent of the fuel is converted entirely to fly-ash which escapes with the flue gases. A 250 megawatt station produces about 30 tonnes of ash per hour which, distributed over one square kilometre around the station, would in a few years result in a layer several centimetres thick. A reliable electrostatic precipitator is therefore indispensable.

Figure 7: From Teachers' Guide Unit - Electricity, electrons and energy levels

- Demonstration
2.16 Spooning charge (using electrometer)
 1006 electrometer
 1003/1 milliammeter (1 mA)
 1004/1 voltmeter (1 V)
 1041 potentiometer holder
 with
 1051 preset 5 k Ω
 1051 capacitor, polystyrene, 0.01 μ F
 14 e.h.t. power supply
 1033 cell holder with 1 U2 cell
 51 Malvern electrostatics kit (parts)
 1000 leads

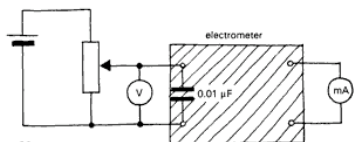


Figure 30
Calibration circuit.

The electrometer should be calibrated, after allowing a 'warm-up' period, using the circuit of figure 30. A 0.01 μ F low leakage capacitor is connected across the input terminals, unless an internal switched range for 'charge' measurement includes a capacitor of at least this value. (A lower capacitance requires the insulated conductor to be charged to a low voltage, and readings are not reliable.)

Figure 31 shows the charge measuring circuit.

Small conductors with 4 mm plugs, such as may be provided amongst the accessories, are plugged into the e.h.t. positive terminal, and into the input of the electrometer. With a p.d. of 1000 V, charge is transferred from the e.h.t. supply to the electrometer by the small proof plane, the meter reading being recorded after every five transfers of charge. A graph of meter reading against number of charges transferred should be a straight line.

The p.d. used may be varied and the difference between the two proof planes shown. When the larger proof plane is used, the meter reading should be taken after each transfer of charge.

Note for teachers on incomplete transfer of charges

If the charge on an object of capacitance C , initially at V_1 , is shared with the electrometer, so that it and the electrometer come to V_2 , there is charge CV_2 left on the object out of the original charge CV_1 .

As V_2 is of the order of 1 volt, there will be negligible error if V_1 is of the order of 1000 volts. But if C is larger, so that V_1 must be only, say, 10 volts for V_2 to be less than 1 volt, about 10 per cent of the charge will be left behind on the object.

Spooning charge

The following demonstration emphasizes that charge, like milk or sugar, is a quantity of something that can be measured out and passed from one place to another without being lost. It makes sense to ask, 'Where did that dollop of charge go to?'. There are quantities for which such a question makes no sense, such as pressure or temperature.

The demonstration also introduces the electrometer as a charge-measuring device, whereas it was used earlier (2.9) as a voltmeter.

Demonstration

2.16 Spooning charge (using electrometer)

It is first necessary to make clear that with a charged capacitor across the input of the electrometer, the p.d. can stay almost steady for a long while because the electrometer passes so small a current. (For example, 0.01 μ F at 1.0 V has charge 10^{-8} C. Even if the electrometer passes 10^{-12} A, and it should pass less, the charge would last more than 10^4 seconds.)

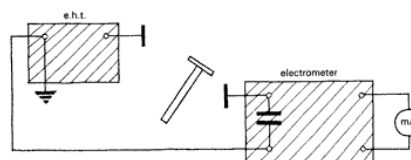


Figure 31
Spooning charge.

Take a 'spoonful' of charge from the terminal of the thousand volt supply, and carry it across to the electrometer input. The electrometer gives a small, but steady reading. Further transfers raise the indication, and the indicated p.d. rises in proportion to the number of transfers.

Try quickly a different voltage and a different size of conductor. It seems that the electrometer measures charge, and that the charge on the conductor depends on its size and is proportional to the voltage. Graphs of charge transfer and potential difference for several different insulated objects of varying size can be plotted, different students plotting different sets of results.

Show also that there is no significant charge left on the conductor after touching the electrometer, though there should be a warning that this might not be so for a larger object.

Figure 8: From Students' Book Unit 2: Electricity, electrons and energy levels

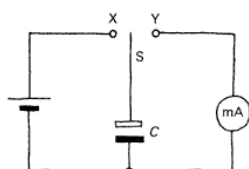


Figure 23

47 Alf finds that when he moves the switch S from X to Y in the circuit in figure 23, using for the capacitor C the following different arrangements, he obtains throws on the meters as below:

Capacitor C_1		Throw 1.5 divisions
Capacitor C_2		3.0 divisions
Combination C_1 and C_2		4.5 divisions

Brenda says that the results suggest that the throw of the meter is in fact proportional to the charge flowing through it. Colin says that that would depend on whether the charges on C_1 and C_2 added up in the third arrangement.

Dorothy thinks that the meter is one she used a week before and that she had shown experimentally by a different method that its throw was in fact proportional to the charge.

Alf then claims that, if Dorothy is right, 'charge is conserved'. Brenda wants to know if they can now work out how much bigger C_2 is than C_1 .

Dorothy claims that the experiment also shows, given her earlier experimental result, that $C = C_1 + C_2$ in a parallel arrangement.

Take each statement in turn, and comment on it. Make any calculations the speakers propose, if it is possible to do so.

48 An isolated sphere of radius 0.9 m has a capacitance of 100 pF between it and the distant earth or walls of a room. ($1 \text{ pF} = 10^{-12} \text{ F}$.)

Two plates, each 0.1 m square, separated by 1 mm of air, have a capacitance of about 100 pF; when separated by 1 mm thickness of paper they have a capacitance of about 500 pF.

A polythene-insulated coaxial cable has a capacitance of about 75 pF per metre. The capacitance between two telephone wires stretched between telephone poles is about 6 pF per metre.

Make rough guesses or estimates of:

- The capacitance of a man falling freely through the air.
- Your capacitance when standing on an earthed floor with insulating soles 10 mm thick on your shoes.
- The capacitance of a coaxial down lead from a television aerial on the roof to a television set in the house.
- The capacitance between the mains lead of an oscilloscope and 1 metre of insulated wire connected to the Y input of the oscilloscope and running fairly close to the mains lead.
- The capacitance between yourself and this wire when you hold the insulation in your fingers.

49 A student produces a model, shown in figure 24, intended to represent a capacitor in a circuit.

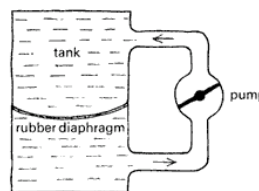


Figure 24

A pump P pushes water into the top of a tank, which is divided into two compartments by a leak-proof rubber diaphragm. The whole model is filled with water. When the pump is running, the diaphragm bulges as shown.

Formative assessment: materials to support only pedagogy

This particular piece might seem a surprising inclusion here. It did not produce either curriculum or assessment materials: it was solely about pedagogy. Yet by any standards it has been influential, producing a very widely cited research publication, two booklets for teachers — each of which has sold over 50 000 copies — and a book which has been a ‘best-seller’ according to both the publishers and Amazon. What makes it relevant here is this sharp contrast with the other examples.

The work began with a review of research evidence about the nature and effectiveness of formative assessment ([Black and Wiliam 1998a](#)). This showed two outstanding features, one being that there was strong evidence that formative assessment practices did produce significant enhancement in pupils’ attainment, the other that these practices were not to be seen in most classrooms. We decided to highlight this message, by a booklet addressed mainly to teachers, but also to policymakers and others. The key feature here was to make the message short, assertive and as simple as possible. This was done with a 20 page A5 booklet ([Black and Wiliam 1998b](#)). About half of the text presented a digest of the evidence, whilst the rest made a series of recommendations about what action should follow ([Figure 9](#)). A press conference served to attract publicity and requests for copies and talks to meetings soon followed.

The second phase of activity was to set up a project to tease out how the evidence might be used to change the pedagogy of teachers. Teachers in six schools, about 40 in all, accepted invitations to work with us in turning some of the ideas from the research into classroom practice. We emphasised that research could not provide recipes for teaching - it only provided ideas which might suggest new approaches that teachers might incorporate in their own daily work; in so doing they would be inventing new practical knowledge, not ‘applying’ research in any direct sense ([Black & Wiliam, 2003](#)). A further feature was that the project was to explore such invention within the context of the existing constraints of curriculum and summative testing in their schools, so that our concern was restricted to provoking and evaluating changes, and supporting the teachers - mainly by providing feedback from observing their teaching and also by providing regular project meetings, one every five weeks over two years, in which they could all meet and share experiences.

One outcome was that test scores, on the normal tests that were being used in their schools, were significantly higher than those of comparable control classes ([Wiliam et al., 2004](#)). Another was that the teachers expressed strong satisfaction with the changes in their own work. A third was our finding that such changes took time. Indeed, after one year of work in which the teachers had been happy to be involved, our classroom observations showed that little had changed. It was only in the next six months that the project ‘took off’ in that teachers were now teaching in different ways. We could then produce a second short booklet and a book for teachers ([Black et al. 2002, 2003](#)), in both of which we made extensive use of quotations from the written reflections of the teachers.

The core activities developed and promoted here were at the heart of the ways in which

teachers interact with their students, whereby they elicit and then respond to students' own thinking about ideas central to their learning. Such interactions could occur in oral dialogue, the minute by minute exchanges in a classroom, or in the more measured composing of guidance in responding to students' written work. Both require a shift of orientation, from framing responses as grading or judging, to making them serve, and be seen by students to serve, as guidance to respect, yet challenge and improve, the learner's thinking about the tasks that the activity had revealed. This could enrich the teaching of almost any curriculum, and is in principle quite separate from the long-term checking up of assessment of learning.

However, widespread dissemination has involved dilution to the extent of undermining the idea. Adoption has been superficial by many who do not grasp that behind the surface tactics lies a need for most teachers to re-think their beliefs about, and personal role, in students' learning. The use of the title 'Assessment for Learning' as a simpler alternative to 'Formative Assessment' has not helped, and both in the USA and in recommendations of the government in England this title has been applied to regimes of frequent summative testing, which the original evidence for formative assessment does not support.

Figure 9: from the 25 page A5 booklet for teachers: *Working Inside the Black Box*.

One teacher summarised the overall effects of her efforts to improve the use of question and answer dialogue in the classroom as follows:

Questioning

- My whole teaching style has become more interactive. Instead of showing how to find solutions, a question is asked and pupils given time to explore answers together. My year 8 target class is now well-used to this way of working. I find myself using this method more and more with other groups.

No hands

- Unless specifically asked, pupils know not to put their hands up if they know the answer to a question. All pupils are expected to be able to answer at any time, even if it is an 'I don't know'.

Supportive climate

- Pupils are comfortable with giving a wrong answer. They know that these can be as useful as correct ones. They are happy for other pupils to help explore their wrong answers further.

Nancy, Riverside School

Increasing the wait time can lead to more pupils being involved in question and answer discussions, and to an increase in the length of their replies. One particular way to increase participation is to ask pupils to brainstorm ideas, perhaps in pairs, for

two to three minutes prior to the teacher asking for contributions. Overall, a consequence of such changes has been that teachers learnt more about the pre-knowledge of their pupils, and about any gaps and misconceptions in that knowledge, so that their next moves could address the learners' real needs.

To exploit such changes it is necessary to move away from the routine of limited factual questions and to refocus attention on the quality and the different functions of classroom questions. An example is the use of a 'big question': an open question, or a problem-solving task, which can set the scene for a lesson by evoking a broad-ranging discussion, or by prompting small group discussions, so involving many pupils. However, if this is to be productive, both the responses that the task might evoke and the ways of following up these responses have to be anticipated. Collaboration between teachers to exchange ideas and experiences about questions is very valuable. The questions themselves then become a more significant part of teaching, with attention focused on how they can be used to explore and then develop pupils' learning.

I chose a year 8 middle band group and really started to think about the type of questions I was asking – were they just instant one-word answers, what were they instigating – knowledge or understanding, was

I giving the class enough time to answer the question, was I quickly accepting the correct answer, was I asking the girl to explain her answer, how was I dealing with the wrong answer? When I really stopped to think I realised that I could make a very large difference to the girls' learning by using all their answers to govern the pace and content of the lesson.

Gwen, Waterford School

Effective questioning is also an important aspect of the impromptu interventions that teachers make once the pupils are engaged in an activity. These often include simple questions such as 'Why do you think that?' or 'How might you express that?', or – in the 'devil's advocate' style – 'You could argue that...'. This type of questioning can become part of the interactive dynamic of the classroom and can provide an invaluable opportunity to extend pupils' thinking through immediate feedback on their work.

Overall, the main suggestions for action that have emerged from the teachers' experience are:

- More effort has to be spent in framing questions that are worth asking, i.e. questions which explore issues that are critical to the development of pupils' understanding.

- Wait time has to be increased to several seconds in order to give pupils time to think and everyone should be expected to have an answer and to contribute to the discussion. Then all answers, right or wrong, can be used to develop understanding. The aim is thoughtful improvement rather than getting it right first time.

- Follow-up activities have to be rich, in that they provide opportunities to ensure that meaningful interventions that extend the pupils' understanding can take place.

Put simply, the only point of asking questions is to raise issues about which the teacher needs information or about which the pupils need to think.

Where such changes have been made, experience has shown that pupils become more active as participants, and come to realise that learning may depend less on their capacity to spot the right answer and more on their readiness to express and discuss their own understanding. The teachers also shift in their role, from presenters of content to leaders of an exploration and development of ideas in which all pupils are involved.

Reflections and conclusions

It is not easy to distil common themes from these examples because of their diversity. What I want to suggest here is a set of strategic questions which must be answered in the first stages of designing educational materials, using the four cases to illustrate a range of answers.

What research evidence is needed – and is it available ?

For Formative Assessment, the research evidence was the essential starting point, both by showing its potential to improve attainment, and in developing ways to realise this potential. Research also provided an essential basis for the Primary Science in helping to develop activities which would be both feasible and effective in securing its aims. Design and Technology called for a new configuration of curriculum topics, and whilst some relevant research basis was being developed, the project had to move rapidly into practice because of national legislation. The A-level physics, being less radical and looking to evolution of existing good practice, did not need a new basis in research evidence.

Is the curriculum an established constraint – and is it likely to change?

This dimension was irrelevant for the Formative Assessment example. The A-level Physics was pushing the limits of existing curriculum norms, exploiting the curriculum flexibility allowed in its context to promote new aims. Such freedom was not enjoyed by Design and Technology, for whilst it successfully helped to define the new subject, its development was dogged by changes in the national curriculum specification. Primary Science established a new approach to the subject's curriculum, in a context which initially allowed freedom, but changed later in ways which made it unviable.

Does summative assessment provide an opportunity or a straitjacket?

This issue was marginally relevant to the Formative Assessment, in that the evidence that it could lead to higher scores on existing tests helped make it attractive to teachers. Whilst the A-level Physics had freedom of manoeuvre to compose a summative assessment system that supported its aims, the Primary Science innovation did not formulate a summative assessment system, and when such a system was imposed, it became hard to sustain. For assessment of Design and Technology, the national requirements were not unhelpful, in that emphasis on teacher assessments of pupils' design-and-make tasks was acceptable.

What style of classroom pedagogy is intended and how is it to be achieved ?

One aspect here is evident in Primary Science, which faced the obstacle that nearly all of the teachers lacked confidence in their knowledge of the subject, so that they felt unable to cope with the imaginative questions that their pupils might raise. Hence, the guides for teachers had to be supplemented by a book about the science itself, whilst explicit texts for pupils were also essential.

Design and Technology faced a similar problem in that being new, the collegiality and

shared culture on which established subjects could draw did not exist: teachers of diverse experience had to forge a new identity. Here there was a clear need for materials for teachers to support them with guidance about the rationale of the course and about the way in which the materials reflected this rationale, with a unified approach across the various topics which would be taught by different teachers. But there was an equally strong need to have a rich set of materials speaking directly to students to complement this support. At the same time, because of the distinctive nature of the work, conventional textbooks would be inadequate. The combination of files of capability and resource tasks, with small books that provided 'craft resources' and background information, met the need.

The A-level Physics project also had problems, for it both presented novel topics and called for big changes in teaching practices. Many teachers who found the new content attractive showed, in trials, that they had not grasped that the new practices required radical changes in their teaching style. The publication of a pupils' book for the two very new units was essential, yet the other eight demanded a new style and a new articulation of the unusual resources: the change to more conventional pupils' books at the first revision may have been inevitable.

Pedagogy was the central concern of the Formative Project: promoting teacher change in this dimension was the focus of its work. It succeeded with its design challenge of achieving texts which combined brevity, clarity, practicality, and, through the use of teachers' own writing, credibility.

Designing for sustainability?

It is inevitable that new educational materials may either become non-viable because of changes in the national context, or decline in popularity as they are replaced by later novelties. Their success may then be measured by the extent to which their ideas are incorporated in rival materials – imitation being the most sincere form of flattery.

Whilst it is hard to see how design can, or even should, make materials less fragile to such changes, it is likely that the survival of their most valuable features will eventually depend on these becoming part of the valued practice of teachers. They will achieve their common aim, of engaging pupils in successful learning, insofar as they can enhance the essential determinants of successful learning, the quality of the close interaction between teacher and pupils, and between pupils themselves, and thereby expand the capacity of the teacher to work creatively with the ways that pupils respond to the tasks and challenges set before them. My Formative Assessment example is particularly significant for it is only by working to challenge and so help develop these crucial features that teachers can promote learning in any innovation. So the question for the designer to face is: what types of teaching and learning activity do you envisage, what theories, of learning and of pedagogy, provide warrants for your choices, and in what ways do your products help such activity to happen?

Any set of materials must match and support the classroom work of teachers, but many under-estimate the difficulty of achieving teacher change, and it is in this dimension that the design of any materials becomes a central and subtle issue. One element which

these four had in common was to take seriously fundamental aims in learning, aims to which none could object but few seemed committed to achieve in practice. It is a well documented finding that achieving teacher change is slow steady work ([Schulman and Schulman, 2004](#)) – to imagine that a short in-service course will be enough is usually a fantasy. The most subtle task of designers is to catalyse such change, within any materials, through work on the context in which they will be used, and through sustained support for the teachers who are translating their aims into practice.

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Diagrams

Figure 1: Page 11 from Nuffield Primary Science Teachers' Guide Key Stage 1: Materials. London: Collins 1993..

Figure 2: Page 9 from Nuffield Primary Science Pupils' Book Years 3-4: Materials London: Collins 1993.

Figure 3: Pages 3-4 Nuffield Design and Technology Key Stage 3: Capability Task File Weighing. London: Longman. 1995

Figure 4: . Page 9. Nuffield Design and Technology Key Stage 3: Resource Task File Alarm Circuit. London: Longman. 1995

Figure 5: . Nuffield Design and Technology Key Stage 3: Students' Book: Chooser Chart. London: Longman. 1995

Figure 6: Pages 10-11 from N.D.Felici "Electrostatics and the engineer" p.3-22 in Nuffield Advanced Physics Students' Book: Physics and the engineer: Harmondsworth: Penguin 1973

Figure 7: Pages 60-61 Nuffield Advanced Physics Teachers' Guide Unit 2: Electricity, electrons and energy levels. Harmondsworth: Penguin 1971

Figure 8: Pages 34-5 Nuffield Advanced Physics Students' Book Unit 2: Electricity,

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Figure 9: Pages 6-7 (2002) Black, P., Harrison, C., Lee, C., Marshall, B. & Wiliam, D. *Working Inside the Black Box*. London: GLAssessment.

About the Author

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For many years he was involved closely with curriculum development work with the Nuffield Foundation in science and in design and technology, at primary, secondary and tertiary levels. He was chair of the government's Task Group on Assessment and Testing in 1987-88 and deputy chairman of the National Curriculum Council from 1989 to 1991. He has served on three committees on the USA National Research Council.

He took his first degree in physics, and subsequently obtained his Ph.D. in Crystallography at the Cavendish Laboratory in Cambridge in 1954. Between 1956 and 1976 he was a faculty member in the Department of Physics in the University of Birmingham but his interests gradually moved from research in physics to research and development in science education, culminating with his move to Chelsea.

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