Practical Mechanics in Primary Mathematics:

A preliminary report

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Practical Mechanics in Primary Mathematics is a two year research project, funded by the Australian Research Council, carried out in collaboration with Julian Williams, director of the Mechanics in Action Project in the UK. Research indicates that children's spontaneous concepts in mechanics clash with accepted scientific concepts, are remarkably resistant to change and are already deep-seated by grade 4. Practical Mechanics in Primary Mathematics is designed to investigate ways in which practical mathematics activities can be used to foster links between upper primary children's spontaneous concepts and Newtonian mechanics. The first phase of the project, being carried out in 1995, is examining how children interact with equipment based practical mechanics activities. Inparticular: Which aspects of such activities are attended to by children? What mathematical and other techniques are used by the children to record and represent their experiences? What is the nature of the discussions between the children? Forty grade 5 and 6 children are being video-taped while working in groups of five on a series of practical activities, after which they are interviewed individually. During 1996, teaching experiments will be carried out in five grade 5 and 6 classrooms for one term to determine the extent to which an appropriate program of practical mechanics activities, in which teachers have a knowledge of the children's spontaneous concepts; draw children's attention to the critical features of the activities; encourage effective recording and representation; and engage children in discussions which support theory building; results in a shift towards more formal scientific concepts by the children. This paper will outline the project and briefly report on some aspects of the work carried out during 1995.

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Introduction

Practical Mechanics in Primary Mathematics is a two year research

project funded by the Australian Research Council. The project, which commenced in 1995, is designed to investigate ways in which practical activities can be used to foster links between upper primary children's spontaneous concepts and Newtonian mechanics, and develop their skills in using mathematics to model real world phenomena. The project is being conducted in conjunction with the, up until now mainly secondary student orientated, Mechanics in Action Project, directed by Julian Williams at the University of Manchester.

National goals for Australian schools stress the importance of mathematics and science in enhancing children's understanding of the world and in developing skills to explain and predict everyday events (Australian Education Council, 1990, 1993). Mechanics was chosen as the focus for this project because the principles of mechanics underpin a wide range of other scientific disciplines. This will make the outcomes of the project extremely valuable for many aspects of mathematics and science education.

This paper will outline the Practical Mechanics in Primary Mathematics project and briefly report on some aspects of the work carried out during 1995.

Background

Children's spontaneous conceptions in science

While very little research into the learning of mechanics appears to have been carried out in mathematics education, there is an extensive body of literature in science education, where students' conceptual models in various domains have been the focus of research for over two decades (Driver & Erickson, 1983; Jagger, 1985; Gunstone, White & Fensham, 1988; Driver, 1989). This research indicates that students come to science classes with spontaneous conceptions which differ from accepted scientific conceptions (Osborne & Freyberg, 1985); prevent the internalisation of scientific concepts (Victorian Ministry of Education, 1987); are remarkably resilient to change, particularly in the area of mechanics (Gil-Perez & Carrascosa, 1990); (at least for force and motion) are already deep-seated by grade4; and are not completely eradicated even by formal university study (Eckstein & Shemesh, 1989). Teaching experiments in mechanics have, however, emphasised secondary or tertiary students (for example, Thorley & Treagust, 1987; Williams, 1988; Savage & Williams, 1990; Thijs, 1992) rather than primary pupils (Marioni, 1989).

While identifying students' spontaneous conceptions and taking account of the similarities and differences between these and scientific conceptions has been recognised as important for teaching for conceptual change (Osborne & Freyberg, 1985; Adams, Doig & Rosier, 1991), early attempts to change conceptions have not been successful (see, for example, Gunstone, Champagne & Klopfer, 1981). Although students appear to learn the required science concepts, they frequently adopt "two perspectives" a major perspective which is applied to the real world and a minor one for textbook and examination purposes (see, for example, Graham & Berry, 1993). The difficulties of bringing about deep conceptual change have been likened to what historically represents a scientific revolution (Gil-Perez & Carrascosa, 1990).

Clement (1982) remarks that rather than being simply capricious, students' beliefs appear to be a plausible theory constructed on the basis of experience. More recent research has questioned whether in fact these conceptions are coherent and stable alternative frameworks, or whether they are context dependent ideas based on students' previous experience and notions such as animacy (Svensson, 1989; Whitelock, 1991; Tytler, 1992; Palmer, 1993).

The rôle of mathematical modelling

The use of mathematics for modelling real-world situations is often viewed as a secondary school activity at best. However, from their earliest days at school children are modelling their environment in many mathematical ways, using number, measurement and pictorial representation as modelling techniques (Groves & Stacey, 1990). The Practical Mechanics in Primary Mathematics project set out to investigate the mathematical modelling possibilities inherent in these practical activities.

One aspect of the project which was seen as a basis for mathematical modelling was the extension of measurement to derived units, in this case speed. Much of the research relevant in this instance appears as commentary on difficulties children have with distance-time graphs. These difficulties have been well-known since the early 1980s (Hart, Kerslake, Brown, Ruddock, Küchemann & McCartney, 1981) and re-iterated since (Swan, 1988). However, problems with aspects of graphical work in general were thought to be pertinent for example, an analysis of current curricula shows clearly the limited range of graphs and data to which primary children are exposed (Australian Education Council, 1990). This limited experience contains its own consequences, both immediate (Pereira-Mendoza, Watson & Moritz, 1995) and for adults (Watson, 1995). Children at upper primary school level have difficulties with scales, and with drawing inferences and making predictions (Asp, Dowsey & Hollingsworth, 1994; Doig, Piper, Mellor & Masters, 1994). It appeared that the inclusion in the project of time-distance relationships would interact with some, if not all, of these difficulties.

Conceptual development and pedagogy

The difficulties experienced by older students and adults in forming scientifically acceptable concepts are well documented (Fensham, Corrigan & Malcolm, 1989). As pointed out by Linn (1987), studying science does not imply that a student no longer holds these naïve ideas. An obvious question is "When do these naïve ideas form?" The answer must of course be "From the earliest years". As Fensham et al. (1989) indicate, naïve notions are already present by the end of primary school. Stead and Osborne (1981) emphasise that the "views held by younger children … can be held by older pupils" (p. 57), while McDermott (1984) states that views prevalent amongst older (tertiary) students can be found in younger students also.

Vygotsky (1962) characterised children's scientific conceptions as developing downwards, while their spontaneous conceptions develop upwards, stressing the importance of the interaction between these, with spontaneous concepts enriching scientific concepts with meaning and scientific concepts offering generality to the spontaneous concepts. This is sometimes described as the vine metaphor.

Pines and West (1985) adopt the vine metaphor as a framework for considering different prototypes of learning situations presented by considering the extent to which the "upward and downward growing vines" clash or are congruent. They consider meaningful learning to take place when the two vines become intertwined, with the new scientific knowledge serving to make sense of the learner's world of experience. They state that a case can be made that school science should be concerned with nurturing the upward growing vine, with teachers attempting to extend the experiences of children and their sense-making within an intuitive framework. As a consequence, identifying students' alternative conceptions has been regarded as important for science teaching partly because these conceptions can interact in unanticipated ways with attempts to encourage students to develop more scientific concepts (Adams, Doig & Rosier, 1991), but also because of the central importance of the similarities and differences between children's science and scientists' science in these attempts (Osborne & Freyberg, 1985).

While there has been extensive research into children's spontaneous conceptions, McCloskey (1983) recommends that research should be carried out into determining how such naïve conceptions develop, which in turn requires exploring what sorts of information people glean from experiences with moving objects and how they generate from this a theoretical framework for explaining their behaviour. However, making observations is an active process, which is itself influenced by the observer's conceptual frameworks, with observers often "seeing what they want to see" and hence focussing on irrelevant factors or neglecting relevant features (Driver, 1983; Duschl & Gitomer, 1991). Moreover, in order to develop children's scientific concepts, guidance is needed to help children assimilate their practical experiences. Osborne and Wittrock (1985) stress the active rôle of the learner in constructing meaning, which requires links to be generated between stimuli and existing knowledge.

Observations alone will not promote conceptual development it is discussion about and reflection on observations which are needed (Gunstone & Watts, 1985). Jagger (1985) reports that one of the few mathematics education references to the teaching of mechanics, the Report of the Mathematics Association (1965), stresses the use of discussion, appeals to intuition and recognises the value of experience and experiment. Cockcroft (1982) stresses the importance of practical experience and experiments for the understanding of mathematics at all stages, and recommends that the early stages of mechanics need to be taught slowly, allowing ample time for discussion in order to allow the concepts to "sink in and develop". Champagne, Gunstone and Klopfer (1985) suggest that such discussion is possibly the crucial link in developing new knowledge structures.

The   Practical Mechanics in Primary Mathematics project

The research questions

The aim of the Practical Mechanics in Primary Mathematics project is to investigate ways in which practical mathematics activities can be used to nurture upper primary children's "upward growing" spontaneous concepts regarding force and motion, in order to establish links with the "downward growing" scientific concepts. Research focuses on addressing those aspects of practical activities which impinge on the "growth" of concepts, and those aspects of classroom practice which promote their "intertwining".

Specific research questions addressed by the project include:

- How do upper primary children interact with equipment based practical mechanics activities?

In particular:
-which aspects of such activities are attended to by children?
-what mathematical and other techniques are used by the children to

record and represent their experiences?
- what is the nature of the discussions between the children?

•To what extent does an appropriate program of practical mechanics activities,
in which teachers:
-have a knowledge of the children's spontaneous concepts;
-draw children's attention to the critical features of the activities;
encourage effective recording and representation; and
-engage children in discussions which support theory building;
result in a shift towards more formal scientific concepts by the children?

The research plan and its implementation

Developing and trialling the practical activities
The first phase of the project, mainly being carried out in 1995, is examining how children interact with equipment based practical mechanics activities.

As part of this phase, a variety of practical mechanics activities were developed in collaboration with Julian Williams and trialled with small groups of grade 5 and 6 children at one Melbourne school during the first half of 1995. These activities have as their focus the following broad concepts related to force and motion:

•speed as distance travelled in unit time;

•acceleration and deceleration;

•force as a "push" or a "pull";

•force is required to produce a change in motion; and

•friction and the force due to gravity as forces which can produce deceleration and, or acceleration.

A number of the activities involve children recording the distance travelled in successive seconds (by a person walking, or a ball or trolley rolling on a track placed at different angles or covered with velvet ribbon) and displaying their results in graphical form. A metronome is used to time one-second intervals, with different children marking positions of the moving object by placing small blocks on the floor or table. Paper streamers are then used to measure distances between the blocks to construct the graphs. Different experiments result in (approximately) uniform motion, acceleration and deceleration due to gravity, and deceleration due to friction. Another activity uses a ball with a built-in stop watch to explore vertical motion under gravity. Children also make (and later use) their own forcemeters from dowelling and elastic.

The use of streamer graphs is designed to facilitate the mathematical modelling of situations using the data obtained, but without the need to resort to complicated calculations or accurate graphing with pencil and paper.

From the activities trialled, those deemed most suitable for the age-group, most easily conducted in a classroom and most clearly focussed on the key force and motion concepts, were selected to form the basis for an extended classroom trial in two grade 5 and 6 composite classes at the school during the last term of 1995. A total of eight lessons, each of approximately 90 minutes, were planned.

"Workbooks" were prepared for the children for most lessons. These were accompanied by detailed lesson notes for their teachers. All lessons are being observed by the project team.

During the early part of 1996, at least three grade 5 and 6 teachers at another school will trial the next version of these lessons.

Analysing children's interactions with the activities

In order to address the research questions relating to how upper primary children interact with this type of practical activity, forty grade 5 and 6 children, at a school different from that used for trialling in 1995, were video-taped while working in groups of five on a subset of these activities.

The forty children were selected from the total group of ninety grade 5 and 6 children at the school on the basis of their level of conceptual development in the area of force and motion, as determined by their performance on a modified version of the Force and Motion unit of the written science assessment instrument Tapping Students' Science Beliefs (Doig & Adams, 1994). Children were selected in such a way that four homogeneous and four heterogenous groups were formed on the basis of performance, while achieving a balance within and across groups on gender, grade levels and classes. So, for example, if the "best performer" in one heterogeneous group was a grade 5 girl, we would endeavour to select a grade 6 boy as the "best performer" in another heterogenous group.

In order to obtain more detailed information about the range of spontaneous concepts regarding force and motion held by the children, which aspects of the activities were attended to by the children and the rôle of discussion, all children were interviewed individually on the same day as their group activity took place. These interviews were also video-taped.

Summaries of the video-taped group activities are currently being produced to facilitate analysis based on a number of factors for example, children's spontaneous concepts as indicated by their explanations of the causes of the phenomena observed; the effect of discussion on these explanations and the extent to which certain children were influenced by other children in changing their views; the patterns of interaction in homogeneous versus heterogeneous groups. A similar process will be carried out with the individual interviews.

Findings from this phase of the project will be used to inform the professional development program preceding the teaching experiment in 1996.

The teaching experiment

During 1996, a teaching experiment will be carried out for a term in five grade 5 and 6 classrooms to determine the extent to which an appropriate program of practical mechanics activities, in which teachers have a knowledge of the children's spontaneous concepts; draw children's attention to the critical features of the activities; encourage effective recording and representation; and engage children in discussions which support theory building; results in a shift towards more formal scientific concepts by the children.

Professional development workshops will be conducted to familiarise the teachers of these classes with the activities and the pertinent mechanics concepts, as well as children's commonly held conceptions regarding force and motion. The teachers will then conduct the sequence of activities, while project team members observe (and possibly video-tape) them in action. The written instrument used in 1995, referred to above, will be used as a pre- and post-test for the experimental children and a control group, in order to determine the extent to which the program of activities results in a shift towards more formal scientific concepts by the children.

Some preliminary observations

The information gathered in 1995 will inform the further development of the activities for implementation in classrooms in 1996 and the corresponding professional development program. While formal analysis of the data gathered has not yet been completed, field notes taken during activities and interviews, as well as the reflections of the project team, allow some preliminary observations to be made.

Measuring speed

An understanding of speed as distance travelled per unit time is fundamental to most of the activities used with the children.

Most children had little difficulty measuring time intervals, either with the metronome or with a stop watch including the ball with the built-in stop watch although there were some interesting interpretations of the meaning of the hundredths of seconds recorded on the stop watches, including "split seconds", tenths of seconds and even milliseconds. Similarly, using paper streamers to measure the distance travelled in a given time presented little difficulty, even when, occasionally, children were required to measure in centimetres as well.

However, when asked what the strips of streamer represented, many children were unable to connect distance and time for example, children frequently responded that "it is the distance the ball has gone", but no amount of prompting could elicit the ending "in one second".

When presented with streamers of different length on the graph and asked "in which second does the ball appear to be going fastest?", a significant proportion of children identified the shortest strip as representing the time interval in which the ball was going fastest. Some children held to this view tenaciously, while others quickly accepted the prevailing view that covering a greater distance in the same amount of time means that you are going faster although this new view was not always present when returning to these activities later. On some occasions, these children, even when in the minority, persuaded the others that "shortest equals fastest".

Discussion revealed that for many children their most vivid experience of measuring speed is the familiar fact that the fastest runner wins the race in the shortest time. The fact that the distance is a pre-set condition of a race is, in the main, not obvious to children. Walking activities, at a constant slow speed, then a constant faster speed, followed by teacher-led, group discussion about the distance travelled by the "walker" was successful in re-orientating the perspective and understanding for almost all of the children holding this belief although one child insisted that for walking it was "longest equals fastest", but this did not apply to balls rolling on tracks. Children's own bodily experience proved to be a powerful, convincing data source in most cases.

For many children, the fact that the streamers could be used to find the distance (perhaps in centimetres) travelled in one second was not

enough for them to be able to say that they could find the speed of the ball. It was not sophisticated concepts of average speed versus instantaneous speed, for example, which caused the difficulty. Instead, children either believed that the streamer graph could only show how far the ball travelled (without reference to time), or that it showed whether the ball was going fast or slow (but not how fast), or that speed could only be given in units like kilometres per hour (and certainly not centimetres per second).

Handling real data

Many of the activities resulted in "streamer graphs" being produced by using paper streamers to measure the distance between blocks marking the motion of a ball (or child or trolley) at one second intervals and gluing the strips to large sheets of paper. Placing the block at the precise position where the ball is when the metronome ticks proved to be a very difficult task a few children found it almost impossible. Furthermore, it was very difficult to create a "perfect track" usually there were dips which produced unexpected effects. As a result, there were many inaccuracies in the data. While these were usually not critical in assessing whether the ball was accelerating or decelerating, in the case of constant motion these inaccuracies were critical.

Textbook examples of data tend, a priori, to support the expected results of an experiment that is data are manufactured to "prove" the results which are known in advance by the teacher and supposedly discovered by the children. In practical activities there is no such elegance and awkward data is always present. While our adult theoretical framework suggests, for example, that a ball rolling on a smooth flat surface will produce uniform motion (or perhaps slight deceleration), the children's data often did not appear to support the adult theory. The dilemma then became whether to accept the children's data and their inferences from them or to "correct" the data or the children's inferences.

While the inaccurate data provided opportunities for discussion of several features of experimental work, such as the need for repeated trials, accuracy in measuring and the use of some form of averaging for data smoothing, many children were fixated on even quite small differences in strip lengths. They often constructed quite complex explanations for the ball's differing motion in each of the seconds, whether their own observations, theoretical explanations or predictions supported this or not.

While the project seeks to use the collection and representation of data as a vehicle to promote reflection and hypothesising, it was disturbing that the reverse seemed to occur. Children could agree that the data was suspect, but at the same time use it to provide an apparently precise description of the motion of the ball. Often the children commented that "it doesn't really make sense" or, worse still, "what I have learnt is that whatever I think will happen won't". The graphs were seen as "real" while the motion of the ball was adjusted to suit. These attempts, apparently to force one-to-one mappings of the data to "reality" were reminiscent of the "pattern-forcing" recorded by Pereira-Mendoza, Watson and Moritz (1995) with respect to graphs. Alternative solutions, such as noting that the differences were (frequently, but not always) small when viewed as a proportion of the total lengths, or of averaging the entire set of strip lengths, were rarely raised by the children.

Practical activities in primary classrooms

Conducting practical activities of the type outlined here presents some difficulty in the normal classroom. As activities were trialled with small groups in the first instance, it was sometimes difficult even for some members of the project team to see how they could be translated to a classroom. Difficulties arise from the need for many sets of equipment and considerable space, if all groups are to do the same activities at the same time (which was the preferred option because of the belief that class discussion would play a crucial rôle in the learning process).

There was also the question as to how feasible it is to expect the children to set up the equipment in such a way that it behaves as well as possible, given the difficulties of laying a smooth track on school floors and tables which are themselves not level to begin with. The project team had developed many techniques to improve the efficiency of the equipment, but it was not clear what the best way was to convey these to the children or their teachers.

In fact, many of these difficulties appear to have been overcome. The classroom teachers have moved from attempting to find space elsewhere in the school to conduct the activities to modifying their classroom arrangements to accommodate the lessons. This has resulted in a great saving of time and much better opportunities for class discussion. The project team have written "workbooks" for the children which, among other things, include instructions on setting up the equipment and carrying out the activities.

After initial attempts by the teachers to encourage children to work independently using just their workbooks, a pattern of using workbooks in parallel with teacher direction and class discussion is beginning to emerge, with most children carrying out the required tasks quite successfully. Children have become adept at using the equipment provided (stop watches, metronome, forcemeters, etc), developing the skills of measuring quantities (time, distance, etc) and recording data (tables, graphs, etc). Most activities require children to work in groups of six, with an occasional whole class lesson.

Teaching for conceptual development

The rôle of language

Classrooms are social environments. The language used to communicate science ideas are drawn from the common language register of teacher and children; science on the other hand has its own register that requires words and phrases to have specific, precisely defined meanings. Activities which resulted in acceleration or deceleration, for example, revealed the importance of developing an agreed vocabulary which suitably distinguishes between different potential meanings. The project team often found it impossible to decide whether children who said "the ball goes faster" meant "faster than last time" or "goes faster and faster and faster" i.e. accelerates. It became obvious that the concept of acceleration and the availability of a word to describe it were often closely linked.

The project team were initially surprised by a phenomenon which occurred relatively frequently during activities relating to acceleration and deceleration. When asked to describe the motion of a ball or trolley, one child would point to a particular spot on the track and say "the ball starts to slow down here". Other children would then either agree and say "Yes, yes, that is the spot where the ball slows down" or dispute it, pointing to a nearby position, saying "No, no, this is where it starts to slow down". (Even some members of the project team began to see "the spot".) We believe this confirmsthe need for a suitable vocabulary to adequately support the type of thinking which is required here. It also highlights the importance of the theoretical framework which structures an individual's observations. Once we accepted that there was a point where the ball started to slow down, we could all see it (well, almost all of us anyway).

There was considerable discussion among the project team about the best way of introducing terms like "acceleration" or "friction", or even "force". This is seen as a different situation from, say, telling children that force is measured in Newtons. Although this is clearly a case of the teacher using their authority, it only requires acceptance of a convention, while the use of terms such as "acceleration" and "friction" may be taken to imply some form of conceptual understanding. We would not like to make the assumption that such understanding is present merely because the teacher has introduced (and probably explained) the term.

Allowing time for conceptual development

Underpinning the whole of this research is the belief that children's spontaneous conceptions not only need to be listened to and acknowledged, but that there is no easy short cut to developing more scientific conceptions. A major difficulty, when attempting to develop materials for classroom use by others, is the need to adequately convey the thrust of the lesson (which is critical, if for no other reason than to help teachers avoid the trap which the project team fell into during the early stages of developing the activities, of wandering off on dead-end paths) while at the same time retaining sufficient flexibility to allow children to actively pursue their own lines of thinking.

Coupled with this is the widespread notion that "good teaching" must always involve achieving some form of closure. While we don't necessarily dispute this, the nature of the closure and how and when it is achieved are important factors to consider. In the lesson outlines we provided, we attempted to discourage premature closure by indicating for each lesson not only the focus (for mathematics, language and practical skills, as well as for science), but also the concepts which are being introduced, revisited or established in the lesson. So, for example, the concept of speed as distance per unit time is introduced in the first lesson, but it is not until very much later that it is anticipated that even a sizeable minority of the children might have any intuitive idea of this. We are deliberately setting out to delay closure, especially the type of closure where, at the end of a lesson introducing a new concept, the teacher quickly sums up the lesson and states the main conclusion.

The rôle of discussion

The rôle of discussion in enabling children to build on their own spontaneous concepts, while moving towards the development of more scientific concepts had been mentioned above.

In the early trialling of activities, different models of organisation were used in an attempt to find the best way to engage children in meaningful discussion. Attempts at getting children to engage in the type of discussion we had in mind within small groups, without teacher intervention, were generally unsuccessful children tended to read the focus questions and quickly answer them, saying "OK, now we've done that one, let's move on to the next question". There was very little, if any, actual discussion taking place. For this reason, teacher-led discussions are now planned for strategic points in each activity.

The lessons, which are quite long (up to 90 minutes) are designed to be broken up into a sequence of activities and discussions. However, it appears quite difficult for teachers to conduct these discussions at the suggested times. While classes were held in different parts of the school, there was a great (and understandable) tendency to attempt to finish the practical activities as quickly as possible and leave the discussion for later back in the classroom, or even for another session, as time usually ran out. Conducting the lessons in the classroom has helped a little, but there is still the problem of inserting the discussions at an appropriate time, when some children move through the activities so much faster than others.

It is hoped that in these discussions children's conceptual understanding will be challenged by the views of other children, as well as by the results of the practical activities. Conducting such discussions places huge demands on teachers, not only in organisational terms, but also with regard to their own background knowledge of the mechanics involved and their knowledge of where children's ideas can lead.

Professional development

In the final phase of the project, in 1996, teachers will occupy a central position. Some of the problems likely to occur have been revealed in the trialling of the sequence of activities in the classroom phase in 1995. The most notable of these concerns relevant science understandings.

The project design includes professional development for teachers who are to be involved in the final phase. It is apparent that this will need to have at least two emphases. The first emphasis needs to be on teachers' own science knowledge and understandings of force and motion. This is not to imply that teachers do not have any understanding in this field, but rather that a deep knowledge of specific aspects of mechanics is needed. For generalist-trained primary teachers such understandings are not usual. We believe that without these understandings the task of implementing the sequence of activities would pose major difficulties.

As a corollary, while we believe that an understanding of the relevant aspects of mechanics is critical, so too is an understanding of children's naïve conceptions in mechanics. Without prior knowledge of the range of children's likely understandings in mechanics, promoting meaningful discussion becomes problematic at best. Teachers who are armed with the appropriate knowledge, however, can direct children's attention to aspects of the activities which can provide counter-examples to these naïve ideas.

A quite unexpected observation, which was made independently by members of the project team (and the video-crew) was the obvious extent of agreement between the children's level of performance in the practical activities (and the subsequent interview), and their performance on the written Force and Motion assessment. This came to our attention in a striking way when, after conducting an activity with a group which was intended to be heterogeneous, we all walked out for morning tea and spontaneously asked which child had scored the "A". When the details were checked, the children in the group were found to have very close scores, with the children in the "top" and "bottom" groups having

scores very close to the borderlines for the "middle" group. This confirmed dramatically the value of Tapping Students' Science Beliefs in effectively identifying children's conceptual development in science. We now have plans to have an independent person view the videotapes in an attempt to confirm the high predictive value of the assessment instrument. This confirmation would be very valuable as it is not practicable for a teacher to interview 30 children.

Conclusion

Although the research is still at an early stage, it is possible to make some general comments. Firstly, it is evident that upper primary children can manage practical activities, collect and organise data, and interpret results of experiments, all with guidance from an adult "expert".

The critical rôle of language, whether scientific or social, has been quite apparent during the developmental phases; the constraints imposed on children's explanations and conceptualisation when they do not have the appropriate scientific language indicates the need for careful research into the "downward growing vine", and how it can be nurtured best.

Mathematics also plays a critical rôle in activities of this type, as is evident from the project's early phases. It is not the lack of arithmetic or measuring skills that cause most difficulties, but the conceptual and experiential aspects of children's mathematics. It would appear that a wider range of experiences, particularly in working with real phenomena and situations, collecting, organising, and drawing inferences from data would be beneficial.

Teachers are central to the children's success or otherwise in school settings. One of the major challenges for the project will be to provide appropriate professional development for the teachers taking part in the teaching experiment to enable them to fulfil the expectations for what constitutes "an appropriate program of practical activities" as indicated in the original research question.

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