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the **CONTROL** variable
the **DEPENDENT** variable

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CHILDREN'S ALTERNATIVE PROCEDURAL FRAMEWORKS:their possible origins, and their influence on performance

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THE VARIABLE STRUCTURE OF AN EXPERIMENT

The classical experiment is constructed around three major classes of variable. These structural characteristics, which have become known more recently by science curriculum developers as 'key' variables (Gott et. al., 1988), are used as the organisational basis for the construction of programmes for teaching and assessment in science:

the **INDEPENDENT** variable

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The major focus of this paper is an investigation of 11-year old pupils' perceptions of variable-based investigations and experimental design. The general term I have used to describe this aspect of science education is *variable-handling*.

Although the domain of variable-handling may be fragmented into several component ('process') skills such as identification and manipulation of these 'key' variables, these may be seen as only a part of a more fundamental theoretical framework which, it is widely assumed, pupils will eventually learn to operate as a holistic cognitive schema. *'Procedural knowledge'* is the umbrella term used to describe such a framework, to contrast it with the more familiar area of *'conceptual knowledge'* (DES, 1987, p.12). This schema supposedly forms the basic framework within which pupils are required to operate if they are to produce rational experimental designs, and thus to act 'scientifically'. If pupils are to apply the variable-handling model in anything other than a simple, algorithmic fashion, then they will require a broader procedural understanding. In short, the variable-handling model may be an important aspect of procedural understanding, but it is merely a part of it; mastery of the former does not necessarily imply acquisition of the latter.

The presence, partial absence, or complete absence of such procedural understanding will determine the extent to which pupils can effectively design, carry out, and interpret experiments. One possible categorisation of pupils' levels of procedural understanding may include the approaches described below. Each has implications for the teaching and learning of experimental design, and we might further hypothesise that each will give rise to a corresponding level of performance on typical primary level variable-handling problems.

HOW PUPILS MAY APPROACH VARIABLE-HANDLING

A The **'confirmatory'** approach

Here, at the lowest point on our proposed performance scale it is possible that, for some pupils at least, there is no theoretical basis for a procedural understanding which fits the variable-handling model. Children operating within this framework merely set about **confirming** their own intuitive prejudices and beliefs. Pupils may have no logical procedural framework for the gathering of scientific evidence on any objective basis, as they have simply pre-judged the outcome. An 'experiment' to them is merely a confirmatory exercise which, for example, demonstrates that a certain paper tissue is indeed stronger than others. This may be an approach which is particularly prevalent amongst younger children. It might correspond to a broadly Piagetian view of the ability to control variables Moreover, the precursor to an abstract procedural understanding, which can only be applied when the child has reached the stage of formal operations, is a much more experiential understanding grounded in personal belief, rather than impersonal enquiry. This reflects the findings of Osborne et al. (1983), who showed that pupils tend to focus on different aspects of experience rather than on abstract ideas, often taking a person-centred point of view.

B The **'fair test'** approach

The notion underlying 'fair testing' is well documented; permeating much of the work which for many years has been influential in primary science education in the U.K. (e.g. Harlen, 1983). However, although the simple notion of controlling variables in this way may serve as a powerful idea for young children with a keen sense of fair play, and as a useful introduction to experimental science for inexperienced primary teachers, it may have limitations if equated with an 'all other things equal' model. There is strong evidence that this model has been adopted by those responsible for the construction of the National Curriculum for England and Wales. However, this model has been critically scrutinised in the past (Lucas and Tobin, 1988). The 'fair test' notion therefore needs to be carefully explored lest it be seen as an end in itself rather than as a **means** to the more powerful end of developing a 'mature' procedural understanding.

C The **'mature'** approach

A fully-developed experimental strategy would fulfil the criteria for placing a pupil at this level of understanding. However, we need to be clear about how we are to judge that fulfilment. For example, a pupil might provide a clear, unconfounded design for experiments which require the manipulation of only **one** independent variable. However, in situations where **two** independent variables (e.g. the volumes of two liquids which react together) have to be manipulated, and when they are **continuous** variables as in this case, then we may obtain a rather different picture of the level of understanding displayed. Moreover, views of competence or mastery must be clearly seen to depend fundamentally on the level of sophistication of the design required **for that particular experiment**, as well as on any generalised view of the pupil's variable-handling 'ability'. Assessment evidence must therefore be carefully collected and scrutinised if we are not to make unsupported assumptions about the level of variable-handling skills and, most importantly, their **transferability** across contexts. It is inadvisable to think of variable-handling ability as an absolute, since it will always be to some extent task-specific.

SOME GENERAL COMMENTS ON PROCEDURAL UNDERSTANDING IN SCIENCE

In the procedural, as in the conceptual domain, we inevitably encounter the issue of the pupils' use of **language** to describe their thoughts and actions. This issue also needs to be explored if we are to disentangle, within children's responses, any evidence of an underlying variable-handling schema from a purely experiential knowledge of its essential structural features (viz. the 'key' variables). Without undertaking this task, it will prove very difficult to judge whether pupils actually **lack** understanding, or whether the use of unfamiliar language is merely serving to block their access to it. Only by researching pupils' responses in this way can we move towards developing effective teaching strategies to address the problem We need to explore its limitations fully if the 'fair test' model is not inadvertently to limit the development of pupils' deeper procedural understanding.

A further issue within this approach is that of 'relevance'. What pupils actually **choose** to vary in an experiment may well depend on their **personal** view of what the problem is about and what is important to them as individuals. Their perception of what is relevant in the problem may limit their ability to develop a variable-handling model fully and thus to provide, when assessed, adequate evidence of having mastered it. The 'fair test' model may provide a useful and accessible **route** for 11-year olds and their teachers into the basics of experimental design, but its limitations must be recognised if it is not to be presented as the *sine qua non* of experimental design. The 'fair test' notion, although limited in its scope, is nonetheless a performance construct to which we should look in pupils' responses, not least since it has now become part of the orthodoxy of science education; certainly in the U.K. An important analytical feature will therefore be the extent to which pupils' responses fit the 'fair test' model.

In both approaches **A** and **B** above, language may play a crucial rôle in terms of assessment; particularly where questions are set in a written context in which we are seeking to describe the structural elements of a sophisticated procedural framework as simply as possible to our young scientists. Misunderstandings and misconceptions may therefore not only pose a threat to pupils' understanding but also, as we shall see, to the collection of reliable assessment evidence. This points to the need for assessments to be made in **practical** as well as in written contexts.

Pupils' **'alternative conceptions'** of scientific procedures may have a similar origin to that which has been documented for some of the major **content** areas of science (e.g. the concept of energy as described by Solomon in 1983; where she points out that pupils may have a firm understanding when the context is food as a source of their own energy, but cannot generalise this to the abstract idea of energy stored in a spring). Pedagogically, it will mean that we cannot afford to treat procedural understanding any differently from the understanding of substantive areas of scientific content, and that we should therefore aim to ensure that pupils' alternative procedural conceptions are clearly understood, elucidated, and ultimately confronted if meaningful learning is to take place – through the reformulation of their intuitive belief systems into a more rational model of experimentation. This, of course, for the pupil who ‘knows’ which paper tissue is strongest will not be easy, and would indicate that some instruction in the nature of science and its accompanying methodologies is required if (s)he is to adopt a more objective stance, or even to realise that there is, in fact, a problem to investigate in the first place.

The evidence presented in this paper suggests that ‘procedural’ understanding at age 11 is tenuous indeed. Even for science graduates, procedural understanding is strongly affected by both problem perception and by the context of problem presentation; both of which can lead to highly task-specific responses (Dawson and Rowell, 1986). An abstracted understanding of a clearly-formulated problem-solving approach is sometimes absent even in highly-trained specialists. It may therefore be unrealistic to expect that 11-year olds will possess anything approaching such a generalised understanding, without a good deal of instruction in the nature and methodologies of science.

A TYPOLOGY OF PUPILS' RESPONSES TO VARIABLE-HANDLING TASKS

CATEGORY A

The operation of a pre-existing 'belief' system based on intuition and/or prior experience may give rise to the absence of any perceived need for a controlled experiment. This is a fundamental misapprehension of the way in which science operates: on belief rather than logic, thereby negating the need for experiments which test hypotheses.

It will be difficult to explore fully this radical approach to learning here. However, I feel it is important that we at least entertain the idea of children's alternative procedural frameworks, since it will indicate potentially fruitful directions for further research, and certainly adds a further dimension to any sensible interpretation of performance evidence. If it does prove to constitute another dimension to pupils' learning, which has been overlooked in present views of science education, then it is important that it should not be further overlooked in the clamour to find reliable assessment instruments. Reliability may ultimately be attainable only at the cost of ignoring pupils' **individual** perceptions of the problem put before them; thereby rendering assessments much less effective for **diagnostic** purposes and for curriculum development.

CATEGORY B

Here we should look for some evidence of the 'fair test' syndrome in operation. This might manifest itself as an incomplete grasp of the rational design of the experiment, but with some evidence of the three major structural features having been identified, if not completely operationalised. Inappropriate or inaccurate use of language may also be in evidence here.

CATEGORY C

This would require evidence of all three major components of the variable-handling model across a number of contexts: independent variables, control variables, dependent variables and their operationalisation. The ability not only to carry out but also to **evaluate** experimental design critically, would indicate a more generalised understanding of the rational requirements of the model.

CHILDREN'S VIEWS OF VARIABLE-HANDLING

One way of measuring pupil performance against the expert variable-handling model is simply to attempt to judge how well the former fits the latter. However, if we are to adopt a more **constructivist** approach to learning, it is important to bear in mind that the concepts and beliefs which pupils **bring to** the learning experience exert a powerful influence on the way in which that experience is viewed, and thus on what is subsequently internalised and **taken from** that experience. Although most of the constructivist research has concentrated on investigations of children's conceptions of substantive content areas (so-called 'children's science'), it seems not unreasonable to hypothesise that pupils also bring to their science alternative **procedural** conceptions.

Children's **written** responses to variable-based problems will allow us only a limited insight into their world. Any such insight is further limited if, in the process of assessment, we constrain their scope for responding, as we do when we apply an expert model of variable-handling to define the assessment criteria.

With this concern for valid assessment in mind, it was decided to interview children from 6 typical primary schools (in the West Midlands area of England), as they planned or reflected on investigations involving the need for variable-handling procedures. Interviews allow for the collection of more naturalistic assessmnt evidence and for a much closer scrutiny of responses, in an attempt to probe any underlying misconceptions. Moreover, rather than adopting a task-centred approach to assessment, the focus was shifted towards the child. Although potentially more complex and messy than a logical task analysis from which assessment criteria can be more readily extracted, focussing on the children might help us to gain some idea of how they view the investigation. Do they, in fact, see it in terms of its variables, or do they have a different perception of what constitutes its most important features? A logical task analysis might also have seduced us into thinking that there is an underlying psychological learning sequence of variable identification, articulation, separation, and finally operationalisation: is such a sequence detectable in these interview data?

I now wish to propose several tentative hypotheses concerning children's responses to tasks structured around the variable-handling model. There may well be a certain amount of overlap between these hypotheses, as they all stem from the central notion that pupils and assessors may hold differing views of problem-solving tasks. However, they may provide a useful organising structure for considering pupils' perceptions of such tasks.

There is a limit to which a pupil-centred stance can be maintained with a view to establishing the quality of pupils' responses, using traditional assessment techniques. Moreover, the hypotheses suggested here hinge upon the way in which pupils **perceive** the task, since this will fundamentally affect how they respond to it. I am interested in establishing the consequences of pupils' failures to engage with the model which underlies the task. How do **they** view the task, and is their model for scientific procedure matched to the 'expert' model?

HYPOTHESIS 1: Perception of the Problem

To what extent do pupils share with the teacher/assessor the basis on which the problem is posed? Do they, in fact, perceive the problem from a procedural point of view or do they have their own agenda? If their concerns are altogether different, and they are at odds with the expert model, then it is unlikely that they will be able to engage with the problem from this point of view.

Andrew was described as a "very able" pupil by his class teacher. He undertook an investigation of the way in which hull shape and sail shape affect the speed of toy boats (*'SAILBOATS'*) very competently; producing a convincing design which indicated that he was able to separate the relevant variables and operationalise them within the parameters of the problem as presented. The interview with Andrew revealed that, unlike the vast majority of pupils, he investigated the situation before actually embarking on the 'experiment' systematically:

> P.S: *'Andrew, I'm interested in what you were doing before you started. Could you tell me what you were trying to find out?'*
>
> ANDREW: *'I was just seeing what was happening when it was going along. Just getting used to doing it. Then I'd do the actual experiment. Actually thinking out the experiment'.*

This open-minded approach to the problem seemed to allow him to formulate further ideas for modifications to the boats:

> ANDREW: *'the actual boat, the wooden bit, the water was going over it. So it might weight it down a bit. So if it had about a half centimetre of side the water drips might not get in and it might go a bit better'.*

Nicola held a much more qualitative notion than Andrew of which is the best boat. She did not measure it's speed as Andrew did, but:

> NICOLA: *'I worked out which one went straighter. And the one with the rectangle* [sail] *and the point on* [the boat] *went straighter.'*

An investigation into the speed at which toy parachutes descend;carried out with a mixed group of Y5 and Y6 children, revealed rather lower levels of reflection and explanation. Here, children were operating even further outside the variable-handling model, as the following transcripts illustrate:

> P.S:*'Can you tell me, in your own words, what was the problem you were trying to solve?'* (Pupils had already been told in the introduction to the lesson that their task was **'to find out which parachute falls quickest'**)

SIOBHAN: *'We was trying to solve the weight of the parachute'*

SAM: *'We were trying to solve who was the fastest'*

MATTHEW: *'Whose parachute was going to go the highest'* (sic)

Personalising the investigation, as Sam and Matthew have done, was a common trait amongst those children who experienced the greatest difficulty formulating a procedural approach to the investigation. Such children apparently find it even more difficult to detach themselves from any **personal** outcome: where the experimenter is expected to take up an **objective** stance in relation to the investigation. It is also clear that such children quickly lose sight of the formal purpose of the investigation. In doing so, they will thus be less likely to concentrate on the dependent and independent variables stated in the introduction to the experiment.

Questioning another group of children from the same school prior to an investigation into how far toy cars will travel from the top of an inclined ramp, revealed that their interests and concerns were not necessarily those shared by the teacher. In answer to this very open question, *'What would you like to find out from this experiment?'* Pupils answered thus:

MARY: *'I'd like to find out what it is made of'*

PAUL: *'I would like to find out about how the little seats are fitted in the back and front'*

AMANDEEP: *'I would like to find out what's the names of the cars'*

BEN: *'How many miles it has done. If it's in good condition.'*

For these children, there is apparently a conceptual chasm to be bridged between the level at which they are operating, and the expert level demanded by the variable-handling model. Indeed, their concerns may be totally different from those which they are actually called upon to investigate. From these children we glimpse something of 'chidren's different images of the world and their places in it' (Murphy, 1991, p.119).

HYPOTHESIS 2: Perception of Variables

Any assessment of variable-handling ability tacitly assumes that children accept the assessor's view of the nature and status of the 'key' variables. If they focus on other ('irrelevant') variables which they suspect may affect the outcome of the investigation but which do not figure in the assessor's perception of the task, then they are likely to seek to design an experiment which does not match the problem as presented.

Children who had just completed *'TOY PARACHUTES'* were asked a series of questions about specific aspects of the investigation. In answer to the question, *'What things make a difference to how quickly the parachute drops?',* children were generally able to **list** relevant variables, but were often confused about the relative status of those variables within their investigation. One child (Lee) answered:

> LEE: *'wind... the wind can make a difference'*
>
> *'plasticine .. yes, the plasticine so we can make the weight heavy or light'*
>
> *'the height.....so we can time the time it takes to get down'*.

Even when pupils were more accurate in their identification of, for example, the dependent variable, they had severe difficulty in explaining how this variable was operationalised in their experiment **even when they had done so quite adequately in the course of the investigation**.

Thus, another pupil from the same group answered the question about what to measure in the following way:

> P.S: *'O.K. Can you tell me if there is anything you* **measured** *in your tests?'*
>
> MARK: *'The time'*
>
> P.S: *'Good Can you tell me a bit more about that? Pretend you are explaining to someone who didn't see you do the experiment'*.

MARK: *'Well, to measure you need a ruler and a metre stick'*

P.S: *'I see. But you told me you were measuring the* ***time'***

MARK: *'Oh! Yes! .... the height .... so we can time the time it takes to get down'*

For such pupils there were clearly a number of variables to be taken into consideration, but despite their reasonably competent attempts at the investigation itself, a coherent description of the procedure, and the nature of the variables proved beyond them in many cases. Such responses reflect the trial-and-error approach to these practical investigations which children frequently adopted. A pre-planned, systematic approach to an investigation was generally notable only by its absence. Even when encouraged to plan in advance, children constantly abandoned the plan as they interacted with the apparatus and responded to ideas from other members of their working group.

HYPOTHESIS 3: The 'Fair Testing' approach

If the 'fair test' logic, despite its appealing simplicity, is still too great an abstraction for pupils to comprehend, then they will tend to offer confounded designs, precisely because they are capable of seeing greater complexity in the problem than the 'fair test' scenario allows them. 'Fair testing' is a reductionist view, but pupils may actually view the problem much more holistically. (That is to say, from a 'real world' rather than strictly 'scientific' point of view).

Alex is a boy who was said to be "slightly below average" for the class. He was asked to carry out an investigation to test balsa wood bridges of varying thickness to find out which supported the most weight. He too was not very rigorous in his approach; only judging the best bridge by estimating the extent to which it sagged under a given load:

ALEX: *'I felt how much further down it could go. I tested how far you could bend it before it looked like breaking.'*

In this situation Alex performed a rather perfunctory exercise which relied on subjective judgement rather than on rigorous testing and measurement. However, given a different context, Alex showed that he **could** design a fair test. When shown the question *'CRISPS'* (see Appendix A), this was his response:

> ALEX: *'I would.....em.....I wouldn't change the mass of the crisp because if one was harder to crunch than the other one it would say that the one that wasn't harder to crunch* ***would*** *be harder to crunch if it changed the weight. You have to change the type of the crisp because you want to find out different types. If you change the position of the crisp it might be different. And you have to keep the size of the crisp* [the same] *or it's easier to crunch one if it's smaller or bigger than the other.'*

Although not as articulate as either Andrew or Nicola, Alex has been successful in this context. However, changing the context yet again (to the question *'FISH FOOD'* (Appendix B), gives a very different view of Alex's ability:

> ALEX: *'Change the type of fish food. Change the water so it's the same as last time* (sic). *Keep all the things in the same position .....um.....ooh!.....they should keep all the plants in the same position.'*

Not only does Alex fail here to separate the independent variable and control all the others, but he also introduces another variable which he apparently sees as being important; the position of the plants. This indicates that his attention is focussed more on the details of the particular problem as presented in the accompanying graphic, than on any underlying strategy for ensuring a fair test. It appears that Alex is entirely caught up in the context of the question, and that this has distracted him from applying the same logic which brought him success in *'CRISPS'*.

Andrew, however, was keen to ensure that an element of control should be exerted over some of the potentially competing variables in his *'SAILBOATS'* investigation:

> ANDREW: *'Well I tried to keep the fan at the end of the tray.....and when I put the fan on I pointed* [it] *in the direction of the boat and pressed "start" at the same time and stopped it* [the timer]*when any part of the boat hit the end'*.

Nicola had a similar view. Her's was a less rigorous approach than Andrew's, but she shared the same notion of 'fair test' as meaning equality of treatment:

> P.S: *'You did three little experiments. What did you do to make sure each was a fair test?'*
>
> NICOLA: *'I started them all off right at the back so they were all touching* [the end of the tray] *and I made sure the fan was working so that it didn't like stop half way.'*

In short, the idea of 'fairness' may well be one which is quite keenly developed in pupils of this age, but it may be unsafe to assume that this can be taken as the rudiments of a generalised, procedural strategy, indicative of pupils' underlying ability to separate variables. Indeed, later in his interview, Andrew revealed that, given another context (the question *'COOLING TEA'* – Appendix C), he was still apparently confused over how to design a simple fair test. He had not readily transferred his earlier systematic approach to this new context. In his answer to this question, he stated that he would change **two** of the control variables as well as the **independent** variable:

> P.S: *'Can you explain to me why you put down this answer?'*
>
> ANDREW: *'All of these make a difference – amount of water and the amount of sugar especially and how quickly he stirs. Because if he stirs it quickly he might crush the sugar and dissolve it quicker.'*
>
> P.S: *'Do you think that would be a fair test?'*
>
> ANDREW: *'I'm not sure'*.

In this case Andrew struggled with a number of ideas about which might prove to be the 'key' variables. He could only manipulate them here mentally rather than practically as in *'SAILBOATS'*, and had difficulty in separating the variables in such a way that would have allowed him to tackle the **procedural** aspects of the problem.

Similarly, when attempting the question *'TEDDY BEAR'* (Appendix D) he appeared to lose sight of the problem itself; concentrating more on the dependent variable than on simply changing the independent variable:

> P.S: *'What are you actually trying to find out?'*
>
> ANDREW: *'Em.....if the soft toy bounces.....em.....how quickly it bounces up and down.'*

Finally, Lee's idea of fairness in relation to the toy parachutes investigation, was even more vague:

> P.S: *'what did you need to do to make sure it was a fair test?'*
>
> LEE: '*check that they are all pretty strong'*

To involve children in the investigation itself was rarely a problem. However, it became obvious that obtaining from the children a plan of their work or a systematic description of the procedures they adopted, was often very difficult indeed, and was certainly not something which they displayed consistently across contexts. It is clear that these pupils seem to lack experience in describing and explaining their science activities in procedural terms. Although they may well be aware of the importance of certain features and parameters of the investigation, it is unlikely that they see these as variables to be controlled, manipulated, quantified, etc., as part of a coherent stategy for thought and action.

HYPOTHESIS 4: Contextualisation and the influence of prior knowledge

Variable-handling problems are not usually presented in a completely abstract form. For educational purposes they are often couched within a context designed as a device for ensuring pupils' engagement with the problem: attempting to match the context to some familiar experience. However, if that context actually evokes a conceptualisation of the problem which does not match that which was intended, then it is unlikely that pupils will be able to abstract the central, variable-based problem sufficiently from that context in order to apply a 'fair test' strategy. Moreover, do pupils take the context too literally so that their thinking becomes inadvertently constrained rather than extended by it?

Nicola, described by her class teacher as being of "average" ability, did not tackle *'SAILBOATS'* with the same degree of pre-planning or open-mindedness as Andrew had done earlier:

> P.S: *'Nicola, you've had a go at the 'Sailboats' problem. Can you tell me what you found out?'*
>
> NICOLA: *'Well.....ehm.....with the bits of wood.....em.....because they're all different shapes it makes a difference 'cos if it's one that's square then it's bound to go wobbly, sort of. But if it's one that's rectangle with a point on the end then it's bound to sort of go mostly forwards.'*

Here, Nicola seems to be struggling towards an **explanation** of her observations. This, of course, goes beyond the purely procedural parameters of the problem, but is a type of response noted in research into pupils' attempts to describe graphs (Kerslake, 1981). Moreover, Nicola appeared to misconstrue the demand of the problem as seeking an **explanation** rather than as the (inductive) procedural **route** to such an explanation. She called upon 'tacit' knowledge to explain her observations, rather than systematically separating the effects of sail and boat shape, and then investigating each variable objectively, as the problem demanded.

Nicola's tacit knowledge is also much in evidence when she was later called upon to extrapolate from the graph shown to her in the question *'SUNFLOWER'* – (Appendix E):

> P.S: *'What would you expect the height of the sunflower to be at **seven** weeks?'*

NICOLA: *'It would be somewhere* ***down*** *from here* [the last point on the graph] *'cos sunflowers go up and then they come down if they haven't got enough water.'*

HYPOTHESIS 5: The Interpretation of Variable Relationships

Pupils find it difficult to look at a variable-handling problem as an abstraction. That is to say, if bound up by both the context **and** their prior knowledge of the phenomenon under test, then they will find it difficult to interpret the problem simply in terms of the relationship between the pre-determined independent and dependent variables. They will wish to bring their tacit knowledge to bear, but this may be inappropriate for the procedural demand of the problem, as we have already seen. Their use of a simple 'keep everything else the same' design strategy is therefore highly unlikely in these circumstances.

A further aspect of the interview with Andrew shows that the **abstracted** process skills presented him with much greater difficulty than they did when presented as part of a holistic investigation. When asked to explain how he arrived at answers to the question *'WET LOG'* – (Appendix F) – Andrew's description of the graph was much less fluent than his description of the *'SAILBOATS'* investigation he had carried out earlier:

P.S: *'Can you just describe in your own words what you notice about how the weight of the log changes with time. Can you try and put the graph into words?'*

ANDREW: *'Well it tells you .....how long of course it took to dry, which is obvious, and.....em.....how many grams it was changing each day. And.....because of the lines you can see there's ....er.....quite a large drop from five hundred down to one hundred and ninety-nine'*.

Despite his earlier, extremely competent, handling of the *'Sailboats'* investigation, Andrew now found it very difficult to encapsulate in words just what the relationship is between the variables in the graph. His final effort mentioned that the log 'changes' in some way over time, but he neglected to actually name the dependent variable (i.e. the **weight** of the log), which lies at the heart of the relationship:

> ANDREW: *'It shows.....the graph shows you.....em.....how the log changed in a certain number of days and how many days.'*

HYPOTHESIS 6: Formulation of Testable Hypotheses

When stated in a formal manner, hypotheses based on the relationship between two variables are again an abstraction. If pupils perceive the problem predominantly from the point of view of seeking an **explanation** of why the dependent variable behaves as it does, then they may again be diverted from the procedural objective of testing just one independent variable at a time. In short, because they have many (often original) ideas about what affects the dependent variable they will attempt to test all of these at once.

Adam was another pupil of "above average" ability. When called upon to carry out the *'SAILBOATS'* investigation, he did so systematically and with confidence. However, it became clear that the interpretation of his 'results' was very much coloured by his preconceived ideas about what might be causing the different sailing characteristics of the boats:

> P.S: *'What did you actually find out from from your investigation?'*
>
> ADAM: *'I think that the 'point one end'* [boat shape] *is the best.'*
>
> P.S: *'So, it didn't matter which type of sail you used, as long as the boat had a point at one end. Is that what your results show?'*
>
> ADAM: *'Yes, I think so.'*
>
> P.S: *'But if you add up all the times for the one with the point at **both** ends, you see it has actually gone faster!'*
>
> ADAM: *'I still think it's the best.'*
>
> P.S: *'Tell me more about why you think that Adam.'*

> ADAM: *'It's just that when it was in the water it kept on* ***not*** *hitting the sides, and all the other times, in all the other boats, it* ***always*** *hit the sides, usually.'*

Clearly, Adam had in mind a rather different agenda; one which was at odds with the procedural thrust of the problem. Like Nicola, he had an explanation in mind, based on his observations of how smoothly each boat travelled along the channel, which proved difficult to dislodge even in the face of conflicting evidence. For Adam too, the procedural basis of this investigation, and the assessment criteria which result from it, are not matched by his perception of, and approach to, the problem. His approach demands an explanation of what he has observed, despite the more convincing objective evidence from his timing of the boats. This problem of mis-match was apparent throughout these interviews, but becomes very obvious and compelling in the following extract.

That Adam's is a **conceptual** as opposed to a **procedural** approach to the problem, is clearly illustrated by his response to the problem *'PLANK'* (Appendix G):

> ADAM: *'I think the length of the plank overhanging should stay the same, else if it bends too much it might snap the wood.'*

His reason for controlling the length overhanging is **not** born out of a desire to produce an unconfounded design, but rather for a concern with the practicalities of the problem as he sees it.

SUMMARY

In the light of such findings it seems that, for most children of this age, it is the over-arching **model** which requires explanation, rather than merely its structural components seen as separate process skills. Researching the way in which children actually **conceptualise** experiments may now be necessary if we are to understand how and why children respond as they do to process-based science tasks.

Furthermore, the extent to which children's concerns differ from those of their assessors will aid interpretation of assessment results, since performance may be more than just a 'cognitive' response. Indeed, it may be the result of a much more subtle interaction between child, question, and the context in which it is set. Only evidence of the type discussed in this paper however, can begin to reveal such subtleties. There is evidently a need to view quantitative performance data in the light of children's idiosyncratic (*'alternative'*) procedural responses.

It is important that we should not allow a logical analysis of variable-handling in terms of its structural components to obscure a more holistic view of the domain. Only from a holistic stand-point can we begin to explain pupil performance adequately, in such a way that its implications for classroom practice can be clearly expounded and then translated into sensible teaching strategies. If these principles of holism, and of valuing the personal responses of children are not established, then we run the risk of severely limiting the scope of **all** our pupils to maintain an interest in science.

We have seen that, in their attempts to describe variable relationships, pupils often produce a number of responses which may eventually prove to be 'alternative frameworks' of procedural understanding. If we are to confront such frameworks in our teaching, it seems reasonable to suggest that they should be studied in a similar way to that in which areas of conceptual knowledge have been elucidated, and then to recognise these explicitly as starting points for teaching strategies.

However, we must be cautious before suggesting that an 'alternative frameworks' approach may herald a new way forward. It should be borne in mind that the degree of consistency of pupils' frameworks in conceptual knowledge **at the individual level** is not high (Clough and Driver, 1986). These authors found that 'accepted [scientific] responses appear to be used more consistently than alternative responses' (p.488). Significantly, they go on to state not only that responses often varied across different question contexts, but also that performance was affected 'when tasks probing the same scientific idea are perceived differently' (ibid.). We should therefore not see learning simply as requiring a change to be brought about from a single ‘alternative’ view to the accepted scientific view. Moreover, if we are to take seriously the notion of children’s alternative **procedural** frameworks, we must draw on the experience of the ‘children’s science’ approach to the learning of concepts. Such frameworks are idiosyncratic and dependent on the way in which pupils **perceive** the problem they are presented with: ‘for some of the ideas students were using different alternative frameworks in response to parallel questions’ (op. cit., p.489). This is also something which became apparent in the interviews quoted above.

Lack of homogeneity in control-of-variables performance across tasks has also been reported by Pulos and Linn (1981). They found that ‘stategies employed on controlling variables tasks are inconsistent both within individuals and within tasks. Clearly, predicting whether or not a person can control cannot be based on a single task’ (p.34). Interestingly, Pulos and Linn suggest that a possible explanation for such heterogeneity of performance may be caused by the ‘subject’ and the ‘experimenter’ viewing the task differently: ‘In other words, [having] differing preconceptions about the operant variables in the task...’(ibid.). This might also explain why pupils focus on ‘irrelevant’ variables. In assessment terms, the result of this will be to underestimate pupils’ underlying **competency** by concentrating solely on their **performance** .

The use of ‘tacit’ knowledge is also much in evidence whenever children are called upon to respond to variable-based questions. This is perhaps indicative of just how unfamiliar to pupils is a procedural approach in general, and the variable-handling model in particular. Moreover, children may be so unfamiliar with operating in what is essentially an **inductive** mode, that they assume that they are being asked for an **explanation** rather than an **interpretation** of the data, since this is the more familiar demand of the questions they are routinely confronted with. There are clearly many factors affecting performance, other than the purely cognitive. It is likely that the variable-handling model is so far removed from the personal concerns of most 11-year olds, that there is the strong possibility of mismatch between pupil and ‘expert’ views.

The prevailing practice in primary classrooms over the last decade has been a fairly unstructured 'discovery' approach. This (essentially inductive) model of science has been attacked from a philosophical perspective as over-simplified and naïve (e.g. Millar and Driver, 1987), thereby leading to difficulties for both pupil **and** teacher education. Furthermore, the narrow formality of the 'fair test' approach to procedural knowledge may be analogous to that which has pervaded the traditional (conceptual) approach to science and which has patently led to the commonly-felt disillusionment with science by pupils who no longer see it as an 'innovative adventurous activity' (Head, 1985, p.37), due to its perceived lack of relevance to the real world. The 'fair test' approach (a rather abstract view of the real world), will do little to enable educators to present science in its social and applied context, in order to enhance its appeal to the majority of pupils: a criterion against which the more traditional approaches have largely failed. The inductivist approach on which the 'fair test' procedure is based relies on the assumption that there is such a thing as a 'scientific method', which can be reduced to a procedural algorithm for the purpose of education in science. Is such a position tenable?

It is conceivable that our haste to depict the methodology of science simply as the replacement of subjective, personal impressions of the world by a systematic and unfailing process of careful observation, measurement, and control of variables will, far from equipping pupils with transferable skills, only serve to make the pursuit of science an even more remote and meaningless chore for the vast majority of pupils. It is essential that we avoid this, by providing not just an 'expert' view of science to which pupils must aspire but, much more importantly, a lasting appreciation of how science affects the lives of us all as individuals and as part of a technological society.

If pupils have some entirely different frame of reference then, as we have seen, it is quite possible that their performance may not match their underlying competence. Qualter (1991) has detected this effect to be particularly prevalent among younger children (Year 4 in this case), in their responses to questions about controlling variables. She found that such children 'do not necessarily focus on the issues of fair testing when they are concerned with the wider problem of the investigation' (p.19). She also concluded that 'if children believe they already know the answer, they don't see any problem' (ibid.). These, I feel, are two very important insights into children's behaviour in the face of procedurally-based questions and will, as I suggested, have a profound affect on both the teaching and assessment of this aspect of science.

If procedural knowledge is seen by the majority of pupils to be remote and largely unattainable, then it will serve only to alienate them and thereby lay itself open to the same criticism as that levelled at an esoteric, conceptually-based approach: namely that it is relevant only to those few indivivduals who go on to study science beyond the age of compulsory schooling. This would be ironic indeed, as the process approach was heralded at its inception as a means of bringing science to the masses ('Science for All' was the slogan which epitomised this view). If we are to avoid this unfortunate state of affairs then it is essential that the process approach is not allowed to become part of this 'élite knowledge' (Fensham, 1985).

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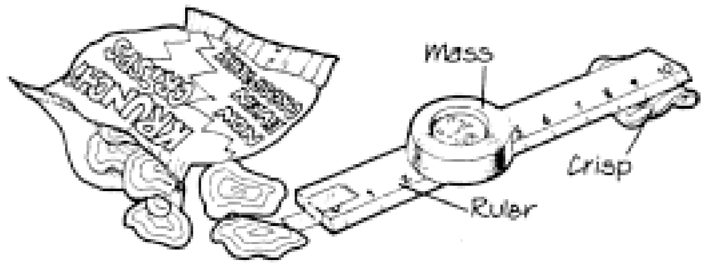
Appendix A

Gavin was testing different brands of crisps to find out which ones were hardest to crush.



He was going to move the mass along the ruler and see at which point the crisps broke.

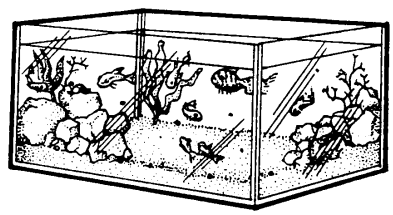
For a fair test there are some things Gavin should keep the same and some things he should change to decide which crisps are hardest to crush.

Tick Change or Not change for each of the things below.

	Change	Not Change
The mass	☐	☐
The type of crisp	☐	☐
The position of the crisp	☐	☐
The size of the crisp	☐	☐

Appendix 3

David and Alberto had some goldfish in a tank. They wanted to find out which type of food they preferred. They planned to watch the fish very carefully when they were fed each day and see how quickly the food was eaten.



For a fair test what should be changed in their investigation and what should they keep the same?

Tick Change or Not change for each of the things below:

	Change	Not change
The amount of food	☐	☐
The type of food	☐	☐
The time of feeding	☐	☐
The goldfish	☐	☐

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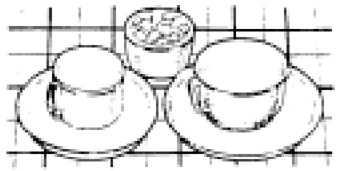
Appendix C



William wanted to find out if sugar dissolved just as quickly in a small cupful as in a large cupful of tea.

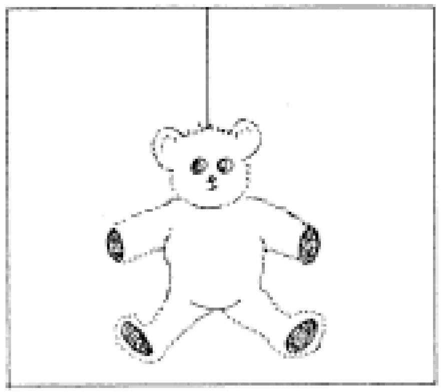
For his tests he used water instead of tea so that he could see when the sugar had dissolved.

Which things should he change in his tests and which things should he keep the same?

Tick Change or Not change for each of the things below:

	Change	Not change
The amount of sugar	☐	☐
The amount of water	☐	☐
How quickly he stirs	☐	☐
The spoon he uses	☐	☐

Appendix D



This toy bobs up and down on an elastic string.
Two children wanted to find out whether the thickness of the elastic makes any difference to how quickly the toy goes up and down.
For their experiment they had:

thick and thin elastic
long and short pieces of elastic
large and small toys.

How do you think they should do the experiment?

The 3 ticks in the first row show how they started.
Put 3 ticks in the bottom row to show what you think they should do then.

First see how quickly it goes up and down when

the string is	short	✓	the toy is	large		the string is	thick	✓
	long			small	✓		thin	

Then see how quickly it goes up and down when

the string is	short		the toy is	large		the string is	thick	
	long			small			thin	

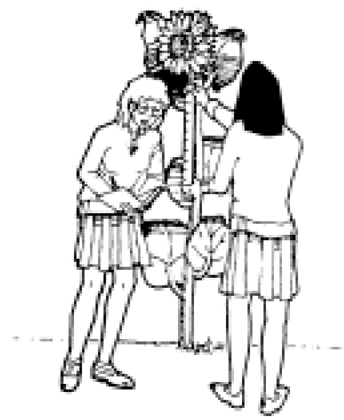
Appendix E

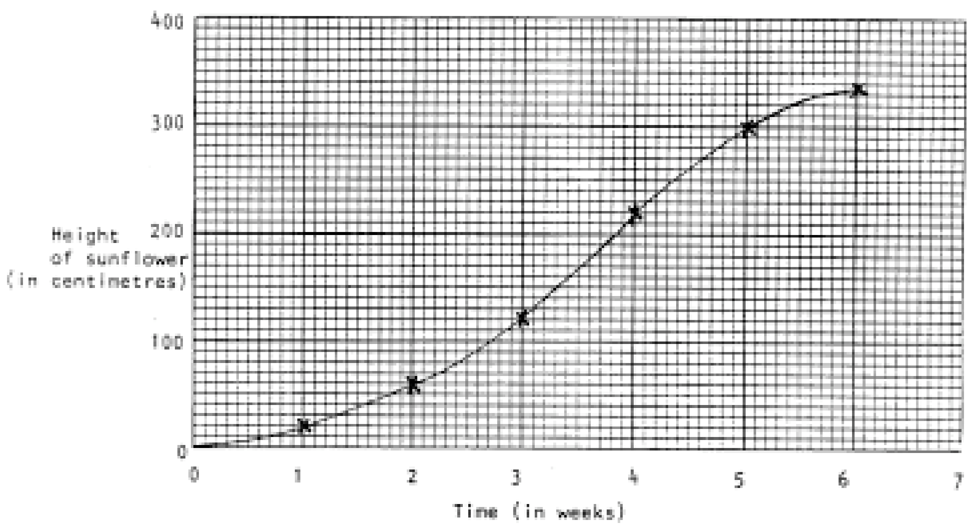
Anne planted a sunflower in the school garden.

She wanted to find out how quickly it grows.

To do this, she measured the height of the sunflower each week.

Then she put her results on a graph like the one below:





Now use the graph to help you answer these questions:

a) How many times did Anne measure the height of the sunflower?

Answer . . . .

b) What was the height of the sunflower at <u>5 weeks</u>?

Answer . . . .

c) What was the height of the sunflower at <u>3 weeks</u>?

d) What was the highest point reached by the sunflower?

Answer . . . .

e) What was the change in height from week 4 to week 6?

Answer . . . .

f) For how long was the height of the sunflower more than 220 centimetres?

Answer . . . .

g) What would you expect the height of the sunflower to be at 3 1/2 weeks?

Answer . . . .

h) What would you expect the height of the sunflower to be at 7 weeks?

Answer . . . .

i) Describe what happens to the height of the sunflower between week 1 and week 3.

. . . .

. . . .

j) When was the sunflower growing quickest?

Answer . . . .

k) Describe what you notice about how the height of the sunflower changes with time.

. . . .

. . . .

. . . .

. . . .

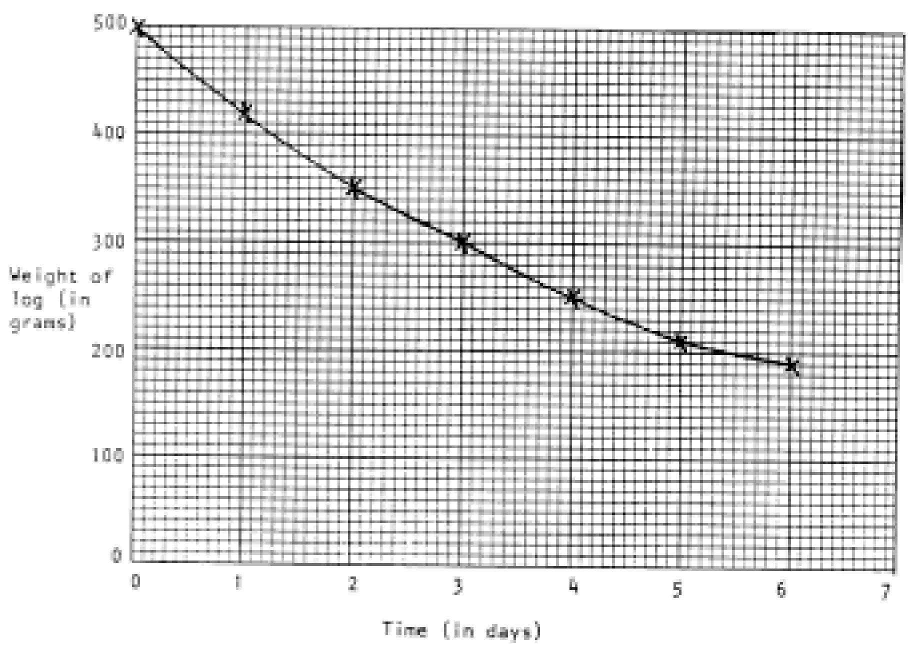
please turn over ......

Appendix F

Simon was trying to find out how quickly wet logs of wood take to dry out.

He decided to weigh a log after it had been soaked in the rain and then kept indoors for several days.

He drew a graph of his results like this one:



Now use the graph to help you answer these questions:

a) How many times did Simon weigh the log?

Answer . . . .

b) How long did it take for the weight of the log to reach 300 grams?

Answer . . . .

c) What was the weight of the log at day l?

Answer . . . .

d) What was the biggest weight in Simon's results?

Answer . . . .

e) What was the change in weight from day 2 to day 4?

Answer . . . .

f) For how long was the weight of the log more than 350 grams?

Answer . . . .

g) What would you expect the weight of the log to be at 4 1/2 days?

Answer . . . .

h) What would you expect the weight of the log to be at 7 days?

Answer . . . .

i) Describe what happens to the weight of the log between day 3 and day 5.

. . . .

. . . .

j) When was the log drying out slowest?

Answer . . . .

k) Describe what you notice about how the weight of the log changes with time.

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

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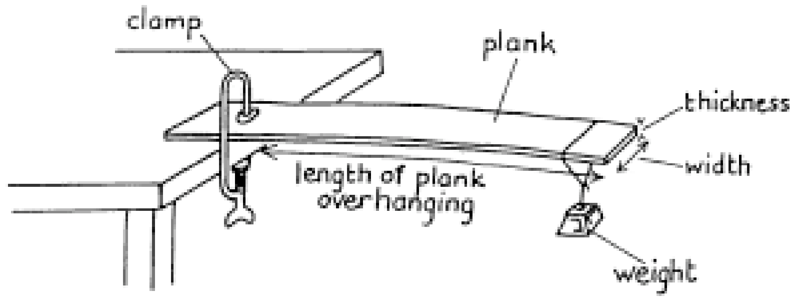
Appendix G

Anna was trying to find out which wood was the best to use for making some shelves for her books and records.



She was using this equipment to find out how much a plank of wood bends when a weight is hung at the end.

Suppose you use the equipment to find out <u>if the type of wood the plank is made of makes any difference to how much it bends</u>.

What would you change in your test and what would you not change to make it a fair test?

Tick <u>Change</u> or <u>Not change</u> for each of the things below.

	Change	Not Change
The weight hanging on the end	☐	☐
The type of wood	☐	☐
The length of plank overhanging	☐	☐
The thickness of the plank	☐	☐