

Capability Lost and Found?

The Maurice Brown Memorial Lecture

Introduction

The title of my lecture parodies Milton in his search for paradise. Technology education in its many guises in the UK has the idea of 'capability' embedded within it. Like Milton's search, there has been a search for capability's identity. The nature of capability has varied over time and among different advocates. Although capability has been central to the debate about technology education for the last 10 years or so, we have vacillated in what we understand by the term. However, in the final version of the National Curriculum, we find capability expressed as a tripartite relationship of designing, making and knowledge. The Programmes of Study for each key stage start with the statement:

Pupils should be taught to develop their design and technology capability through combining their Designing and Making skills ... with Knowledge and understanding ... in order to design and make products." (DFE/WO, 1995)

What remains unclear is just how the 'combining' takes place, an issue that has been present in all the models of capability that have emerged over the past 10 years. These models started with the recognition of the combination of process and content; for example, that of Black and Harrison (1985) shown in Figure 1. But they also emphasised the link between thinking and action. Black and Harrison saw capability in terms of being able "to perform, to originate, to get things done, to make and stand by decisions" (Black and Harrison, 1985, p. 6). It is the ability to

act that is the predominant idea in capability. The APU model similarly linked thought and action through the model of the interaction of mind and hand (Figure 2), and its model of capability reflected the link of process and knowledge, with the process being that of design (Figure 3).

The role of using 'knowledge' has always been present in ideas of capability, but its relationship to the process is ill-defined, as is how knowledge is used in action. Although we started with a clear focus on both action and upon the combination of knowledge and process, we have moved the focus to process alone, leaving the role of knowledge unclear. Paradise lost?

I shall argue that we need to examine again what we mean by capability and in particular to try to locate the role of knowledge. This argument has a number of strands. First that we cannot continue to use models of capability that rely on processes that exist independent of knowledge. Second, that the use of knowledge, particularly from science and mathematics, is more complex than the injunction in the National Curriculum (quoted above) presents it. Third, we need to examine the nature of the knowledge that is used in technological activity, and to explore qualitative knowledge. In presenting this argument I shall draw upon some of the research that my colleagues and I have undertaken at the Open University.¹

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Figure 1: Model of technological education.

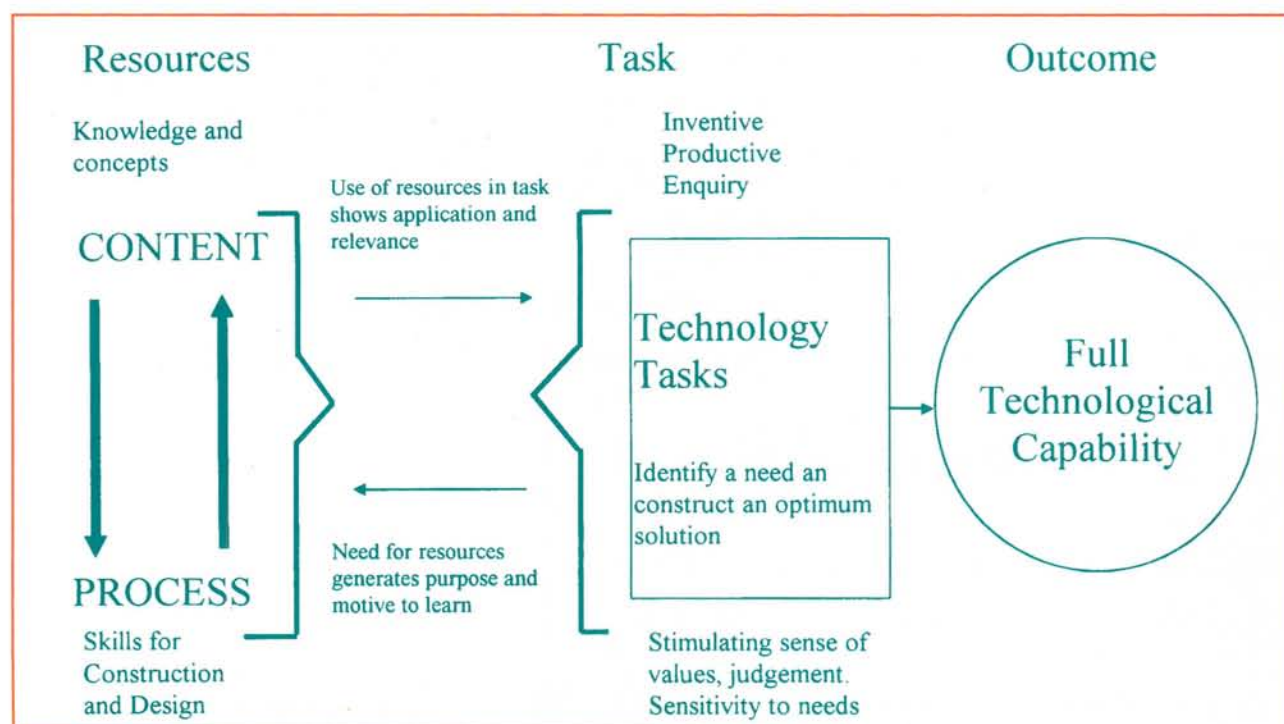
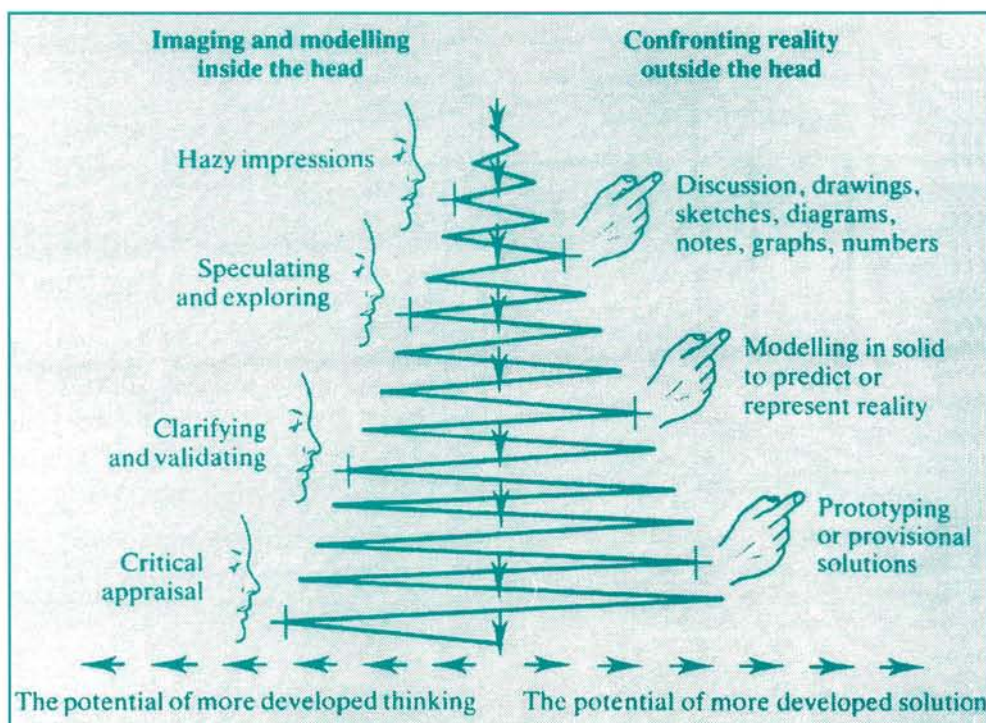


Figure 2: The interaction of mind and hand.



Capability as process

The focus on processes within capability, particularly the design process, added important dimensions to technology education:

- giving pupils decisions and hence control over what they produce
- allowing opportunities for creative responses to situations
- reflecting an important element of technology in the world outside school
- providing a powerful motivational tool.

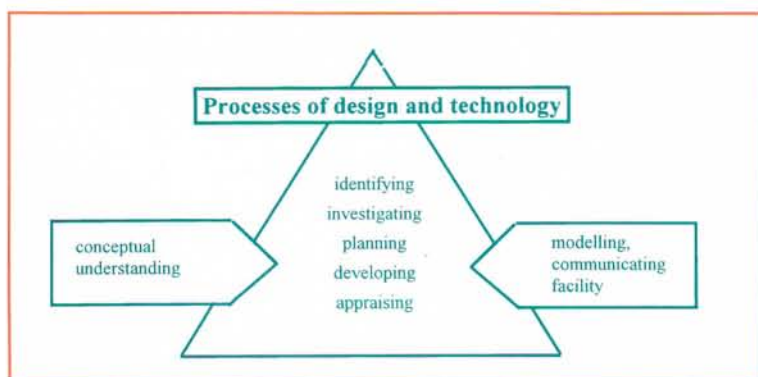
For those teachers who have some personal design experience, particularly in a professional design capacity, this approach offers a chance to deal innovatively with an approach to learning. For those less experienced, the warnings in the *Non-Statutory Guidance* for the National Curriculum (NCC, 1990) and the APU report

(APU, 1991), to avoid treating the design process as a series of unchanging steps to be used in all situations, have not always been heeded. In our own work, where we have examined teachers' approaches to process at Key Stage 3, we have found that the 'design process' is treated by some teachers as an algorithm; that is, as a series of steps that are used invariably in all situations. It is used ritualistically to structure pupil activity, but plays little part in the pupils' design thinking (McCormick, Murphy and Davidson, 1994; McCormick and Murphy, 1994; McCormick, Murphy and Hennessy, 1994). Teachers will structure a series of lessons to correspond to each of the steps in the design process (first lesson is identifying a need, second create several solutions, third to choose one solution and develop it and then make and evaluate). This not only takes away design decisions from pupils, but also misrepresents the way design may be carried out.² In as much as the design process is seen as a problem solving process, this corresponds with the findings from problem solving studies in other domains.

The coincidence of problem solving and design processes is, however, not accepted by all. Our interviews of teachers show various views of the two and of their relationship (Murphy *et al*, 1995):

1. some saw the two as synonymous (as in Table 1)
2. others saw a 'problem' as the starting point for a design activity (though they

Figure 3: The dimensions of capability.



did not always ensure that pupils found it problematic)

3. some even saw the design process as a planning process, providing pupils with a systematic sequence of activities to keep them on track.

Each of these approaches is defensible, but pupils are likely to meet all three from teachers of design and technology during their school career, with little explicit discussion to aid their understanding of the nature of the processes they are experiencing. Are they to assume that each approach is equivalent, or that they are just different things deserving the same name? Will pupils be involved in any discussion about the different approaches teachers take?

Where the problem solving process was important, there was little attention to what pupils found problematic or to teaching pupils strategies or skills in problem solving. Indeed the pressure on teachers to ensure that all pupils produce a successful product can mitigate against giving attention to supporting problem solving (McCormick and Davidson, 1996). Where design is seen as distinct, the attention to pupil learning fares no better. Kimbell and his colleagues concluded that, across the key stages in England, there was little continuity in the teaching of design and technology (Kimbell, Stables and Green, 1996). Even where pupils at Key Stage 4 are involved in 'simulated technology' ('how real designers work' Kimbell *et al.*, 1996, p. 46), earlier evidence (Jeffery, 1990) indicates that the need to record it for assessment purposes leads to similar rituals to those that we observed at Key Stage 3. We need to replace rather mechanical views of such processes with those that are based on how children and indeed real designers actually work. There are, however, relatively few empirical studies of either problem solving or design in the classroom, but this situation is changing.³

Problem solving and the design process need to be seen as forms of knowledge about how to proceed. This *procedural knowledge* operates at a number of levels (McCormick, 1997). At the lowest level are simple 'know-how-to-do' skills that are employed to, for example, use a solvent to adhere two styrene sheets along their edges. At a higher level there needs to be strategic procedural knowledge that determines the order things are to be done in. This knowledge includes the processes of design and problem solving. Knowing how to evaluate a set of design alternatives can be learned as some form of procedural knowledge, but knowing *when* to do it requires higher-level knowledge; a more strategic approach. This kind of procedural

Table 1

Design

- Identify the need or opportunity
- Create alternative design ideas
- Choose one idea and make or model it
- Evaluate the product made

Problem solving

- Define or clarify the problem
- Create alternative solutions
- Implement the best solution
- Evaluate the solution

knowledge is complex and requires close attention to support pupils and ensure they can learn to solve problems and design (Murphy and McCormick, 1997). The APU model (Figure 3) steers us away from a simple sequence, but still leaves a complex process of knowing when it is appropriate to 'identify', 'investigate' etc. Just 'doing' design or problem solving activities does not ensure they are learned, at least not with the relatively modest level of experience of design and technology lessons that can be given in the years of compulsory schooling.

In addition to the issue of understanding the nature of problem solving and design processes and how to support them in the classroom, there is a more fundamental issue. This concerns the basing of any model of capability around a process, without paying adequate attention to the role of knowledge (factual and conceptual). There is substantial research on problem solving, which has established that, treating it as an abstract process to be employed in any context, it is unhelpful. The crucial finding from decades of research is that problem solving skill is dependent upon considerable domain knowledge (Glaser, 1984 and 1992). Thus, rather than it being a general skill that can be employed with equal success in a variety of areas, it requires expertise in the context of its application. Models of capability that assume problem solving or design are general transferable skills, whatever the particular context, do not represent how real problem solving and design take place. Those who solve problems rarely resort to general processes. Research does not support the idea of general transfer of skills, nor does it support the teaching of problem solving as an abstract general-purpose process (Hennessy, McCormick, and Murphy, 1993). Models that see a complex interplay of processes such as 'identifying', 'investigating', 'planning' etc., are based on the requirement of the use of considerable conceptual knowledge.⁴ Although they are more realistic they hide the complexity of the nature of this 'knowledge' and how it is used. The role of 'knowledge'⁵ then, must be re-examined to find its place in capability.

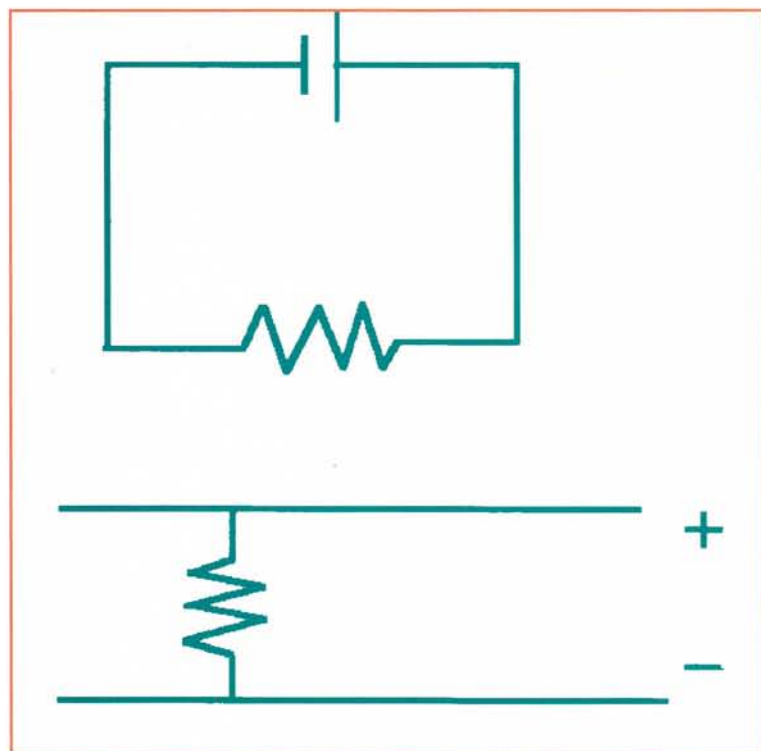


Figure 4: Circuits in (a) science and (b) technology.

Capability and knowledge

To understand the role of knowledge in capability we have to examine some fundamental ideas on learning, which in turn leads to an examination of the nature of knowledge. I will do this through first showing how knowledge is itself context dependent, and then by examining how knowledge is linked to action. This of course relates well to models of capability that stress the importance of 'action'.

The importance of context

Researchers at the Harvard Smithsonian Institute for Astrophysics showed graphically how knowledge is linked to context in their work in high school science lessons. (This was shown in a BBC television programme *Simple Minds*.) A girl, who had done some work on simple electric circuits using standard science lesson equipment (battery, bulb, bulb-holder, and wires), was interviewed following the lesson. Prior to this work in science she was able to connect up a battery to light the bulb using only wires. When, in the interview, she was given the materials she had used in the science lesson, she drew a circuit diagram that would get full marks in a test, but, as she connected up the circuit, she insisted that the circuit needed the bulb-holder. Even when pressed by the interviewer, she said the circuit would not work without it, and was astounded when it did. Thus, when this girl learned about electric circuits she associated bulb-holders as a necessary part of the circuit. Imagine this girl, before she had that misunderstanding corrected, going into a technology lesson here she would be confronted not with wires, bulbs and bulb-holders but with ceramic resistors and Printed Circuit Boards. What is she to make of these, and how is she to 'transfer' the ideas from the science lesson to the technology lesson? Not only are the physical items different, but the representations can be different; in science she will see a circuit represented in an abstract form as a circular path (albeit in the form of a square!), and its equivalent in technology would be quite different (Figure 4). There is an enormous amount of research in science education that indicates the difficulties that children have with learning abstract science ideas (e.g. Driver, Guesne and Tiberghien, 1985; Osborne and Freyberg, 1985). It is unlikely therefore, that their understanding will be robust enough for them to be able to use that knowledge in other situations; such as in the technology class.

Similarly issues arise with mathematical concepts. In technology the ideas in orthographic projection are based on mathematical ideas such as 'parallel' and 'perpendicular' lines. Technology teachers assume that they do not have to teach these basic concepts. However, research in

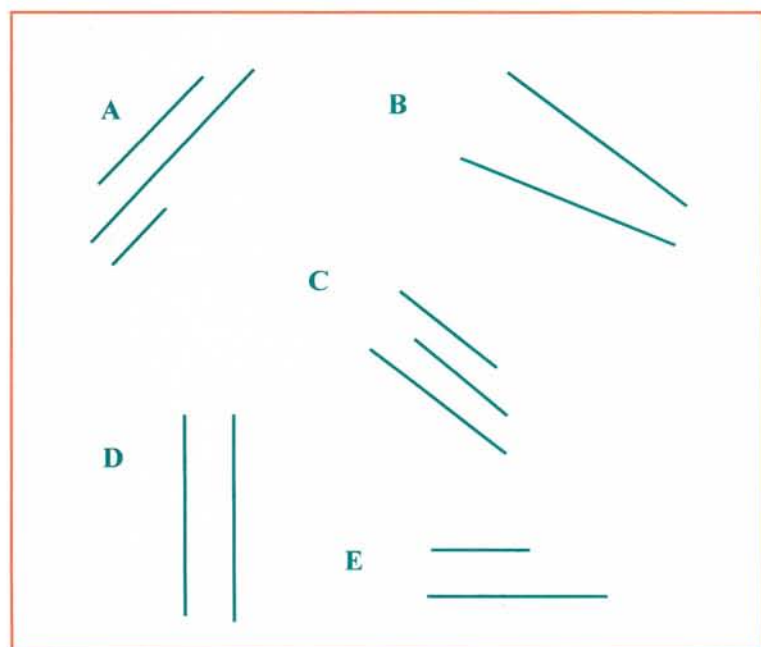


Figure 5: Evidence from an APU study of pupils' understanding of parallel lines. In which of the following A, B, C, D or E are the lines not parallel?

56% of 11-year-olds answered this question correctly.

In a similar test, 82% of 15 year olds were successful.

mathematical learning indicates that pupil understanding of what 'parallel' means may be insecure. An APU (undated) study asked pupils aged 11 and 15 years the question in Figure 5.

The expected answer is option B but over 20% of the 11-year-olds put a cross on more than one set of lines. They seem to have been distracted by factors such as three lines being present or lines of unequal length or lines angled to the edge of the page. These results confirm the findings of an earlier study by Kerslake (1979) with 10-year-olds, which concluded that the children had assumed equality of length to be a criterion for lines being parallel and had missed the point that the lines are always the same distance apart. Similar results were obtained in the APU study (undated) where pupils were asked to complete the sentence "Two lines are parallel to each other if..." Only 30% of 15-year-olds gave a response similar in meaning to "the distance between them is constant". Thus we have a situation where pupils' mathematical concepts are not robust even in the limited range of contexts they encounter in mathematical lessons; for example the changing of the lengths or orientation of the parallel lines. Their problems are inevitably magnified when they encounter these in the more embedded situations typical of design and technology projects.

This complexity is evident when the knowledge is to be *used*, as is the case in the example of orthographic projection mentioned earlier. We have developed our work on problem solving in design and technology projects to consider how the children use mathematics in design and technology projects (Evens and McCormick, 1997 and 1998). We have observed several teachers teaching orthographic projection (see Figure 6). In observations of a teacher explaining how to make an orthographic projection we find, not surprisingly, that he focused on procedures. Some of his words indicated this:

guidelines, all line up
drop down (the vertical lines)
project the information round
transfers the sizes.

This compares with the approach typical of mathematics classrooms, where the focus is on concepts (Table 2).

We have characterised this difference in terms of the technology teacher's concern with *procedural knowledge* and the mathematics teacher's concern with *conceptual knowledge*. It is a common view that knowledge that is used (called by some 'practical knowledge') is procedural in its nature (Sternberg and Cravso, 1985).

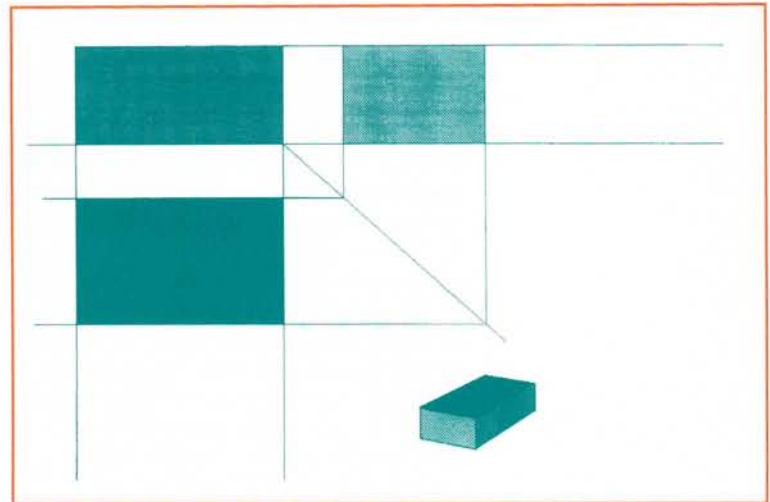


Figure 6:
Orthographic
projection of a
cuboid.

Incidentally, it is also evident that one of the reasons that the technology teacher does not articulate concepts such as 'parallel lines' or 'perpendicular lines' is that these ideas are incorporated into the T-squares and set-squares, which are the tools used in this kind of drawing (but not used in mathematics). This is another illustration of the way knowledge is bound in with context (in this case the tools). These observations about the use of knowledge become more understandable when we consider the nature of knowledge in relation to action.

Knowledge and action

Most of us no doubt assume that knowledge is in the head, and that we dig it out of our memory banks to use it for some task. There are, however, a collection of approaches to cognition and learning that argue that the knowledge is integrated with activity, along with the tools, sign systems and skills associated with the activity. In this sense knowledge guides action, and action guides knowledge. A classic study of dairy workers illustrates this inter-relationship of knowledge and activity (Scribner, 1985). One part of the study looked at how their various jobs (clerical, delivery or warehouse), affected how they thought about the dairy products, compared for example with consumers. Most consumers thought of the products in terms of 'kinds' (e.g. milk and cheese), whereas drivers thought about 'kind' and 'size' (e.g. quart),

Table 2: Comparison of terms used by technology and maths teachers in orthographic projection

Technology teacher	Mathematics teacher
guidelines, all line up	parallel lines
drop down (the vertical lines)	perpendicular lines
project the information round	reflection on line of symmetry
transfers the sizes	transformation

and warehouse workers in terms of 'kind', 'size' and 'location'. Each of the groups of dairy workers had their thinking organised by the kinds of activity they engaged in. But their knowledge also guided action. When warehouse workers made up an order from an order form, they would group the items on the list to be brought for central loading in ways that reduced journey distance. They used the accumulated social knowledge that went into the layout of the warehouse and individual knowledge that reflected the current stacking arrangement. Observations showed that they would take very efficient travel paths in terms of distance, and would group items on the order form in ways that aided this efficiency. Looking at this from the point of view of learning (i.e. to be a dairy worker), Scribner (1985) concludes that "What you learn is bound up with what you have to do." (p. 203) This explains the situation the girl predicting the circuit operation with a bulb-holder; the activities and artefacts she worked with in science lessons determined what she learned about how circuits work. If she moved to technology lessons the different activities and artefacts would require different knowledge.

In cognitive psychology, those who deal with 'real-world' tasks see knowledge as the 'knowledge of devices or systems' (Gott, 1988). In the area of 'real-world' tasks it is this 'device knowledge' that makes fault finding, for example, successful. The nature of such device knowledge may reflect as much the context of the device (e.g. its operation) as any abstract knowledge taught in science. For technologists this is important, not just because they deal with devices and systems (designing, making and repairing them), but because their conceptual knowledge will be linked to these devices and systems, rather than to abstract concepts, typical of science. (Just as was the case for the girl learning about circuits in science.) The way knowledge is viewed (indeed what counts as knowledge) is determined by the actions associated with it. Thus rather than seeing an electronic circuit in terms of a differential equation (a mathematical abstraction), engineers often see it in terms of Nyquist diagrams that reflect the effect of the components on the operation of the circuit (Bissell and Dillon, 1991). This is their 'device' knowledge that contrasts with mathematical knowledge. It also turns out that, as the complexity of devices increases, so does the importance of the interaction of device knowledge and procedural knowledge (Gott, 1988, p. 120). Again, it is 'device' knowledge, not the conceptual abstractions of mathematics or science.

Taking stock so far, I have drawn attention to the importance of procedural knowledge, and its link with device knowledge. This latter knowledge stems from the fact that useful knowledge is embedded in objects, and related to action. This is the kind of knowledge that experts use in their problem solving.

The qualitative nature of expert knowledge⁶

It is already well understood in the field of problem solving, for example in physics, that experts always start to work on problems by thinking about them in qualitative terms (Glaser, 1984). This stands in stark contrast to the way we start novices off on learning how to do such problem solving; invariably with the figures and equations, working without much overall understanding of what they are doing. Chris Dillon, in his account of qualitative approaches used by experts, characterises them by the degree to which they reflect the device (that is to be controlled or understood) on the one hand, in contrast to the mathematics (or science) model that could be used to represent the device's operation, on the other (Dillon, 1994). This in part reflects the device knowledge indicated earlier and in part the fact that in a practical situation the science cannot cope with the complexity involved.

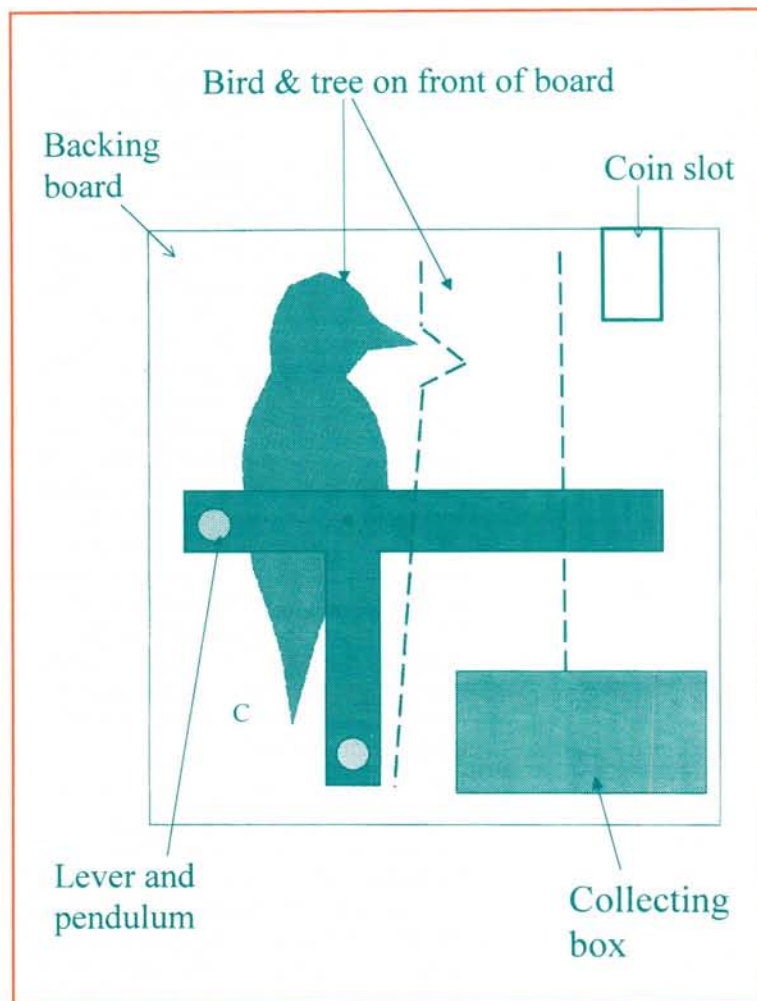
Let me illustrate the kind of complexity where qualitative approaches are useful, and do this in the context of a simple mechanism. As part of our research into problem solving in design and technology lessons at Key Stage 3, we observed two 12-year-old girls working on a mechanism that was used to collect money for charity. The mechanism contains a number of components (Figure 7): a falling coin channelled (A) to hit a balanced beam (B) with an integral pendulum (C), with an off-set pivot (D) connected to a bird shape on the other side (E), that would rock to peck a tree trunk (F). There is an operational principle of the overall mechanism, which the pupils have to understand. Each of the components (e.g. the force exerted by the falling coin, the pendulum swing) could be understood with science, and made to operate successfully. For example, varying the distance of fall of the coin to allow enough momentum to be gained so that even a small coin would cause rocking; balancing the beam horizontally by altering the off-set pivot and counterweight, such that the beam would move on impact. Now the science of this is well beyond children of this age, and it would be likely that even a professional engineer would be hard pushed to put down all the quantitative science and mathematics to represent the operation of

such a system as a whole. Of course it wouldn't be worth it! Any engineer would use qualitative reasoning to ensure a working mechanism. There would be some experimenting with the size of coins on simple beams to determine the amount of fall necessary, and similarly with the counter weight on the beam (the beam size is a function of the overall size of the money box), and so on. It might look like trial and error, but in fact it would be qualitative reasoning supported by a knowledge of science. However, it would be a level of science at a much simpler level than required for the full explanation of the operation of individual components. The reasoning is a combination of procedural knowledge and device knowledge, which seeks to explain how the initial fall of the coin works its way through the mechanism to end up in the desired effect of the bird pecking the tree.

The qualitative reasoning is not just a feature of the way an engineer might work, but also of the two girls and their teacher. In our classroom research of this project we recorded their reasoning at three points. The first is at the beginning of the project when the pupils go to the teacher with their idea of a woodpecker that pecks a tree when money is put in the box. The teacher illustrates the rocking movement with his hand. As he does this he says "Transmit movement (from lever⁷ to bird) to the front...", and then tells the pupils that they must lock the pivot to the lever "to make sure it runs ... (with the lever)". Neither of these statements draws on much conventional science and the wording is close to the physical nature of the mechanism.

The second point we observed was when, later in the first lesson, the pupils started to model the mechanism in card, working from an example mechanism of a rocking boat. The girls try to decide on the positions of the components, including the bird, based on how much the beam moves for different sized coins. At first one girl tries to locate the bird (cut out as a separate piece) relative to the tree trunk that she is trying to draw on the front cover sheet. She starts with the bird in its normal upright position and then rocks it, saying: "It'll be in that position first of all, then it's going to go knock, knock." (The "knock" is the sound of the bird pecking the tree.) She then moves to the example mechanism and reasons about how it operates with different sized coins:

P: It depends how much money they put in, because if it's a 50p, it's going to go 'dong' like that, so it's going to go really far.



P: Then if it's a 5p ... it will still move ... but only a little bit...

The girl is using language that reflects the object ("dong" the sound a big coin makes), and it is qualitative in the way it describes the amount of movement ("really far", "a little bit").

In the second week of the project, when they were making the actual mechanism the pupils went to the teacher for help and he said they had to balance the beam. This was done with BluTack as the counterweight on the left-hand end of the beam (Figure 7). He used phrases such as:

Balance that (lever) up with a bit of BluTack ... stick another bit on it...

The further over you get it (BluTack) ... some more leverage ... it's beginning to balance now.

There are some scientific ideas involved, but it is very qualitative, with language close to the operation of the mechanism.

Such qualitative reasoning could be improved if it was the focus of the learning. In the end

Figure 7: The components of the woodpecker money collection box.

the pupils are working out the effect of dropping different sized coins, and the way that effect works its way through the mechanism. The teacher could encourage the pupils to follow his reasoning, and to explain to him the effect of dropping coins. The science that they used could be related to how certain effects can be changed (e.g. to increase 'sensitivity' of the beam to small coins), so that pupils could predict the likely effects of changes. This reflects the approach of the 'causal accounts' that Dillon (1994) describes as one kind of 'qualitative reasoning' that is being formalised as a way of dealing with complex situations. He also notes that these are the kinds of explanations of electronic circuits found in undergraduate texts, and our researches on design and technology have indicated similar teacher explanations for circuits in secondary schools (Levinson, Murphy and McCormick, 1997; McCormick and Murphy, 1994). If such qualitative reasoning is so much a feature of technological thinking and action, then we should make sure that we try to develop pupils' abilities to use it.

The usual way in which we think about explaining devices and systems, such as mechanisms or electric circuits, is to use knowledge from science. There are a number of assumptions that underlie this. The first is that the science does indeed explain the devices. Layton (1993) has reminded us of Polanyi's idea of the *operational principle*, which according to Polanyi, determines how components in, say a machine, fulfil their functions and combine in an overall operation that achieves the function of the machine (Polanyi, 1962, p. 328). Layton contrasts this operational principle, as technological knowledge, with that of science; science he argues cannot contrive such a principle, but can explain the success and failure of it, and lead to improvement of it. This then sees science and mathematics in a supportive role, not a determining role, and the idea of technology as the "appliance of science", as Zanussi uses in its advertisements, is a misrepresentation of the situation. This is evident in the case of the mechanism of the money-box.

Capability Found?

My argument has had a number of strands to get me to the point of seeing a role for qualitative knowledge within capability. First, I have tried to illustrate that early models of capability were based upon processes. This focus put knowledge to one side, and, I argue, also characterised the process (design or problem solving) in ways that did not do justice to its use in practice (by learners or experts). Expert problem solving, for

example, is based on rich knowledge of the context and the substance of the problem and its solution. Although it has a strong procedural element, it is not simply procedural. Where (conceptual) knowledge is assumed to be relevant (e.g. the use of science or mathematics), insufficient attention is paid to the nature of that knowledge. The context within which knowledge is learned and used has a profound impact on how it is conceived by individuals (learners and experts). Knowledge that is used by experts is not only tied to the context (device knowledge), but it is qualitative in nature. This links the conceptual knowledge to the procedural knowledge. Indeed, the division of the two becomes less significant, as causal explanations are essentially procedural and yet indicate relationships that are typical of conceptual knowledge. As procedural knowledge is the substance of processes such as problem solving and design, these processes cannot be seen in isolation from conceptual knowledge.

Thus we arrive at the situation where we must consider processes (procedural knowledge) as intimately linked with conceptual knowledge, and that also this conceptual knowledge is related to the objects in technology (e.g. the tools and devices); hence the use of the term 'device knowledge'. Qualitative knowledge, and with it qualitative reasoning about the devices in technology, are central to this view of knowledge. Qualitative knowledge is linked to action of all kinds, whether that be designing or solving problems.

I have argued for the importance of qualitative knowledge and the reasoning associated with it. Given this importance, we must teach this kind of knowledge, and ensure a greater role for it in teaching pupils to act technologically. Some of this teaching will be through pupils being helped in trying to understand devices (products and applications). When pupils are investigating or dismantling products they can develop ways of reasoning about the operation of these products. Some of this can be done through the more usual design-and-make activities, where making modifications to, or trying to establish new products, will give opportunities for reasoning, in the way the two girls did with their money-box. But to be true to my earlier concerns, we still have as much to do to investigate what teachers and pupils currently do with regard to this kind of knowledge. Any experienced teacher will reason qualitatively quite naturally, and all they need to do is to make this more explicit, and to support pupils in developing this kind of reasoning. In some ways this may come more easily to them than the design processes that they are required to teach, especially

where they are not expert practitioners of design themselves. We still have much to do in understanding how we teach design and problem solving, and how qualitative reasoning links with these processes.

The way those involved in design and technology have refined their views on processes, albeit slowly, now needs to be developed to incorporate those of knowledge. My exploration of this kind of knowledge has sought to suggest that we should not look in the first instance to the abstraction of science and mathematics, but to the practical knowledge used by technologists. This search does not imply a swing from 'process' to 'knowledge', but the search for the relationship of the two. Nor does this imply that science and mathematics are to be ignored, but that their role in the design and technology lesson may be more complex than assumed. For me this route would lead to the finding of that 'paradise', if that is indeed what it is.

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Notes

1. In particular I will draw on work funded by the ESRC (Grant number R00023445 *Problem solving in technology education: a case of situated learning?*), the Design Council (Mathematics by Design), and the Open University. I would like to acknowledge the work of Patricia Murphy, Marian Davidson and Hilary Evens, all of whom have contributed to the research, thinking and writing that formed the basis of this lecture. I would also like to acknowledge the help of Frank Banks, Gwyneth Owen-Jackson, and Frank Whiteman, all of who commented on an earlier draft.
2. Ofsted reports have highlighted the way lessons often leave pupils with no real decision making or creativity (e.g. Ofsted, 1995, p. 11).
3. When Murphy *et al* (1995) reviewed the field they found relatively few, more recent studies have improved the situation (Doornekamp and Streumer, 1996; Kimbell, Stables and Green, 1996; Mioduser, 1998; Murphy and McCormick, 1997; Roden, 1997; Welch and Lim, 1998).
4. Science education has gone through a similar realisation from the early days of process science, to the current position where 'process' is associated with particular conceptual areas. See Murphy and McCormick (1997) for a comparison of science and technology with regard to process.
5. 'Knowledge' used in this general way refers to 'factual and conceptual knowledge', although, as it will become clear, even these categories are insufficient to explain the situation.
6. A version of this sub-section is published in McCormick (1999).
7. The teacher refers to the 'beam' as a 'lever', reflecting the kind of science terms with which the pupils would have been familiar.