Primary SPACE

Science
Processes
And
Concept
Exploration
Project

Research Reports

Forces

by
Terry Russell, Linda McGuigan
and Adrian Hughes

LIVERPOOL UNIVERSITY PRESS

THE UNIVERSITY of LIVERPOOL

First published 1998 by
Liverpool University Press
PO Box 147, Liverpool L69 3BX

British Library Cataloguing in Publication Data
Data are available

ISBN 0 85323 068 4

Printed and bound by
Graphic Offset Ltd, 3-4 Phillips Street, Liverpool L3 6HZ

PRIMARY SPACE PROJECT
RESEARCH REPORT

1998

FORCES

by
TERRY RUSSELL, LINDA McGUIGAN
and ADRIAN HUGHES

LIVERPOOL UNIVERSITY PRESS

ACKNOWLEDGMENTS

The research reported here was made possible as the result of the dedication and professionalism of the staff of all the schools which participated. Our thanks go to them and the children whose ideas are the subject of this report.

To Lisa Caslin and Lucy Boardman, our thanks for their painstaking care and patient attention to detail with the DTP demands of producing this report.

CONTENTS

1. INTRODUCTION

1.0 Background to the project

This research report builds upon the methodology developed in the course of a significant programme of research by CRIPSAT over the last decade. There are several reasons for revisiting the domain of forces following some preliminary exploration by the SPACE project team in 1989. That Nuffield funded original research was conducted prior to the introduction of the National Curriculum. The original research informed the development of the curriculum materials published in the Nuffield Primary Science Series (CollinsEducational) but was not published in the form of a separate research report. The introduction of a prescribed curriculum carried with it a new set of demands. Firstly, there was a change from most teachers' emphasis, which was primarily a process approach, to a concern for both content and processes. Underpinning a nationally prescribed curriculum is a pupil entitlement to certain content and teachers' obligation to deliver that content. It was important that, in this new educational context, the domain of forces should be revisited in order that the research should have direct curriculum validity.

A second consideration was that the implementation of a prescribed curriculum across four Key Stages opened possibilities of the idea of progression in pupils' conceptual understanding being on the research agenda. Concerns about matters of progression cannot be confined to a single classroom or Key Stage. The 'Evaluation of the Implementation of National Curriculum Science KS1-3' project (Russell *et al.,* 1994) demonstrated the insights which could be gained through exploring conceptual progression with teachers across the three Key Stages, KS1-3. Whereas the original SPACE research limited itself to the first two Key Stages, the experience of working with an extended age range made the advantages of this approach clear. Primarily, this involved a recognition of the importance of the concept of progression to a constructivist approach to teaching and learning science. Fundamental to this approach is the idea that, rather than being either right or wrong in their thinking, children's ideas are more usefully considered as revealing commonly recurring intermediate understandings. The greater the age range researched, the clearer the emergence and shifts in such ideas was apparent. Indeed, there is a strong argument in favour of extending any such research beyond the age range which is the immediate concern or focus for action, since it is only when antecedent and subsequent ideas are revealed that progression in the thinking of the age group under direct consideration are placed in developmental context.

A third consideration was that the implementation of a prescribed curriculum, together with its associated assessment arrangements, placed increased demands on teachers' own understanding of science. It has been argued that many primary teachers lack an appropriate level of understanding for teaching National Curriculum science. Forces in particular has been raised by teachers as a source of concern, (Kruger *et al.,* 1990). Moreover, Russell *et al.* (1994; *op cit.*) suggest that limitations in teachers' understanding is not restricted to primary teachers but represents a source of concern for those Key Stage 3 and 4 teachers teaching outside their subject specialism. CRIPSAT's experience of helping teachers develop their understanding (Schilling *et al.*, 1992) was used to assemble some support materials for teachers involved in the Forces project. This material, together with the cross-Key Stage dialogue between teachers which was promoted by the nature of the research, attempted to support teachers in their pedagogical subject knowledge.

Another significant change in orientation, compared to the original SPACE project approach is that this research is underpinned by a particular formulation of conceptual progression which evolved from experiences gained in other empirical progression enquiries (Russell *et al.*, 1994). This formulation differs from attempts to describe cognitive development as something capable of being separated from socialised development, as Piaget attempted. Nor is our formulation of progression limited to a notion of an ideal, logical sequencing of ideas to be taught. Instead, it is explicitly recognised that these major factors - the individual's developing cognitive capacities and the particular set of ideas to which a society decides individuals will be exposed (or 'enculturated') - *interact*. Furthermore, we recognise that there are more effective and less effective ways in which teachers might support intellectual development. Teachers interpret the curriculum in slightly different ways and have their own methods of 'bridging' or 'scaffolding' between what is to be taught and the learners. Thus it is suggested that conceptual progression in an educational context might be understood as comprising these three interacting elements:

the sequencing of the curriculum agenda
developmental and experimental aspects of cognition, and
praxis, the teaching and learning strategies adopted by teachers.

Within an educational perspective, concentration on any one element alone would be insufficient; the three elements must be taken into account in any consideration of the nature of National Curriculum related conceptual progression. This notion of progression has led to a refinement of the mode of empirical enquiry (i.e. since the initial Forces research) to attempt to represent more fully the teacher's role in promoting conceptual understanding. Messages emanating from constructivist research approached from this standpoint promise to inform not just our knowledge of likely pathways of individual pupils' conceptual progression, but also pedagogical practice and optimal curriculum sequencing.

1.1 The collaborative nature of the research

The collaborative nature of the research reported here exploited the complementarity of skills offered by teachers and university researchers. The researchers brought with them a systematic research framework which had been assembled through the experience of earlier projects; teachers' ideas and practices were drawn upon and subjected to scrutiny by colleagues in other classrooms. Collaboration between teachers from three Key Stages provided opportunities to share ideas and practices and led to cross-fertilisation across traditional Key Stage divisions. Since this mode of enquiry is classroom-based it takes into account classroom realities (both constraints and opportunities) and examines what is possible within an ecologically valid context. Thus, it continues CRIPSAT's involvement in professionallybased enquiry underpinned by a collaborative methodology. The outcomes of such research have messages for classroom practice, as well as making a contribution to research understanding *per se*.

1.2 Constructivist orientation

The research is underpinned by a constructivist model of learning. Broadly stated, this view assumes that the learner is actively involved in constructing their own understanding of conventional science. The construction of these new ways of knowing are influenced by the ideas children have developed previously and the new ideas and experiences introduced by the teacher. That there is a socio-cultural dimension to these individual constructions is not neglected; personal constructions are influenced by the social context in which ideas are encountered. The culture, the teacher, the peer group and classroom situational effects are all influential in the formation of new understandings:

The university-based researchers' commitment to collaboration with teachers in research activity can also be described as constructivist in orientation. Ideas and practices were considered and developed within a series of group meetings with the expectation that the outcomes of these meetings would provide an agenda for action. Teachers made their own individual constructions of these events and operationalised the ideas and practices in their classrooms in their own ways. While the National Curriculum set the broad agenda for action, what might emerge in matters of detail was open-ended, benefiting from teachers' professionalism, expertise and imagination. Participation in the project and exposure to the views of colleagues expert in other Key Stages was no doubt stimulating. Teachers' interpretations of, and responses to, children's understandings demonstrate the fact that constructivist theory applies equally to teachers (and researchers) as to pupils. It is reflexive; conducting constructivist research is a constructivist activity. Good ideas, effective strategies for intervention, etc., were shared, discussed and recorded as useful outcomes of research activity.

1.3 General approach

The sequence of activities adopted for this research comprised:

Pre-intervention elicitation: a period during which teachers elicited the ideas of all children in their class using concept probes which addressed the concept domains being investigated.
Pre-intervention interviews: a stratified sub-sample of children were interviewed by university-based researchers.
Intervention: a period in which teachers helped children to develop their ideas through a range of empirical and other evidence-gathering activities.
Post-intervention elicitation: teachers collected children's ideas through a series of concept probes matching the pre-intervention probes (though not identical in kind or extent).
Post-intervention interviews: the same stratified sub-sample of children were interviewed by university-based researchers.

A detailed description of these phases is presented in Chapter Two. This research cycle is primarily constructivist in orientation. It was not intended to implement a tightly formulated experimental design in which pre- and post-tests are precisely matched, where commonly applied classroom interventions can be controlled and their effects measured. There are several reasons why these two elements of experimental design are inappropriate for classroom-based research. Constant comparison of data provides immediate feedback which assists in the further development of the data collection techniques. Insights are gained cumulatively and fed back into the programme *iteratively.* It is the nature of collaborative classroom based research that ideas and practices explored in the elicitation phase may be modified, refined or rejected at the point of post-intervention elicitation and interviews. Contexts which fail to engage children's interest may be replaced. It is the nature of the elicitation that ideas in a wide range of areas are probed. Post-intervention elicitation and interviews are tailored to examine changes in understanding in matters which have been approached within the intervention phase.

While a range of interventions are suggested, agreed and refined between teachers and researchers, it is important to recognise that teachers are not simply following an externally imposed input routine. Indeed, given increasing evidence of the role of social processes (Howe 1996) and context (Lave 1995) in promoting conceptual progression, evaluating the impact of specific routines has to be acknowledged to be intrinsically problematic. It is the nature of constructivist collaborative classroom research that teachers construct their own interpretation of the suggested activities and decide the nature and extent of intervention for a particular class. Teachers' judgements and practices are an integral part of the development and operationalisation of the intervention. They select and modify activities according to the prevailing ideas of children in their class and this makes it possible for them to monitor conceptual progression in the social context of classroom interactions. A balance has to be achieved between the need for rigour and systematic data collection and acceptance that the research process is situated in classrooms which are not sterile, controlled environments but are subject to myriad constraints and opportunities. Indeed, this is the very strength of collaborative classroom research, that messages emanating from such enquiry inform the development of theory as well as having classroom and curriculum validity.

Outcomes from such research have the potential to inform teaching and learning of science at Key Stages 1, 2 and 3. Valuable insights are also gained into aspects of the domain which would benefit from further enquiry.

The products of the research programme include the following:

- The report summarises the collaborative classroom-based methodology which informed the programme. It is assumed that this is a replicable methodology which has value in contributing to the development of researched curricula generally and more specifically, the process of review of the science curriculum in England and Wales.

- Much constructivist research itemises pupils' 'alternative conceptions'. We prefer the term, 'intermediate understandings' as this situates children's ideas in the socio-cultural context of science ideas while acknowledging the lack of complete correspondence between the two.

- As well as describing children's ideas, the report reviews qualitative and quantitative evidence of shifts in thinking. It is suggested that the programme could not optimise such developments since it was exploratory and iterative in nature. Nonetheless, certain areas are identified as being particularly promising targets for intervention.

- Given the definition of educational progression which guided this research as including the socio-cultural impact of teachers, it is logical that attention should focus on what appear to be promising strategies for helping children to develop their thinking in the direction of conventional understanding. Such possibilities are reviewed in the final chapter of this report.

- Although the National Curriculum is laid down in law as a pupil entitlement, we have treated it, for the purposes of the research reported here, as an hypothesis describing optimal content and sequencing. We have subjected that hypothesis to empirical enquiry alongside teachers in some of the classrooms in which it is required to be put into operation. This research was conducted during the period of the moratorium on change between 1995 and 2000, but it is anticipated that an important outcome will be a relevant contribution to the process of curriculum review.

- While educational research can never be complete so long as it assumes dynamic systems, we hope that the outcomes of this enquiry will contribute to a cumulative understanding of the science curriculum and teaching and learning science. Even within the domain of enquiry, there are obvious ommisions which will need to be the subject of further research.

- For the future, we anticipate a need to exploit and disseminate the findings reported here more widely through the medium of teacher support materials.

2. METHODOLOGY

2.0 Introduction

The sample, research programme and description of the project are described in sections 2.1. to 2.3.

2.1 Sample

a) Schools

Fifteen schools drawn from seven Local Education Authorities participated in this research. The schools are located in North West England and are situated in both urban and rural areas. Twelve are primary schools (Key Stages 1 and 2) while three are secondary schools (Key Stages 3 and 4). The classes included in the sample covered Key Stages 1-3 and ranged from Reception (usually aged five) to Year 9 (usually aged 14).

The names of the participating schools, Head Teachers and teachers are reported in Appendix One.

b) Teachers

Nineteen teachers were involved in the programme. Eight had previously been involved in collaborative research projects with CRIPSAT. Two had previously been involved in the SPACE project, one had participated in the Evaluation of the Implementation of Science in the National Curriculum project, (Russell *et al.*, 1994), five had participated with CRIPSAT staff in the development of end of Key Stage Two assessment materials. The other teachers had expressed a willingness to participate in the project. Many of these were working in schools in which the headteacher or other members of staff had been involved in collaborative work with CRIPSAT. Most teachers were thus aware of the constructivist philosophy which underpinned this project. Such was the enthusiasm of the teachers that at one school all of the three teachers within the small rural school were part of the sample, and in all cases were willing to modify their schemes of work to accommodate a Forces topic at a time convenient for the research program.

Teachers received support from the University researchers through three whole-group meetings. At the first of these meetings the teachers and researchers discussed and planned ways in which children's ideas could be found out. At the second, ways of helping children to develop their ideas were considered. At the third, changes in children's ideas, conceptual challenges and effective teaching strategies were discussed. Throughout the research period, visits to classes were made by the University researchers.

c) Children

All children in the fifteen classes were involved in the Project work to some extent. Pre- and Post-intervention concept probes were administered by the teachers to all children in the fifteen classes. Data were thus collected from 462 children. A stratified random sample of children was selected for interview at two stages during the work by University researchers. Teachers were asked to assign each child in their class to a Year group and an achievement band (high, medium or low) related to their overall school performance. The interview sample was then randomly selected from the class lists so that numbers were balanced by achievement band, Year group and gender. The sample comprised 118 children ranging from Reception to Year 9 and is summarised in Table 2.1.

Table 2.1 The Interview Sample

		KS1 n = 42	**L KS2 n = 29**	**U KS2 n = 29**	**KS3 n = 18**	
Low	Males	6	3	3	4	16
	Females	5	4	3	2	14
Medium	Males	6	8	8	4	26
	Females	12	3	5	2	22
High	Males	6	7	5	4	22
	Females	7	4	5	2	18
	64 Males 54 Females	42	29	29	18	118

2.2 *The Research Programme*

2.2.1 *Review of associated research literature*

There is a large accumulation of research literature addressing the domain of Forces. This literature documents children's ideas and has increasingly considered the possibilities for promoting conceptual progression within the domain. A comprehensive literature review was carried out prior to the commencement of this study. This review helped to inform the direction and starting points for this research. An outline review of the literature is presented in Chapter Three.

2.2.2 *Introductory meeting of teachers and university-based researchers*

An introductory pre-elicitation meeting was held in November 1996 prior to the commencement of the classroom based research. One of the aims of the meeting was to orientate teachers towards the nature of constructivist research. A second was to outline the research programme. A third consideration was the development of elicitation activities. Both previous research and the techniques developed during SPACE research influenced the selection of the range of possible activities presented to teachers. The suggestions were modified, clarified and added to as teachers discussed in groups whether and how the suggested activities might be tackled in their own classrooms. The range of activities were examined in terms of curriculum validity, Key Stage appropriateness and classroom manageability. The outcome of the meeting was an agenda for a sequence of conceptual probes. This was written up after the meeting and sent to teachers.

2.2.3 Classroom-based elicitation

Classroom work took place in two major phases. The first of these was called 'Elicitation'. Forces is a wide domain in which numerous concepts are embedded. Division of the domain into themes recognised the need to probe children's understanding in several areas. An attempt was made to achieve a compromise between the need for classroom-viable concept probes which would elicit the ideas of all children in numerous areas and the philosophy underpinning the research, that the elicitation of children's ideas should not involve ambushing children with decontextualised questions. Concept probes were thus developed which explored the areas of interest and could be presented within the context of a direct or familiar activity. The mode of response was primarily paper and pencil to maximise classroom viability. Two concept probes booklets were developed, one for Reception and Key Stage 1 and another for Key Stage 2 and 3. Concept probes loosely tailored to Key Stages ensured that children would be able to access and respond to the problems as posed. These are exemplified in Appendix II.

It was intended that teachers should introduce the concept probes with the presentation of associated direct experiences. Exploration of children's views of forces and their effects on objects in water, for example, was supported by a tank of water and a number of objects. Children were encouraged to engage with this direct experience. In the same way exploration of floating and sinking in air was supported by experience of a helium balloon. It was thought that direct experiences would stimulate some reflection on the domain and ensure more considered views were collected rather than catching children by surprise. Opportunities to draw on related everyday experiences were also fully exploited. Researchers distributed items such as helium-filled balloons, magnets and video material to each teacher.

The subject matter presented to children was selected on the grounds that it was likely to be familiar to them. The research team took account of the situated nature of cognition and concerns that children's ideas may be expected to be influenced by both the context and content of assessment materials. Since children's ideas were recognised as being both content- and context-sensitive, there was careful selection of both contexts and content in the development of concept probes. Awareness of context sensitivity resulted in some aspects of forces being explored through more than one situation.

The exact design of the conceptual probes was greatly influenced by knowledge and expertise gleaned from previous research. Many of the teachers and university-based research staff had become aware of the kinds of activities that had proved successful in meeting the dual functions of 'exposure' and 'elicitation'. It was anticipated that a wide range of aspects of forces could be explored with a large number of children in a manner that was classroom-viable. If teachers were to be enabled to explore the limits of children's understanding, such a range was essential.

The successful implementation of these activities as elicitation tools was based on techniques such as the use of open questions by the teacher in discussion with children. More fundamentally, teachers were aware of the rationale for adopting those techniques which enabled them to establish children's ideas. This required teachers to adopt a role in which they deliberately held back from guiding children's thinking during elicitation. They were to help children to clarify their ideas rather than seeking to make them justify or reconsider them. The latter form of activity would need to await the intervention phase.

2.2.4 *Interviews*

A sample of at least six children from each of the classes in the study was interviewed individually (n=118). The sample was balanced for gender and achievement and pupils were randomly selected within these constraints. Semi-structured interviews were used to explore further the ideas emerging from the concept probes. Key questions within the concept probes were identified as foci for the interview. However, in order to maintain informality, interviewers were encouraged to rephrase the questions where children were unclear about what was being asked. They also followed up children's lines of thought by asking additional questions in as spontaneous a manner as possible. Allowing for a flexible response to clarify as well as probe children's ideas meant that interviews ranged from about 20 minutes to one hour.

Members of the project team visited the schools and talked to children either in the classroom or in an otherwise unoccupied room. Permission to interview children was obtained from parents and/or teachers. The interviews were conducted in an informal manner and every attempt was made to put children as much at ease as possible. In fact, in several classes children were not only willing to express their ideas but also were extremely keen to do so.

2.2.5 *Development of intervention activities*

A second meeting was held with the participating teachers following the completion of the elicitation phase. The meeting was attended by the teachers and university-based researchers. Summaries of children's emerging ideas were considered and possibilities for intervention discussed. Micro-domains which were to become the foci of intervention and teaching and learning activities were explored and selected against the background of children's ideas and curriculum appropriateness.

2.2.6 *Classroom-based Intervention*

The second major classroom-based phase was termed 'intervention'. During the previous phase, teachers had been 'holding back' to encourage children to express their own ideas. In the intervention, teachers offered children experiences which gave them an opportunity to reflect on their ideas, test them out, discuss them and amend, reject or retain them. Several data sources provide evidence of the nature of intervention strategies adopted in each classroom. Teachers were encouraged to record the range of interventions used in their classrooms in journals. Where possible, they indicated how these strategies related to children's initial ideas and the outcomes of such interventions. Teachers were also encouraged to describe those aspects of intervention - such as a class discussion - for which a written report by a child would not be available. University-based researchers visited classrooms during the classroom intervention to collect examples of teaching and learning strategies operating in different classrooms. Field notes and video material were used to record the evidence collected during these visits. A further data source was the actual work completed by children and collected by teachers during the intervention phase. Teachers were asked to collect as much of children's classroom work as possible. Detailed descriptions of the intervention activities are presented in Chapter Five.

2.2.7 Post-Intervention elicitation of children's ideas

Intervention was followed by a post-intervention elicitation using concept probes in a similar manner to that described in the initial elicitation. These concept probes examined a narrower range of themes than in the elicitation and focused in particular on themes addressed during the intervention. Concept probe booklets were developed for children in each of the three Key Stages. Teachers for the most part administered the probes to the whole class. Individual interviews were carried out with the same stratified sub-sample as before (n=118).

2.2.8 Reflection and evaluation

A final meeting attended by teachers and university-based researchers was held following the completion of the classroom-based part of the research. At this meeting, shifts in children's ideas were discussed and obstacles or conceptual struggles which appeared to limit children's progress were identified. Particularly effective teaching strategies were shared. The value of collaborative action-research as a means of professional development was discussed. The limited scope of the intervention and targets for future research in this domain and others, were also recognised.

2.2.9 Data analysis and reporting

Interview responses, field notes of classroom visits, teacher meetings, video recordings and children's work provide a rich data source. Interview data were subjected to a long and detailed scrutiny in order to generate a qualitative set of exhaustive and mutually exclusive response categories. These coding frameworks were checked between team members and a coder was then trained. The interview sample's responses were coded, analysed and summarised. Field notes, children's work and impressions from teachers were the subject of constant comparison during the data collection process and informed the development of each phase of the research. Interpretation of the interview data was informed by some of these insights gained during the research programme.

2.3 Structuring the Research Domain

In the early stages of the SPACE project, a list of concepts was drawn up for each of the topics to be researched. This list was intended to delineate the boundaries within which the work would be carried out. With the advent of a National Curriculum for England and

Wales, the document for Science provided a framework in which concepts for investigation could be identified (DES 1993).

2.3.1 *Division into Themes*

The National Curriculum defines programmes of study (PoS) for different age groups of children. The programmes of study indicate the kinds of experiences to which all children of given age groups are expected to be exposed. That for Key Stage 1 (KS1) is applicable for children up to the school year in which they have their seventh birthday, that for Key Stage 2 (KS2) being applicable for children up to the school year in which they have their eleventh birthday, and that for Key Stage 3 (KS3) being applicable for those children up to the school year in which they have their fourteenth birthday.

Each subject of the National Curriculum is divided into a number of Attainment Targets (ATs). Each target is further subdivided into domains. At the time when this research was planned and carried out, there were four such targets designated for Science. The findings of this report pertain to the domain of Forces within 'AT4 *Physical Processes*' in the Science National Curriculum document

The researchers divided Forces into themes, each of which seemed to reflect a relatively discrete concept area within the domain. This process was informed by the National Curriculum '*Forces and Motion*' P.o.S. and the accumulated research literature which reports children's ideas in Forces.

A wide range of themes was addressed within the elicitation phase. This range was subsequently reduced following the elicitation of ideas. An examination of children's ideas across the themes revealed a range of alternative ideas. In one or two themes, children's understanding seemed to be at some distance from the target concept. In terms of conceptual hierarchies these themes were at the upper end of conceptual progression. It was considered to be more useful to focus on the more foundational themes. It was anticipated that making progress with understanding in these themes might provide a better basis for approaching other themes in subsequent learning episodes.

2.3.2 *Issues Within the Focal Themes*

The following issues were chosen from within themes to form the focus of the research.

a) ***Effects of forces***
What do children count as a force? What do children understand to be the effects of forces? How do children explain the behaviour of stationary and moving objects? What understanding do children have of non-contact forces?

b) ***Gravity***
What understanding do children have of gravity and its effects at a local level and on a planetary scale? To what extent are children able to distinguish between mass and weight?

c) ***Friction and air resistance***
What understanding do children have of friction and its effects? How do children conceptualise air resistance?

d) ***Reaction Forces***
What understanding do children have of reaction forces? Are they aware of such forces in both dynamic and static situations?

e) ***Multiple Forces***
What understanding do children have that more than one force may simultaneously act on an object? Can children recognise and explain the different effects when forces are balanced or unbalanced?

The exact manner in which the compression and reduction of themes occurred will be discussed further in Chapter Four.

3. *LITERATURE REVIEW*

3.0 Introduction

This review broadly outlines research within the domain of forces, an area which has received much interest from constructivist researchers. An initial review of the available research revealed aspects of forces which had received most of researchers' attentions and also showed that research had tended to neglect the developing understanding of younger children. Interest has not focused exclusively on the accumulation of children's ideas but has also begun to consider the ways in which teaching-learning interactions might help promote understanding (Pfundt and Duit 1997). It is possible to discern differences in approaches to the elicitation of children's reasoning adopted by different researchers. The approach adopted by the SPACE project is distinct in many ways since an important aspect of the approach is the ecological validity of the ways of eliciting children's reasoning. That is, that the methods used to establish children's initial understanding are based on the non-directive rationale of the Piagetian individual clinical interview, with the important difference that the probes must be 'classroom viable' or capable of being used by teachers in their normal classroom practices.

The literature review is structured in three main sections:

3.1) summary of research approaches to the elicitation of children's ideas;
3.2) summary of children's ideas;
3.3) teaching strategies

3.1 Summary of research approaches to the elicitation of children's ideas.

The elicitation of children's ideas in schools raises many issues including the practical problems of organising and carrying it out, ethical issues such as gaining permission from school, parents and pupils and methodological issues. While the importance of management and ethical issues are recognised it is the methodological issues which are the focus of this chapter.

The individual clinical interview adopted by Piaget, (1929) has come to be recognised as a powerful tool in the elicitation of children's reasoning in science. Interviews enable researchers to gain access to an individual's understanding of events within different domains. Lythcott and Duschl, (1990) describe a distinction between the clinical interview which relies on verbal data and clinical exploration method which yields data based on what the child does. Current elicitation techniques adopted by researchers often include modifications to the classical clinical interview and often include data gathered using both approaches. Interviews enable the researcher to seek a more elaborated response and clarification of emerging ideas and are generally audio-recorded.

A favoured elicitation method with a long tradition is that of 'interview-about-instances', (Osborne and Gilbert, 1980, Watts, 1982). This technique probes children's understanding by posing open questions about particular instances or problems presented in pictorial form. A development of the interview about instances technique has been adopted by Bliss and Ogborn, 1994. They elicited children's reasoning about motion through comic strip sequences It was considered that comic strips had broad appeal to a wide age range and in addition, probed children's understanding of impossible events.

Another approach is the use of survey methods to gather children's written responses to questions posed in a questionnaire. Surveys tend to comprise closed question items and/or multiple choice items (Halloun and Hestenes, 1985; Kuiper, 1994; Palmer, 1997). Fischbein *et al.*, 1989 used a questionnaire supplemented by individual pupil interview to probe impetus conceptions. Open questions may be used within a pencil and paper format to explore understanding of particular events (Clement, 1982; Eckstein and Shemesh, 1993). Arnold *et al.*, (1995) asked children to represent their ideas about the Earth's shape and gravity in drawings, common features then being categorised and coded.

Encouraging children to handle objects and materials, or to draw on some direct experience is increasingly used to encourage the elicitation of children's ideas (Bar, *et al.*, 1994). Gair and Stancliffe (1988), claimed that encouraging the manipulation of objects provided a non-threatening environment for the expression of ideas. Concerns that researchers' questions might steer children towards particular responses led Hamilton, (1996) to explore children's ideas through peer interview. A paired-interview approach was also adopted by Millar and Kragh, (1994) in their examination of children's explanations of the motion of projectiles.

The approach adopted by the SPACE project is to collaborate with teachers in the elicitation of children's understandings. Teachers encourage the free expression of ideas by posing open questions. The atmosphere created in the classroom is one in which children's ideas are valued as being provisional. The ecological validity of the manner in which children's ideas are elicited is the foundation for researchers' confidence in knowledge claims. Ecological validity is achieved through the development of diagnostic concept probes administered by teachers as an extension of their classroom techniques. An important aspect of such concept probes is that children are not ambushed by a decontextualised challenge. Their thinking is orientated towards the domain through the provision of a practical or familiar experience. Children are encouraged to respond in writing, drawing or orally. Confidence in the knowledge claims associated with data collected in this manner (Lythcott and Duschl, 1990) is further reinforced as university researchers carry out audio-taped individual interviews, with a sub-sample of children from each class. These interviews involve probing further ideas expressed through the concept probes. Researchers display unconditional positive regard for children's expressed ideas. They carefully probe emerging ideas and hesitations in order to gain additional insights into children's understandings. It is argued that the collaborative nature of the research means that that the techniques and sequences adopted within the research correspond to a constructivist teaching and learning sequence (McGuigan and Russell, 1997). The gap between theory and practice is narrowed; research data are centred on an agenda of what is possible in classrooms.

3.2 Summary of children's ideas

The domain of forces has received intense interest from the research community. The accumulated data contrast sharply with the dearth of evidence on pupils' ideas about, for instance, sound. This section briefly outlines the scope of research focusing where possible, on the age groups of the sample in the study presented here. Interested readers are urged to consult the primary sources for more detail. The presentation of the literature review will be structured according the themes adopted in the research reported in this volume. The research documents the range and commonalties in children's understanding and the different ways in which children explain the effects of forces. The situated nature of cognition, is illustrated; researchers frequently report that children do not appear to have a consistently applied set of beliefs about forces and their effects. Their beliefs about individual forces appear to be influenced by the specific instance in which the force is operating as well as the nature of the problem posed (Kuiper, 1994).

Recognition of the context-specific nature of children's understanding is not new (Wason, 1977; Donaldson, 1978). The situated nature of cognition has been more recently examined by Lave, (1995) and Hennessy, (1993). In science, examples of how children's understanding of forces differs in different contexts have been reported in the literature. Halloun and Hestenes, (1985) report that university students were inconsistent in their application of concepts across contexts. Palmer, (1997) reported that 15-16 year olds were more influenced by contexts than pre-service teachers. Engel-Clough and Driver, (1986) suggest that it is in those contexts which, according to the children's frame of reference seem to explore different phenomena that inconsistency in conceptual frameworks are revealed. Reif, (1987) suggests that students tend to invoke 'knowledge fragments' rather than generalised understandings in response to physics problems which leads them to express inconsistent ideas. The suggestion that children tend to apply different ideas in different contexts casts doubt, according to Kuiper, (1994), on suggestions that children operate with coherent but different theories to those advanced in science. Kuiper challenges the idea that children operate with alternative frameworks and suggests instead that children could be understood as operating with a loose set of incoherent ideas. Di Sessa, (1989) suggests children's reasoning is fragmentary, the term 'phenomenological primitives' is used to describe the nature of children's ideas. Millar and Kragh, (1994) attempt to identify some of the factors influencing the use of different reasoning in different contexts. They suggest that familiarity of the context, the weight of the projectile and the assumed action of the wind all influence children's causal explanations about the trajectory followed by a passively dropped projectile. Palmer, (1997) found 15-16 year olds' reasoning to be similarly influenced by context. Whitelock (1991) reports that amongst 7- 16 year olds, the active nature of animate moving objects was a powerful influence on causal explanations.

Other theorists suggest that, while children appear to operate with competing and inconsistent theories, there *are* coherent frameworks underlying their reasoning in the forces domain, (McCloskey, 1983; Ogborn, 1985; Bar *et al.,* 1994; Bliss *et al.,* 1989; Mariani and Ogborn 1991; Gutierrez and Ogborn, 1992; Bliss and Ogborn 1993).

Much of the research on ideas about forces has, in the past, been conducted with adolescents and college students. More recently there has been increased, though less extensive, interest in the conceptualisations of younger children. This research review summarises evidence of students' ideas ranging from four years to adulthood. It is of interest that, while some studies report age-related differences in the application of causal explanations across contexts, (Palmer, 1997) many studies report little age-related progression in causal explanations about different aspects of forces (Andersson, 1990; Sequiera and Leite, 1991; Brown and Clement, 1992; Twigger *et al.*, 1994; McDermott 1984).

3.2.1 Gravitational Force

It is suggested that children tend to conceptualise gravitation as a force which requires a medium through which to travel (Andersson, 1990; Bar *et al.*, 1997). The medium most commonly cited as necessary for gravity is air. Sometimes air is conceptualised as the atmosphere in its entirety, as a single-entity, macroscopic view. Others suggest the single particles which comprise air transmit gravity from one to another (Watts, 1982 in a study with pupils in the 6-12 age range). Belief in the necessity of air as a medium for gravity leads to a number of associated understandings. A corollary of this idea is that where there is no air such as in space, there is no gravity (Watts, 1982; Stead and Osborne, 1980; Osborne *et al.*, 1981; Twigger *et al.*, 1994). Another view associated with the need for air is that there is less or even no gravity in water (Osborne *et al.*, 1981; Stead and Osborne, 1980).

Watts (1982) suggests that pupils in the 12-18 age range regard gravity as a constant and that moving objects try and fail to counteract its effects. McCloskey (1983) reports some understanding in his students that gravity can act as a ball moves upwards. Students' understanding of the trajectory of the ball included a view that, as the ball moves upwards the impetus force dissipates and gravity takes over; as the ball peaks, gravity and impetus force are regarded as equal; as the ball falls, gravity takes over. Indeed, Clement (1982) found that only one third of university physics students correctly represented gravity as the only force other than air resistance on an object moving upwards. The situated nature of children's understanding of gravity is suggested by the seemingly inconsistent ideas held. Many children regard gravity as selective in its operation and effects. There is a tendency to explain that it doesn't act on all things in the same way or even on the same things in the same way at all times (Watts, 1982). Items frequently associated with having gravity are heavy, inert things such as heavy boots. Lively, active objects are more likely to be assumed to counteract gravity. The speed of an object is often found to be assumed to influence the amount of gravity operating upon it. Watts (1982) found that the effects of gravity are believed to be greater when an object moves more slowly.

Some research point to a lack of awareness (or use) of the concept of gravitational force in explaining objects motion. Gilbert *et al.*, (1982), in a study of students between 7 and 20 years, reported a failure to suggest gravity acting on a ball moving downwards in favour of the idea that the ball moved freely. This is consistent with Piaget (1929) who also recorded children not using gravity in their explanations. The absence of gravity in some responses may be due to a widely held view that unsupported objects fall (Ogborn, 1985; Bliss, 1989; Vosnaidou and Brewer, 1992 and 1994; Eckstein and Shemesh, 1993). Reyneso *et al.*, (1993) found that eight and nine year olds found it sufficient to reason that objects fall 'downwards' while ten year olds suggested that objects fall to Earth because of gravity and float on the moon because of an absence of gravity. Gravity tends to be associated with downward motion. It is described as a force that 'pulls things down' or something that 'keeps objects down' or something that 'stops them floating away' (Bliss *et al.*, 1989; Bar *et al.*, 1997). No pupils in Bar's sample of 9 to 18 year olds expressed a view that gravitational forces act between two masses. There is evidence that some pupils consider it to be an upwards force and that it can be conceptualised as a push (Osborne *et al.*, 1981). A study Watts (1982) identified the belief that gravity begins to act when an object is falling towards the ground and stops acting when an object comes to rest on the ground. (Participants in Watts' study claimed that a golf ball was acted upon by gravity as it was falling but that gravity ceased acting when the golf ball came to rest). In contrast, Twigger *et al.*, (1994) report that 88 per cent of children aged 10-15 years suggested that gravity operated all the time. (There may be some changes in the pattern of responses towards an increased awareness of gravity as a result of National Curriculum in England).

Bar *et al., (op.cit.)* report an age-related trend in explanations of why objects fall. Young children hold the view that objects fall because they are *unsupported* (4-7 years). This idea persists and combines with causal explanations that the *heaviness* of objects causes them to fall (7-9 years) and later with an emergent idea of the Earth's attractive force (9-13 years). Arnold *et al.*, (1995) probed children's understanding of the Earth's shape and gravity (7-11years). They found that the majority (96 per cent) of children recognised the Earth as spherical but while they reasoned that gravity acted 'downwards' they failed to demonstrate any understanding that gravity acts towards the centre of the Earth.

Quantification of forces is an important aspect of developing understanding. While there is a paucity of evidence about children's understanding of quantification of forces, there is some evidence (Watts 1982) that children understand gravity to be a large force. According to Watts, gravity is conceptualised as a large force because it keeps so many objects on the ground. Children fail to appreciate that the size of gravity is related to the quantity of matter of two objects and the distance between them. A commonly expressed view is that at a local level rather than at an astronomical level, the magnitude of gravitational force changes according to changes in the height of the object above the ground. Furthermore, in this view, gravity increases as an object moves higher (Watts and Zylberstajn, 1981). Those holding this view might suggest that objects higher up would need more force to support them. For instance, a car situated higher up a hill would require more force to support it (Watts and Zylberstajn, 1981; Watts, 1982; Osborne *et al.*, 1981). Suggestions that gravitational force increases as objects move further apart are contrary to Newton's law that gravitational force decreases as the distance between objects increases. Conventional explanations usually treat gravity at a local level (i.e. on the surface of the Earth) as a constant force, while children often treat is as variable.

The science community is equivocal as to whether gravity and weight should be conceptualised as different phenomena. The accumulating research evidence presents a picture of children's understanding of the relationships between gravity, weight and mass. Children tend to distinguish between gravity and weight (Ruggiero *et al.*, 1985). They tend to believe gravity is not closely connected with weight but acts *with* weight to hold things down. Osborne *et al.*, (1981) examined the understanding of students between nine years and tertiary level, some of whom expressed the belief that it is possible to have weight without gravity. Weight is an attribute of an object (Ruggiero *op.cit.*) while gravity is associated with *movement downwards.* (Watts, 1982). Ruggiero *et al., (op.cit.)* explored the ideas of children in the age range 12-13 years about falling objects. They report three kinds of explanations. Firstly recognition of the role of gravity which operates on the weight of objects causing them to fall. Secondly, suggestions that weight and gravity *independently* cause objects to fall. Thirdly, explanations in which fall is due to the absence of support, and where weight and gravity are kept separate. Galili (1993) and Galili and Kaplan (1996) argue that it might be useful to encourage children to define gravity and weight as separate concepts. They suggest an approach which encourages a definition of weight as a force against a support, which can be distinguished from gravity. Bar *et al.,* (1994) probed children's (4-13 years) understanding of weight. Some of the everyday understandings of heaviness they gathered are consistent with other research, including an idea that heavy things exert a force on supporting objects (Minstrell, 1982).

Further confusions emerge when children's appreciation of the distinction between mass and weight are probed. Mullet (1990) records that, regardless of age, *weight* and *mass* tend to be conceptualised as weight, whereas, the *amount of matter* a thing is made of is related to the concept of *mass.* According to Mullet, difficulties in appreciating the distinction between mass and weight are exacerbated by everyday conceptualisations of weight and a tendency to use weight and mass interchangeably It is argued that weight is used in everyday operations when mass is being considered. Furthermore, in an everyday sense, mass can have several meanings - a mass of people or a church service. The substitution of the phrase *amount of matter* for the term mass seems to be of some value in helping students conceptualise the distinction between mass and weight.

3.2.2 Friction

Osborne *et al.,* (1981) examined children's ideas about friction using illustrated cards and interviews about these instances. They found that more than half of children in their sample associated friction with rubbing two surfaces together. As a consequence, friction was commonly associated with heat energy. A second group of ideas was to associate friction with movement. From this view point, no movement meant no friction. A third view expressed by a few students was that friction *was* the movement. A fourth view tended to consider friction as a force. Some responses suggested that friction is a force between two objects. Friction tended to be associated with solid objects although a limited number of children believed friction could occur with liquids. The possibility of friction occurring in air was often rejected.

Twigger *et al.,* (1994) explored children's understanding (in the age range 10-15 years) of friction through several hands-on tasks coupled with interview. The idea of friction seemed to feature in children's explanations at around 11 to 12 years. Their recognition of the role of friction in slowing movement of objects varied according to the context of the task. In the context of brakes being applied to a cycle only 31 per cent mentioned friction as a force. In contrast, in the context of a child kicking a pebble, 61 per cent referred to friction. When interviewed about a railway carriage slowing down or coming to a stop 94 per cent suggested friction, or air resistance (42 per cent). In the context of riding a bicycle 85 per cent mentioned air resistance as a opposing force and 77 per cent mentioned gravity. The increased mention of air resistance in the context of riding a bicycle was thought to be associated with personal experience of air resistance when riding. Detailed probing of children's ideas suggested to Twigger *et al.*, that, in most cases, there was a suggestion that even without friction or air resistance, objects would still come to a stop because the push would be used up. Even when children mentioned friction as a force they tended not to regard it as a force opposing motion. This latter view was reported by Stead and Osborne (1980).

3.2.3 Balanced and unbalanced forces

Twigger *et al.*, (1994) explored children's understanding of forces in instances when objects were moving at steady speeds and when they were accelerating. They found children tended not to recognise the relevant forces acting and often included additional irrelevant forces. Children were largely unaware of the correct relationship between forces. They found a widespread assumption that a constant force was needed to maintain motion accompanied by a belief that the forwards or driving force must be *greater* than any resistance in order for the object to be moving. Ninety-seven per cent thought that if these forces were equal then the object would stop. There was no age-related trend apparent in these explanations. A further task probed children's predictions of what would happen to a wheeled vehicle (a cart) being pulled with a constant force. All the students predicted that the cart would move at a constant speed. Over one quarter of the sample could not explain their observations of the accelerating cart, over half disbelieved that an elastic band was exerting a constant pulling force and incomplete explanations were offered by almost one fifth of children. Similar results were obtained in the context of riding a bicycle on level ground. Nearly all children equated a constant force applied by pedalling with constant speed. Most believed that if the forces were equal the bike would stop. Children's ideas about unbalanced forces were probed by asking them to consider the forces involved when the movement of an object was steadily increasing. All the children explained that a steadily increasing force would need to be applied. Thijs (1992) in a summary of children's ideas about motion, suggested that students' tendency to associate continuing movement with continuing force leads to several associated ideas. One of these is the belief that an *increasing* velocity needs an *increasing* force applied in the same direction as the movement.

3.2.4 Reaction forces.

Erickson and Hobbs (1978) found a tendency amongst a sample of 13-14 year olds not to appreciate that forces act in pairs and as a consequence, a lack of appreciation of reaction forces. Contrary to conventional science explanations, Brown and Clement (1987) report that High school children's reasoning about a collision between two objects led them to assume that the force on each of the two colliding objects was not equal. It was often assumed that the impact of the faster moving of two objects in collision would be greater. The idea of two forces interacting with each other is made difficult because of the language of *reaction* or *opposite* in the context of paired forces. According to Terry *et al.*, (1985) reaction conveys a sequence of events in which one force leads to a second. The word *opposite,* it is argued, suggests to some pupils that the action and reaction forces both act on the same object, simultaneously.

The idea that a push can be exerted by an inanimate, solid object like a table or a chair is according to Minstrell (1982) counter-intuitive. He found students invoked gravity as the explanatory concept to explain how a book is kept down on the table. Some students suggested that air or air pressure helped gravity. Only about half of these high school physics students suggested that the table might exert an upwards push on the book. Of those who cited a combination of forces, most believed that the downward push must be greater than the upward push in order to keep the book down. Simon *et al.,* (1994) noted a similar range of responses when they posed a similar problem with children citing single forces either down or up and occasionally suggesting a combination of forces. Other research has recorded children's tendency to regard gravity as the only force operating when objects are at rest (Kuiper, 1994; Twigger *et al.,* 1994). Gilbert and Watts (1983) identify a conceptual framework that 'no forces act on an object at rest'. However, Finegold and Gorsky (1991) found limited support for suggestions that no forces act on objects at rest. Only nine per cent of students consistently applied this belief across contexts and following teaching, the belief was no longer elicited.

3.2.5 Forces and their effects

Children's understanding of force is often associated with everyday usage of the term 'force'. For instance, everyday interpretations lead children to associate force with compulsion. As a result children might include the idea of being 'forced' to do something in their definitions (Osborne *et al.,* 1981; Gilbert *et al.,* 1982; Gair and Stancliffe, 1988). Gair and Stancliffe propose three frameworks in which children at age 11 years understand forces, ranging from an everyday interpretation of forces to an appreciation of forces as pushes and pulls.

Several researchers report the prevalence of a belief that movement implies a force and that an object requires a constant force to sustain its movement. (Galili and Bar 1992, with subjects aged 15 to adult, Bliss *et al.,* 1994; Champagne *et al.,* 1980; Osborne 1981 with 15 year olds; Watts, 1983; Enderstein and Spargo, 1996; Palmer, 1997) Researchers document a widespread belief in the idea of *impetus* as a force which keeps an object moving until it runs out or is used up (Schollum *et al.,* 1981; Watts and Zylberstajn, 1981; Clement, 1982). It has been suggested that the idea of an 'impetus' has parallels in the history of science, for instance, in the pre-Newtonian ideas of Aristotle (Champagne *et al.,* 1980) McCloskey (1983b,1988) argues that there is a distinction between Aristotle's ideas of an external force such as air which keeps an object moving and the later impetus theorists who believed an internal force was imparted to an object as it was released. Eckstein and Kozhevnikov (1997) conducted a large study of children in grades 3 to 12 and were able to discern three groups of responses which parallel historical ideas.

Two thirds of high school physics students believed a force is transferred from one object to another during impact (Steinberg *et al.,* 1990). An object is understood to acquire a force as it is released or projected and this force dissipates as the object moves along (Viennot, 1979; McCloskey *et al.,* 1983a, 1983b, 1988; Gilbert *et al.,* 1982). McCloskey suggests that the idea of an impetus force is associated with early experiences of objects starting moving and slowing down. Galili and Bar (1992) note the instability of conceptual change indicated by the regression to impetus theories following instruction. Indeed, research indicates the enduring nature of beliefs that a force continues to act in the direction of movement. It seems that this view prevails even amongst large numbers of students following physics instruction at the tertiary level (Palmer, 1997; Clement, 1982).

3.2.6 Momentum

Eckstein and Shemesh (1989) examined 9-16 year old students' reasoning about momentum. They found no age-related differences in children's causal explanations of where the ball released from a moving cart would fall. Children tended not to appreciate the continued forward movement of the ball, suggesting instead the ball would move straight down. Analysis of casual explanations revealed both intuitive and logical reasoning which was consistent from grade to grade. Fischbein *et al.,* (1989) noted that tenth graders gave 'straight down' responses for an object released by a moving carrier. Fischbein suggests that students are more willing to suggest continued forward movement in an *active* motion instance than in instances of *passive* motion.

Millar and Kragh (1994) investigated 11 year old children's understanding of inertia. They found that explanations of the movement of a passively thrown projectile from a moving car rarely indicated that the projectile continued its forward movement. On the other hand, there was some preparedness to suggest forward movement of a paper dart (not thrown, but released by a runner). Graham and Berry (1996) found only 14 per cent of students aged 16-19 years demonstrated a good understanding of momentum. McCloskey (1983a, 1983b) and McCloskey *et al* (1983) found only 45 per cent of college students reasoned that a passively released ball would continue its forward movement once it had left the hand.

3.3 Teaching strategies

The difficulties in helping children develop their ideas towards those more consistent with conventional science explanations is well documented (Gilbert *et al.,* 1982; Thijs and Van Den Berg, 1994). Bliss *et al.,* (1994), recognising the counter-intuitive nature of science explanations of forces, argue that striving for replacement of children's reasoning with a Newtonian view of force and motion is problematic because children's reasoning are developed from very early intuitions about causes of movement, yet in Newtonian physics, constant motion does not have a cause or require effort. Despite these difficulties there has been some examination of how children's understanding might be enhanced. Some studies report successful attempts to promote conceptual development in forces in a classroom setting. Some have explored particular teaching strategies whereas others suggest particular curriculum sequences. A few make recommendations for practice based on evidence of children's difficulties. Scott *et al.,* (1983) review teaching strategies within a constructivist approach and suggest that the range of approaches can be divided into two broad groups: those that focus on provoking cognitive conflict and those which take children's ideas and aim to encourage some development in those ideas. Schollum *et al.,* (1981) present a teaching programme which takes children's ideas as a starting point. This teaching-learning sequence comprises direct experiences and worksheets in which children's understanding is probed. The programme is structured so that firstly, children and their teacher became aware of the prevailing ideas in the classroom. A series of tasks are then suggested which aim to help children develop some key ideas. The first builds on children's intuitive idea of an impetus 'force' by labelling what is believed to be a force as 'momentum'. Further examination of the difference between force and momentum is followed by exploration of the effects of forces in combination. There have been other attempts to derive teaching sequences as a result of research into conceptions (Thijs, 1992; Dykstra *et al.*, 1992; Minstrell, 1982; Millar and Kragh, 1994).

Palmer (1997) suggests that teachers should endeavour to examine with children the different contexts in which a particular instance of a concept applies. In this way, children might be encouraged to generalise their understanding of a concept to new, unfamiliar instances in which the concept occurs. Champagne *et al.*, (1985) recommend provoking cognitive conflict by introducing discrepant ideas and events which can encourage reconsideration of existing conceptions and the construction of new understandings. Dykstra (1991) agrees with the need to provide children with events or ideas which challenge their existing ideas. According to this view, children should be encouraged to question their beliefs and recognise the inconsistency between competing explanations. Dykstra points to the limitations of provoking cognitive conflict and then adopting a transmission model of teaching. He describes how, once disequilibration is stimulated, teaching needs to be sensitive to the individual construction of meaning by encouraging children to put their own ideas to the test.

A teaching strategy which has attracted a large amount of research interest has been the role of analogies in the development of pupils' understanding. (Brown, 1994; Dagher, 1994; Clement *et al.*, 1989). The debate has centred on the nature of analogies and their use in the classroom. The contribution of analogies to children's learning is not straight-forward. Duit (1991) describes how analogies might help students make links between abstract concepts and the real world. However, children may make unintended links and may not recognise the limitations of an analogy. Treagust *et al.*, (1992) examined the practice of teachers who indicated analogies were a frequently used part of their teaching repertoire. They report that analogies were effective in promoting understanding when teachers used them as part of a well prepared teaching repertoire and when there was a teacher expectation that children would construct an understanding rather than passively receive the teacher's analogy. Bridging analogies which attempt to provide children with connections between existing beliefs and the target instance of a concept have been explored, Brown and Clement (1992). Brown (1994) examined closely pupils' interactions with analogies designed to help them appreciate the upward force of a table on a book. They found that analogous instances helped children towards an appreciation that the table exerts an upward force on the book. Analogies were found to be less helpful in helping children towards the abstraction that the upward force balances the downward force of the book. One of the outcomes of research, by Thijs and Bosch (1995) was that bridging analogies were found out to be successful in helping children to develop their ideas in the direction of conventional scientific understanding.

The exploitation of direct experiences has been readily incorporated into teachers' repertoires of practice and has recently attracted some research interest. Hatano and Inagaki (1992) suggest direct experiences make a positive contribution to children's learning. Thijs (1992) reports some changes in pupils' conceptions about motion as a result of direct experiences and opportunities for discussion. The link between direct experiences and discussion is an important one, for it ensures that children are not simply engaged in the physical manipulation of materials but are also encouraged to engage intellectually with the evidence of concepts informed by direct experiences.

Encouraging metacognition has increasingly being advocated as a mode of promoting conceptual change. Researchers (White and Mitchell, 1994; Kuhn, (1995) report that students can be encouraged, during discussion, to consider the content of their knowledge and the processes or strategies they employ in order to gain that knowledge.

In 1985, Gilbert and Zylberstajn suggested that constructivist teaching should make reference to the historical development of science ideas, especially in those areas such as impetus theories for which parallels could be found between children's ideas and the ideas held by conventional scientists. Reference to the historical development of ideas is also recommended as one approach by McCloskey and Kargon (1988).

4. ESTABLISHING CHILDREN'S IDEAS

4.0 Introduction

Previously published reports in this series have documented pupils' ideas prior to intervention. This report differs in this regard, the frequencies with which ideas occurred prior to and subsequent to intervention being reported in Chapter Six. There are several reasons for this difference in reporting structure. Primarily, the large volume of data collected across a broad range of sub-domains has made selection of a sub-set of results for publication essential. This chapter describes the National Curriculum agenda which was the starting point (though not a limiting factor). It also outlines the manner in which the concept probes were structured. The outcomes of the programme of research are presented in Chapter Six, following a review of intervention activities in Chapter Five.

4.1 Scientific content

As indicated in Chapter One the introduction of a National Curriculum had significant implications for teachers across all domains of science. Many felt that they were inadequately prepared for the new demands being made. Eight years later and the domain of forces in particular continues to give rise to considerable concern. The Programmes of Study headed 'Forces and motion' in the three Key Stages currently are as follows:-

Pupils should be taught:

at Key Stage 1:

- *a) to describe the movement of familiar things;*
- *b) that both pushes and pulls are examples of forces;*
- *c) that forces can make things speed up, slow down or change direction;*
- *d) that forces can change the shape of objects.*

at Key Stage 2:

- *a) that there are forces of attraction and repulsion between magnets, and forces of attraction between magnets and magnetic materials;*
- *b) that objects have weight because of the gravitational attraction between them and the Earth;*
- *c) about friction, including air resistance, as a force which slows moving objects;*
- *d) that when springs and elastic bands are stretched they exert a force on what ever is stretching them;*
- *e) that when springs are compressed they exert a force on whatever is compressing them;*
- *f) that forces act in particular directions;*
- *g) that forces on an object can balance, and that when this happens an object at rest stays still;*

h) that unbalanced forces can make things speed up, slow down or change direction.

at Key Stage 3:

a) how to determine the speed of a moving object;
b) the quantitative relationship between speed, distance and time;
c) that unbalanced forces change the speed and/or direction of moving objects;
d) that balanced forces produce no change in the movement of an object;
e) ways in which frictional forces, including air resistance, affect motion;
f) that forces can cause objects to turn about a pivot;
g) the principle of moments and its application to situations involving one pivot;
h) the quantitative relationship between the force acting normally per unit area on a surface and the pressure on that surface;
g) some applications of this relationship.

For the most part these Programmes of Study delimited the range and depth of the research reported in this volume. However, the apparent assertion implicit in the programmes that a particular concept should be taught at a particular Key Stage, and not earlier, did not necessarily exclude that concept from the research with younger children. It was considered that, in some instances, attempts to gain a knowledge of children's earliest conceptions would be worthwhile because it would consolidate understanding of progression in their thinking.

Additional insights into the National Curriculum's assumptions about progression within the Forces domain can be gained from the formal descriptions of the 'Levels' of pupil attainment. The relevant extracts are:

Level 1 - Pupils describe the changes in movement which result from actions such as pushing and pulling objects.

Level 2 - They compare the movement of different objects in terms of speed or direction.

Level 3 - Pupils use their knowledge and understanding to link cause and effect in simple explanations of physical phenomena, such as the direction or speed of movement of an object changing because of a force applied to it.

Level 4 - They make generalisations about physical phenomena, such as motion being affected by forces, including gravitational attraction, magnetic attraction and friction.

Level 5 - They begin to use some abstract ideas in descriptions, such as forces being balanced when an object is stationary.

Level 6 - They use abstract ideas in descriptions and explanations, such as the sum of several forces determining changes in the direction or the speed of movement of an object.

Level 7 - They use some quantitative definitions, such as those for speed or pressure, and perform calculations involving physical quantities, using the correct units. They apply *abstract ideas in explanations of a range of physical phenomena, such as the role of gravitational attraction in determining the motion of bodies in the solar system.*

Level 8 - They use quantitative relationships between physical quantities in calculations that may involve more than one step. They offer detailed and sometimes quantitative interpretations of graphs, such as speed-time graphs. They use their knowledge of physical processes to explain patterns that they find.

It is clear that these Level descriptions do not cover comprehensively the Forces content of the Programmes of Study. The possible progressions in pupils' understanding within each of the strands of this domain are, therefore, in need of exploration by both teachers and researchers.

Additionally, it was not thought prudent to be totally constrained by the content of the current National Curriculum as if it were the last word on the subject. In consequence, consideration was also given to other problematic aspects of 'Forces' gleaned from the literature review outlined in the previous chapter. At the initial exploration phase the net was deliberately cast wide in order to maximise the possibility of capturing insights into children's formative understandings across a broad sweep of the Forces domain.

With this principle in mind the activities and associated questioning covered children's understanding of the following areas.

Vocabulary
the scientific meaning of the word 'force'.

Force and Motion
changes in movement necessitating a force;
static situations requiring the forces to be balanced;
unbalanced forces resulting in acceleration;
constant speed requiring the forces to be balanced;
the qualitative relationship between force, mass and movement.

Friction and air resistance
the effects of friction and air resistance on movement;
the effect of speed on air resistance.

Deformation effects
the deformation effects of forces.

Forces which act at a distance
forces which act without contact - magnetic, electrical and gravitational;
the effect of distance on these non-contact forces;
the nature of gravity;
the effects of gravity on the movement of objects;
the concepts of mass and weight.

Reaction forces
reaction forces.

Upthrust, density and pressure
upthrust in liquids and gases;
the link between upthrust and density and pressure differences.

Measuring forces
methods and units of the measurement of forces.

Arrow conventions
the conventional representation of forces using arrows.

Pressure
the concept of pressure.

Turning effects
the turning effect of forces in situations involving a pivot.

Multiple interacting forces
events in which several forces act enabling pupils to predict outcomes.

4.2 Orientation and elicitation activities

The philosophy underpinning the research was that this science content should be accessed through children's expressions of their understanding of their everyday experiences. Where possible the probes used were introduced by the teachers with practical activities aimed at enabling children to focus on the understandings generated by these experiences.

The initial meeting between participating teachers and researchers concentrated on developing a number of activities which would provide adequate coverage of the science content but, nevertheless, be manageable within the resource and time constraints pertaining. In view of the wide age-range of the children to be involved it was recognised even at this early stage that it would be necessary to tailor the probes for two groupings: one for Reception and KS1 children and one for children at KS2 and KS3. Furthermore, it was agreed that individual teachers would yet more finely tune the probes to suit the children in their classes. Assistance with communicating understanding, for example, would be made available to those with limited ability in this regard. The resulting clustering of probes around activities is outlined below.

Types of force

This activity provided the children with an opportunity to indicate their understanding of the word 'force'. They were asked to write or draw examples of forces, indicate the effect of each force and describe how the force achieves this effect.

Wheels

The starting point for this cluster of probes was the children's experience of riding a bicycle. They were asked to describe what they had to do to start a bicycle moving and then to keep it moving at a constant speed thus demonstrating their understanding of the role of force in changing movement, of friction and air resistance in slowing movement and of balanced forces. For KS2 and KS3 children only, the conventional use of arrows to represent the forces on the bicycle was also explored.

The concepts of inertia and momentum were considered in two further questions about car travel. One asked for explanations of the effect on passengers of sudden braking and the other for predictions of the path of a can dropped out of a window.

Children's ideas about reaction forces were elicited by a question concerning two children on roller skates and for KS2 and KS3 only a further question explored their understanding of acceleration resulting from unbalanced forces acting on a school bus.

Measuring

This cluster contained questions based on activities using objects of different mass, a top-pan balance and a force-meter. Children's ideas about the magnitude of forces and the unit in which force is measured were sought. The opportunity was also taken to gain insights into their ideas about reaction forces using the direct experiences of holding objects on an out-stretched hand and of pushing down on a balance.

Children at KS2 and KS3 were also asked to compare weights in newtons with 'weights' marked on packets of grocery items and hence demonstrate understanding of the difference between mass and weight.

Floating and sinking

The basic activity for this probe involved a tank of water and a plastic bottle so weighted that it floated upright. Explanations in terms of forces were sought. KS2 and KS3 children were also asked to explain the apparent loss in weight of a stone immersed in water and to account for the fact that an object which sank in tap water floated in salt solution. Understandings of balanced forces and upthrust were thus elicited.

Helium-filled balloon

Children investigated the movement of a helium-filled party balloon and were then invited to explain why it moved in such ways. Small masses were then added to the balloon until it ceased to move vertically. Children's explanations in terms of forces for the horizontal changes in movement were recorded. Links with understandings in the floating and sinking activity were sought.

Magnets

Children's ideas about non-contact forces were probed in several contexts. In the magnet activity children were asked to explain an arrangement in which a tethered paper clip was held in mid-air by a magnet clamped to the underside of a chair. They were also questioned as to the reason why two magnets aligned side-by-side on a table repelled each other for a few centimetres only. These activities had the potential for the exploration of understanding of the effect of distance on non-contact forces, unbalanced forces and movement, friction as a stopping force and balanced forces in static situations.

Comb and paper

The effect of a rubbed comb on small pieces of paper was investigated by the children. They were then invited to account for the behaviour of the paper in terms the forces causing the movement.

Tennis ball

For this whole-class activity the teacher threw a tennis ball into the air and caught it as it fell. The children were asked to describe the forces on the ball at various positions during its flight. The responses provided evidence of impetus misconceptions, notions of gravity and of air resistance. The teacher threw the ball into the air for a second time, letting it bounce on the table before catching it. The children then drew their understanding of the effects on the ball of hitting the table. Ideas of deformation and of reaction forces were revealed.

Astronauts

A number of questions were posed in the popular context of space travel. This enabled children to display their understandings of gravity, air resistance and the qualitative link between force, mass and movement. KS2 and KS3 children were also given an opportunity to show their appreciation that, in the absence of frictional forces, no force is required to keep an object moving at a constant speed.

In addition to the above, children in Key Stage 2 and Key Stage 3 classes were given a number of pencil and paper questions that were not initiated by an activity. These questions were used to explore a range of aspects not adequately dealt with previously. These aspects included gravity in various situations, pressure, friction, terminal velocity of falling bodies, the magnitude of the newton and the arrow representation of forces.

4.3 Interviewing

The interviews carried out by the researchers of a sample (see Chapter 2) of the children across the three Key Stages used the responses to the above probes as the basis for discussion. The written or drawn annotated responses were used as a focus in each case for the elicitation of more detailed explanations from individual children. Although teachers discouraged 'don't know' type responses to the initial elicitation, a few children remained reticent. The interviews provided additional opportunities to encourage these children to articulate their understanding. Inevitably for some children the interview was a chance for them to rethink and modifications of their ideas compared to their initial expression emerged. This was not a problem in terms of data collection as it was their current thinking which was recorded for analysis.

4.4 Role of the teachers

The participating teachers were enthusiastic about the activities and elicitation probes and readily accommodated them within their teaching schedules. However, a much more difficult problem was the need to exercise considerable discipline over their professional urge to help the children develop their responses whenever they were perceived to be deficient in some way. Teachers feel a tension when pupils express ideas which are 'incorrect.'

4.5 Limitations on content at intervention

Not all of the aspects of the Forces domain explored at elicitation were carried through to the intervention phase. Some, such as pressure, density, and electrostatic forces, were found to be so far removed from the children's understandings that to pursue them would have been profitless. Others were unfortunately axed by considerations of school resources or of the available time. Even for those for which intervention activities were developed, constraints of classroom and laboratory management and the schemes of work in operation at the time led inevitably to less than complete coverage.

5. INTERVENTION

5.0 Introduction

The term 'intervention' is used to describe all those activities to which pupils are exposed with the aim of helping them to develop their ideas; it is a word which encompasses a range of activities as broad as the imaginations of those who invent or introduce them. It is certainly not the intention to convey the idea of intervention as it is used in the experimental paradigm, i.e. a controlled, standardised procedure. The form of intervention used in this research was imaginative and iterative, responsive to children's ideas. It was exploratory rather than very tightly pre-programmed.

5.1 Planning for intervention

Prior to the intervention, the university-based research team was able to make a preliminary survey of the ideas offered by children during the initial elicitation phase. This interim review, prior to the full data analysis, was based on insights gained during individual pupil interviews, observations of children's responses to classroom based work during the elicitation, preliminary review of children's responses to the concept probes and conversations with teachers during this phase. This survey provided a framework on which the intervention could be built. Outcomes of the survey provided a basis for the second meeting with Project teachers in which plans for intervention were further developed.

Intervention is a phase in which teachers help children transform or develop their understanding. Teachers respond to children's ideas with additional activities, the intention of which is to help children develop their ideas further. To do this teachers have to be aware of:

children's starting points,
directions in which learning might proceed,
a range of teaching and learning strategies,
domain-specific subject knowledge.

At the second research group meeting teachers expressed concerns in each of these four areas. In response, they were provided by the university-based researchers with an intervention booklet which addressed these four elements. The booklets comprised individual planning grids each dedicated to sub-themes or micro-domains. The planning grids described: i) children's conceptual difficulties; ii) a hypothesised description of the likely direction of conceptual development; and iii) an indication of possible intervention strategies. Teachers were encouraged to check the descriptions of children's beliefs against ideas held by children in their own classroom. To assist them in this process, the relevant concept probes used during the elicitation were referenced as a source to which teachers could return for evidence of their pupils' ideas. An important feature of these intervention booklets was that they attempted to make explicit the link between children's ideas and possible intervention activities. The inclusion of additional material to help teachers to develop their own understanding of the domain resulted in a comprehensive intervention booklet.

There was no expectation that teachers should address all the sub-themes identified for possible intervention, or that they should address all the activities within a sub-theme. Indeed, teachers were discouraged from attempting to implement all the possibilities described in the booklet in their entirety. It was important that teachers crafted the intervention to suit the needs and interests of their pupils. Teachers were exhorted to use children's ideas to determine starting points and it was for teachers to judge the point at which to halt the intervention. To assist them in their judgements of appropriate starting points, indications of National Curriculum levels were attached to a description of the anticipated course of conceptual progression which had been outlined in the Booklet. In order to help teachers with the issue of sequencing learning, the five sub-themes were presented in a hypothetical order of intellectual demand. To provide additional support, these five areas were linked to one or more of the three Key Stages. Within these broad indications of Key Stage appropriateness teachers were invited to air their own judgement in the selection of particular sub-themes as foci for the intervention.

5.2 Division of intervention into sub-themes or micro-domains

The brief review of children's ideas provided insights into possible starting points for intervention. The resulting clustering of ideas also formed the basis for structuring the intervention. Five areas in which children's ideas might be most profitably developed were identified. These were:

Forces and their effects on movement;
gravitational force;
friction and air resistance;
reaction forces;
multiple forces, balanced and unbalanced.

5.2.1 Forces and their effects

Firstly, it was anticipated that children would benefit from help in refining their ideas as to what counts as a force, together with an attempt to extend their understanding of the effects of forces. Children across the three Key Stages showed limited understanding of what counts as a force. At the same time they expressed limited understanding of the *effects* of forces. There was little appreciation amongst younger children that forces start things moving. Across Key Stages 1, 2 and 3 there was little awareness that forces are essential to slowing down, or stopping movement. The effects of forces on changing the shape of materials tended not to be appreciated. Children's experience of the quantification of forces was probed at Key Stages 2 and 3. On the whole, these children did not appreciate that forces could be quantified and measured in newtons. They seemed not to understand that changes in the direction of movement are not possible without a force, or, forces being applied. There was no obvious appreciation of the effects of turning forces on movement, or of the concept of pressure.

Intervention focused on what counts as a force and the effects of forces on objects. Key Stage 1 children explored whole body movements to extend their understanding of forces as pushes and pulls and to resolve confusions which had become apparent amongst this age group between a push and a pull. The introduction of sequencing forces according to estimations of magnitude and non-standard measurement of forces was thought to represent a useful preparation for more formal quantification. Key Stage 2 and 3 children also considered what counts as a force but extended this work to carry out some practical measurement of forces using force-meters. These ideas were developed further by considering different sized forces and their effects.

5.2.2 Gravitational force

The second area of development was that of children's understanding of gravitational force. The term 'gravity' was used by some children in Key Stages 2 and 3, but not always appropriately. Their explanations of gravity seemed to be extremely context-sensitive with different instances provoking differing explanations. Children sometimes appeared to hold more than one, often inconsistent, notion of how gravity works, suggesting for example that it can both push and pull objects down. Most had a localised, ground-centred, or Earth-centred view of gravity suggesting that it operated on Earth but was not operating in space, or more specifically not operating on the Moon. Children at Key Stage 2 and Key Stage 3 draw on their everyday experience of weight and frequently distinguished between gravity and weight identifying them as separate phenomena. Few associated gravity with the mass of objects. It was therefore of interest to see whether intervention might help children develop more helpful explanations of the *nature* of gravity which would enable them explain the *effects* of gravity in different contexts.

5.2.3 Friction and air resistance

A third area for development was children's understanding of friction and air resistance. Children demonstrated confused use of both terms. Friction was often associated with objects such as handlebars, pedals, or wheels of bikes and buses. However its precise role in the movement of these objects was less clear. While many children suggested friction was synonymous with 'grip', fewer were aware that it slows down movement, or that it can occur if there is no movement of one object relative to another. Children's understanding of air resistance was often confused by their everyday experience of wind moving. Their use of the term 'wind resistance' seemed to constrain appreciation of the nature of the resistance due to movement through static air. Intervention used empirical investigations of the effects of air resistance and friction to raise children's awareness of the effects of these forces.

5.2.4 Reaction forces

A fourth area of intervention was children's understanding of reaction forces. While children cited numerous forces in different contexts, most focused on separate forces rather than forces in pairs. Intervention through empirical investigations, direct experiences, social challenges and bridging analogies aimed to help children to understand the behaviour and effects of reaction forces.

5.2.5 *Multiple forces*

The fifth cluster of ideas upon which intervention focused was children's understanding of multiple forces and their effects. Children across Key Stages 2 and 3 could cite numerous forces operating in different instances. Most were able to suggest that more than one force could operate on an object at a particular time. However, the effects of these forces were often considered separately. Their effects in combination were rarely appreciated. The concept of balanced forces on stationary objects was not well understood and was often conceptualised as a resolution of a physical struggle, the stronger force overcoming the weaker, rather than in terms of equivalence of magnitude of forces. A similar explanation was often offered to explain the movement of objects. The upward movement of objects might be explained in terms of the *lightness* of the object, or of the upward force *overcoming* the force downward. Movement downward might be attributed to the *heaviness* of an object, lack of *support,* natural *inclination* or the *strength* of the downward force. Rarely were unbalanced forces advanced as explanations for changes in the movement of objects. Intervention in the form of direct experiences, social challenges and empirical investigations attempted to help children appreciate the effect of unbalanced forces on the movement of objects and to develop an awareness of balanced forces acting on objects moving at constant speed.

These sub-themes were sequenced hierarchically so that children at the Lower Key Stages, for example would be expected to consider only the first sub-theme, that of forces and their effects.

5.3 *Evidence of intervention strategies*

There are several sources of evidence as to the intervention strategies adopted in different classrooms. Video-recordings and field notes of visits to classrooms provide a rich and detailed source of data. This evidence also captures something of the situated nature of the intervention strategies and some detail about the ways in which teachers operationalised the intervention suggestions. Important insights into children's emerging understandings are revealed by these data. Insights into the teachers' aims and practices are additionally available from their narrative descriptions of particular instances of intervention. Some teachers indicated how activities were tailored to particular ideas. Children's work reveals evidence of the range of interventions and provides important evidence about children's responses to the learning activities.

Teachers and researchers working on previous enquiries under the umbrella of the SPACE project as well as other collaborative research at CRIPSAT, had developed a number of strategies for intervention. The research team was also aware of recent developments in understanding the nature of cognitive development. The influence of social processes on cognition is well documented by proponents of the socio-cultural views of Vygotsky (1978), and in the situated cognition literature (Chaiklin and Lave, 1993; Lave and Wenger, 1995). More recent interest in cognitive-developmental psychology, has focused on the representational form in which concepts might be constructed, stored and accessed (Karmiloff-Smith, 1992). Karmiloff-Smith hypothesises that cognitive development proceeds through a process of representational re-description. It is suggested by Karmiloff-Smith that representations are stored in different modes which are more or less accessible to the system. Through the organising modality of language. This theory is of importance to the theoretcal understanding of project activities and learning outcomes for several reasons. Firstly, the elicitation phase provided an opportunity for children to make explicit some of their representations. Secondly, the task for the teacher might be described as one in which he or she helps children make their representations explicit prior to constructing links between these different representations. Thirdly, there are important implications for the different sources of knowledge which may be accessed via the classroom and the modes in which knowledge is shared and acquired. It is suggested that teaching and learning strategies which encourage children to re-describe their understanding in different modes might enhance the possibility of conceptual progression. Teachers were therefore encouraged to adopt a diversity of approaches using a variety of modes through which knowledge might be made explicit by the learner. While the project team was interested in particularly effective teaching and learning strategies, it did not assume that 'one-off', closely targeted interventions which could assure conceptual progression would be the outcome. Redundancy in teaching strategies was anticipated and indeed will be regarded as functional once it is accepted that knowledge can be represented in different modes within an individual's cognitive processing system.

Intervention drew on a range of modes of activity which were made explicit to the project teachers. The provision of opportunities for social challenges in the form of small group or whole class discussion was suggested. An opportunity to make ideas explicit and discuss the evidence for those ideas was considered likely to provoke some development in understanding. Empirical investigations were encouraged as a way of children gathering and evaluating the evidence for their ideas. Secondary sources of evidence, for example from videos, was also provided where necessary. Bridging analogies were used to try to help make accessible those visually imperceptible aspects of forces. Creative writing was used as a means of asking children to consider improbable events such as the absence of friction. These improbable events encouraged children to move from the concrete to the abstract. Direct experiences together with some evaluation of the evidence and ideas gained from such experiences were used as a means of helping children to develop their ideas.

The interactive nature of the intervention was important, since it was through teacher-pupil interactions that teachers could monitor children's developing understanding in terms of conceptual progression and determine the shape of subsequent learning activities. A second important feature of intervention was children's active involvement in the accumulation and evaluation of evidence. While teachers ensured that different sources of knowledge were made accessible, it was for the children to decide what counted as evidence in support of (or as a challenge to) their beliefs. The teachers' role was to introduce children to sources of knowledge and help them make sense of that evidence against the background of their own ideas, or the pupil representations generated in the elicitation phase.

In the following sections of this chapter each sub-theme targeted for development in the intervention phase is presented in turn and the nature of the intervention undertaken in the area reported. Some of the sub-theme discussions review evidence of interventions in all three Key Stages; others address interventions explored by just one or two of the Key

Stages. The intention is to give some indication of the kinds of activity which took place together with a sense of some of the outcomes of those activities. It does not reflect the work of any one class but rather, through describing some of the quality of what happened in different classes, presents a general picture of intervention. For any individual teacher it was possible to tackle only a fraction of the spectrum of activities described over the following pages.

5.4 Intervening to help develop ideas about forces and their effects on movement

Many children tended not to conceptualise 'forces' as actions such as pushes and pulls so much as to associate them with objects. Additionally, young children revealed confused understanding of pushes and pulls. This sub-theme was judged to be of primary importance to children's developing understanding of the domain and was therefore a feature of intervention for children in all three Key Stages. Teachers approached this sub-theme in different ways, developing and selecting activities according to the needs of their particular class. Some aspects were briefly addressed by classes of older children while the sub-theme dominated the intervention experience of children at Key Stage 1.

All of the teachers working with children in Reception and Key Stage 1 appreciated the value of children firstly considering pushes and pulls in relation to their own bodies and in the context of everyday familiar activities. An important aspect of the teaching and learning activities at Key Stage 1 was distinguishing between a push and a pull. The example below illustrates how one teacher of Reception and Year 1 children worked with a small group of children, exploring their ideas about pushes and pulls involved in getting dressed.

Tch *How did you put on your hat?*
Ch 1 *I pulled on the hat and then pushed it down. To take it off I need to pull it.*
Ch 2 *I pulled off my cardigan.*
Tch *How are you taking off your shoes Zoe?*
Ch 3 *I pushed first, then pulled them off.*

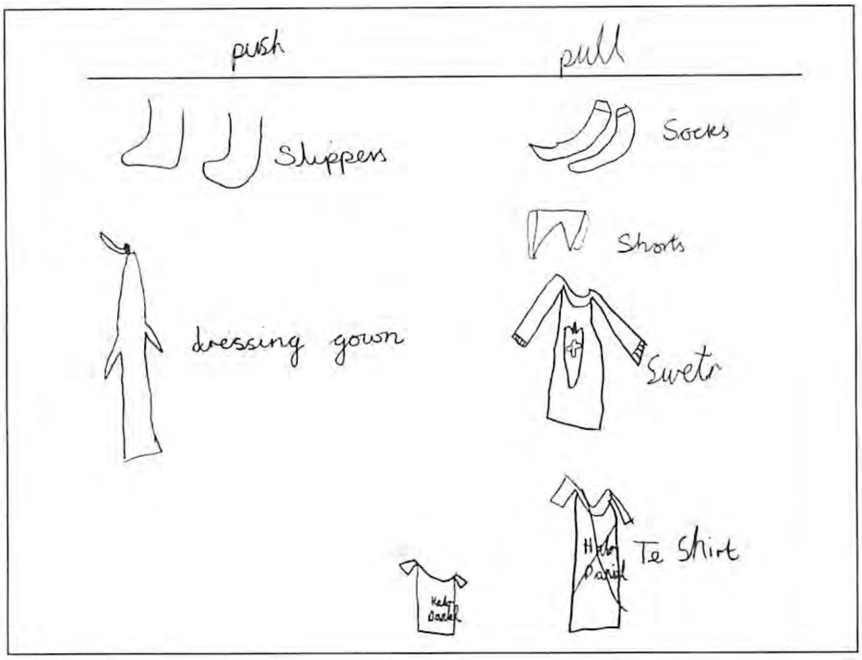
The teacher encouraged children to demonstrate the pushes and pulls which they had described. A Year 2 teacher who used the same activity focussed the discussions on the words children used to describe their actions. Discussions had elicited 'shove', 'push', 'pull', 'slide'. To help children link these actions to pushes and pulls and begin to label their understanding the teacher asked

Tch *Can you think of two special words we have been using?*
Ch *Pushing and pulling.*

Children demonstrated the various actions and group discussions clarified whether the examples were indeed pushes or pulls. They made drawings of their ideas listing actions as pushes and pulls. (See Figure 5.1).

As the teacher used the same activity with different groups of children, she noticed some variation in the ways in which different children approached the task. Some children experienced difficulty generating examples of pushes and pulls. Others readily generated pushes and pulls and observed that some actions involved both pushes *and* pulls. For these children, subdividing actions into pushes and pulls was insufficient; they recognised the need for a third category in which actions involving pushes *and* pulls might be placed. The discussion below shows how other children; with teacher support, gradually came to a realisation of the need for a third group as they were completing their individual drawings.

Figure 5.1



Y2 B M*

Tch	*Did you find that the things you drew fit nicely on one side or the other?*
Ch 1	*Boots, you push your feet in and pull your zip up.*
Tch	*What do you do with those things that are a push and a pull?*
Ch 1	*You could put them in both sides.*
Ch 2	*You could put them half in each side.*

The link between pushes and pulls and personal actions was generalised through direct experience of pushes and pulls in other familiar contexts such as playing and PE. Children discussed examples and then made drawings of their ideas. A focus for their activities was the encouragement of discrimination between pushes and pulls. The teacher noted that children seemed to experience more difficulty generating pulls than pushes. A Year 3 and 4 teacher described how class discussion helped children distinguish between pushes and pulls. Children had been asked to show, on a work sheet, whether different actions were pushes or pulls. Discussion revealed points of difference in children's reasoning and according to the teacher, promoted the possibility of changes in children's ideas.

* These codes identify Year group, Gender and overall achievement, High, Medium and Low.

We then discussed some of the ones where children had different answers. This was useful as children seemed to be consolidating their ideas as they talked about them, or also to change their ideas as they thought about them and as other children were explaining why they had put either a push or a pull. The children came round to deciding that cycling was both [a push and a pull] after various children tried to explain-as some had put 'pull' and others 'push'.

Year 3/4 teacher

It was important to the teachers that children's understanding of forces should be built on the familiar. Many commented upon the value of experiencing pushes and pulls. However, many also recognised the need to extend children's understanding beyond human actions. The work in several classrooms was extended so that children could begin to consider non-human pushes and pulls. While the younger children experienced some initial difficulty generating pushes and pulls exerted by non-human agents, the lists of pushes and pulls generated by a Year five child shows several non-human examples. (See Figure 5.2).

Figure 5.2

Push	Pull
Swimmer - forwards, friction and gravity and muscle power.	swimmer - ~~fork~~ forwards, friction and gravity and muscle power.
water - anywhere, gravity	water - anywhere, gravity
Boat - forwards, gravity, friction.	
Rocket - forwards, upwards, gravity friction.	
Car - forwards, backwards, friction gravity	
Person walking - forwards, backwards sidewards, friction, gravity.	

Y5 G H

Teachers indicated that, at Key Stage 1, the progression from human pushes and pulls to non-human pushes and pulls was a novel approach which they found useful. For children at Key Stage 1 a particular difficulty was the generation of examples of pulls and confusion between pushes and pulls. Teachers in other Key Stages felt the initial focus on the nature of pushes and pulls and their effects was necessary to support later learning in the domain. Helping children appreciate the *effects* of pushes and pulls proceeded in three directions. One way was to consider the effects of pushes and pulls on *movement.* The second was to consider the effects on the *shape* of an object. A third was to consider variation in the *size* of forces and their effects. These areas of understanding were taken up by teachers at Key Stages 1, 2 and 3. The first two areas provided a particular focus of intervention at Key Stage 1 and Lower Key Stage 2 and were used as an important introduction for further work at Key Stages 2 and 3.

5.4.1 Helping children understand the effects of forces on movement of objects

A teacher of Year 1 and Reception children noted that children's work on pushes and pulls revealed that some children did not recognise that pushes and pulls start *movement*. She encouraged groups of children to find ways of making a toy car move (see Figure 5.3). These direct experiences were quickly developed to consider ways of making the car move faster and ways of making it stop. This activity aimed to help children make a direct link between pushes and pulls and changes in the *movement* of an object.

Figure 5.3

In a Year 2 class the teacher provided practical experiences of different ways to start objects moving to help them discriminate between a push and a pull. Children explored moving objects on land and water, by pushing using hands or a stick, and by blowing, using a straw, or a battery-powered hairdryer. The teacher's questions aimed to help children to appreciate that pushes and pulls can operate on the same object, both resulting in the same outcome in terms of movement. Also, some objects could exert a pull but not a push (e.g. the pull of a string) while others could push but not pull (e.g. the jet of air from the hairdryer).

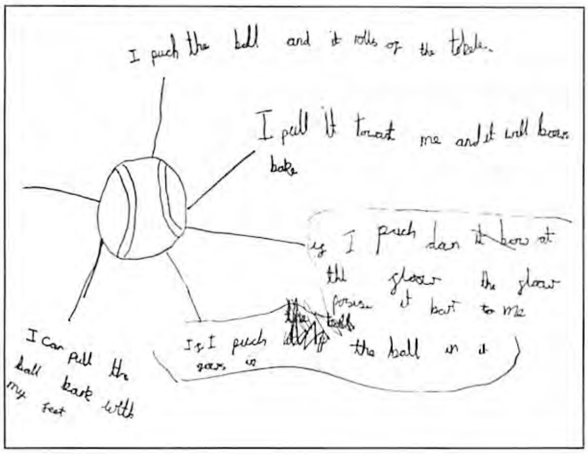
Was it a push or a pull?
Can you pull the boat using the hairdryer?
Can you push the boat with the string?

At the end of the activities the teacher noted that while children appreciated that pushes and pulls start movement, some children continued to have difficulty in identifying a force as a pull when the action is away from the child.

Another Year 2 teacher used the movement of balls to encourage children to consider the range of ways pushes and pulls affect movement. The children noted pushes and pulls could make the balls move downwards, upwards and roll forwards and backwards. Annotated notes on drawings indicate the scope within individual discussions for probing how children distinguish between a push and a pull. The Year 2 child's drawing (see Figure 5.4) illustrates the different ways she noticed pushes and pulls affecting the ball. She observed how pushes change the movement and shape of the ball. The opportunity for individual discussion with the teacher also reveals a surprising ability to link the ball's bounce on the floor to the floor pushing back.

Children suggested that pushes and pulls resulted in objects moving in different directions, but they had some difficulty within the intervention appreciating that an object would move in one direction while one person was pulling and another pushing. Direct experiences of moving large pieces of classroom furniture helped children understand that a push and pull could result in movement in the same direction. (See Figure 5.5).

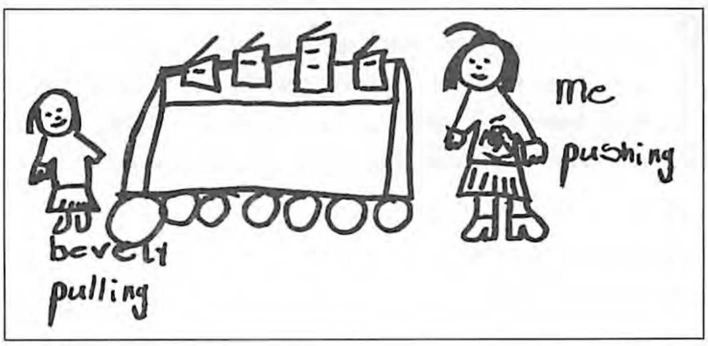
Figure 5.4



I push the ball and it rolls off the table.
I pull it towards me and it will bounce back.
If I push down at the floor, the floor pushes it back to me.
If I push the ball in it goes up.
I can pull the ball back with my feet.

Y2 G M

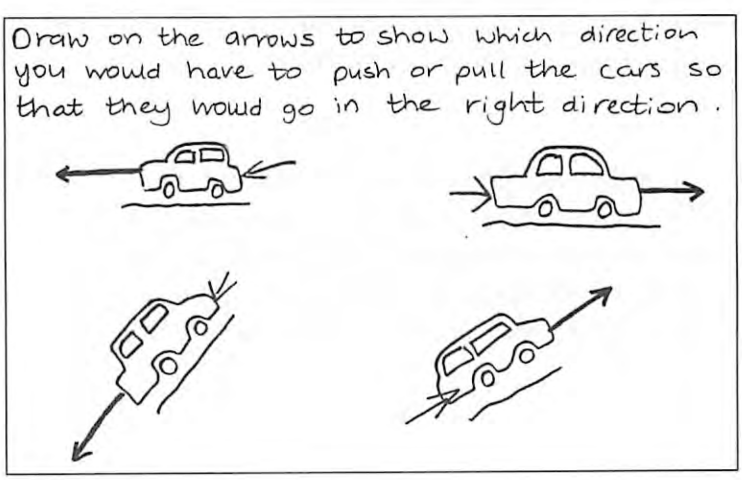
Figure 5.5



Y2 G M

Key Stage 2 teachers believed that an exploration of the effects of pushes and pulls on the movement of objects was important preparation for later work on forces. In one Year 3 and 4 class, children were encouraged to think not just about pushes starting movement but ways of *stopping* movement. This teacher encouraged children to use arrows to indicate the direction of pushes and pulls, to emphasise the direction in which forces were acting. (See Figure 5.6).

Figure 5.6



Y4 B M

5.4.2 Helping children to develop their ideas about how forces can change the shape of objects

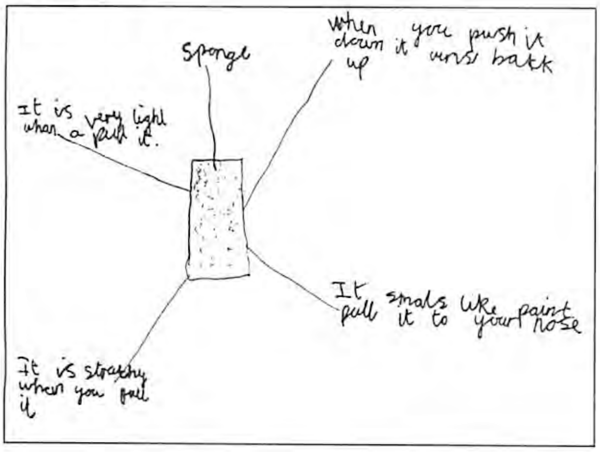
One way of helping children to appreciate that pushes and pulls can change the shape of objects was to provide opportunities for them to explore objects made of different materials. A Reception teacher provided groups of children with a range of materials including modelling clay, sponge, polystyrene and rubber bands (see Figure 5.7). Children were eager to handle the materials and each in turn described what happened when they gave one of the materials a pull, or a push. The focus within work for this class was the oral articulation of ideas and the development of vocabulary with which children could express their observations. Some of the children struggled to express their observations and could not easily produce words like 'squash' and 'stretch'.

Figure 5.7

One Year 2 teacher incorporated this idea into intervention, aiming to help children understand the wider range of effects of pushes and pulls. She gave groups of children a single object and asked them to draw or write what effects pushes and pulls had on the object. The range of objects across the class included springs, plasticine, sponges and elastic bands. The class discussion brought children's experiences of the different objects together. Ideas of the effects of pushes and pulls on different objects were reviewed and common effects of pushes and pulls were added to a class list.

A Year 3 and 4 teacher encouraged children to explore the effects of pushes and pulls on the shape of materials. (See Figure 5.8).

Figure 5.8



Sponge
When you push it down it comes back up.
It smells like paint. Pull it to your nose.
It is stretchy when you pull it.
It is very light when I pull it.

Y3 G L

Discrimination between pushes and pulls was thought to be important by most teachers at Key Stages 1 and 2. They provided initial opportunities for children to generate a range of pushes and pulls and classify these into two groups. The difficulty experienced at Key Stage 1 of generating pulls and of linking pushes and pulls to the movement of objects was not so apparent at Key Stage 2. Nevertheless, they were considered to be a useful way of linking children's direct experience of pushes and pulls and their effects to more abstract consideration of forces in subsequent lessons.

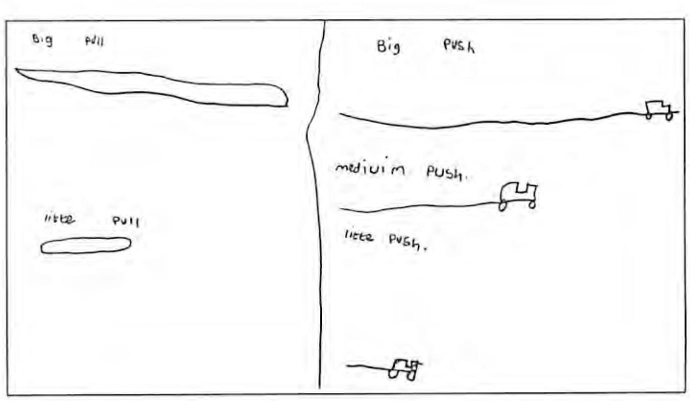
5.4.3 Helping children to understand quantification of forces

The idea that forces can be quantified was introduced to children in different ways across the three Key Stages as children engaged in activities related to a gradual appreciation of measurement of forces. Different starting points and stopping points could be identified and a tentative sequence of activities tailored to children's developing understanding can be mapped out. Interventions in this area will be presented in Key Stage order to demonstrate areas of difference and of overlap.

In some Key Stage 1 classrooms it was possible to extend children's initial consideration of pushes and pulls to help them appreciate that the *size* of pushes and pulls can vary, together with an appreciation that different sized forces will have different effects. It was believed that intervention in this area could help lay the foundations for later appreciation of the quantification of forces.

In a Year 1 class the teacher asked children to think of large and small pushes and pulls. A class list of their ideas was constructed following class discussion. They clarified what counted as a large and small push/pull. Later children investigated the effects of different sized pushes and pulls on different objects. The drawing reproduced as figure 5.9 shows how a Year 1 child identified and represented the effects of different sized forces on an elastic band and the movement of a car.

Figure 5.9

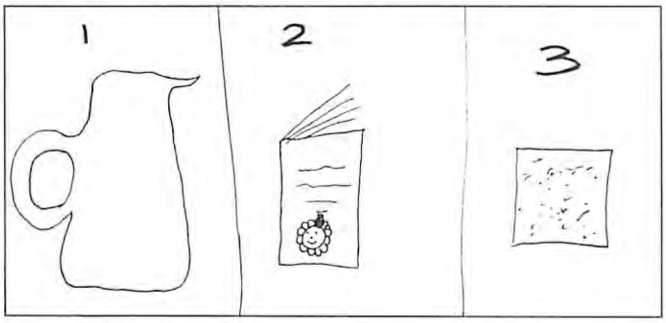


Y1 G H

The class teacher helped one group to quantify the effects of different sized pushes using non-standard measures. These investigations helped children begin to understand the relationship between the size of the force and its effect.

A different way of exploring different sized pushes is to consider how much force is needed to start different objects moving. In a Year 2 class, a few children were given three objects of different masses and asked to sequence the objects according to the size of the push which would be needed to make them move. The children's drawing (see Figure 5.10) together with their expression of ideas shows that they appreciated the relationship between the heaviness of an object and the size of the push needed to make it move.

Figure 5.10



The jug is first it needs a big push.
The book needs a middle sized push.
The sponge needs a little push.

Y2 G M

Many Key Stage 2 children were unfamiliar with newton-meters despite them being available for use in many classrooms. In order to lead children towards an appreciation that forces could be quantified, some Key Stage 2 teachers encouraged them to make initial qualitative judgements about the relative sizes of forces. In one Year 6 classroom, children were encouraged to make their own lists of forces together with estimates of their size. Figure 5.11 below illustrates one such example in which the magnitude of each force is labelled on a three-point descriptive scale: 'small;', 'medium' or 'big.' This reflects the demand of the elicitation probe used in the research and is clearly capable of being extended to more elaborate series, moving to quantified estimates in newtons.

Figure 5.11

1	2	3.
elastic band	pushing force	medium force
elastic thickband	pulling force	big force
thin elastic band	pulling force	small force
plastic skipping rope	pulling force	small force
rope skipping rope	pulling force	big force

Y6 G M

Figure 5.12

Figure 5.13

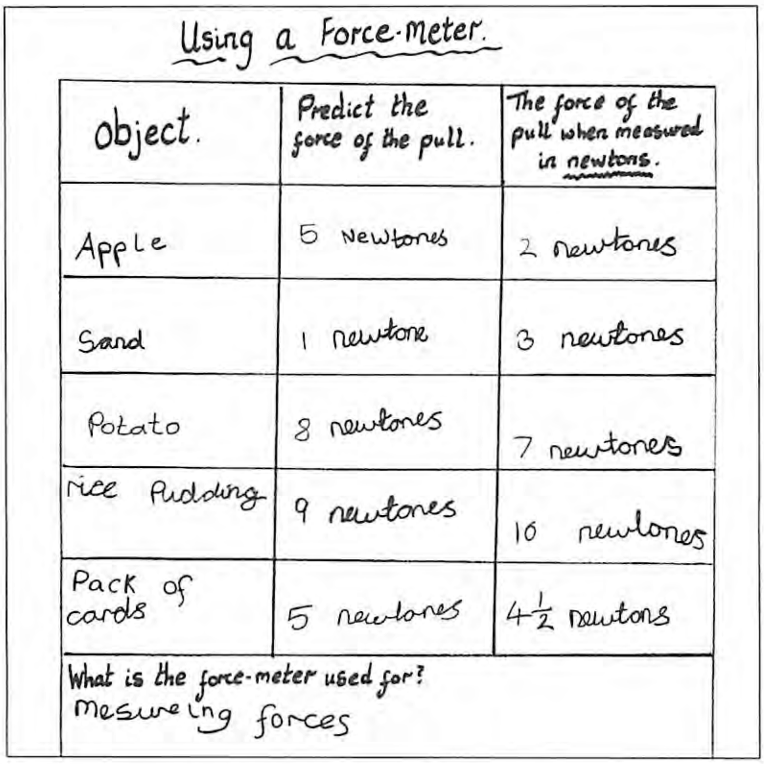
In another classroom, children investigated the pull of different objects using elastic bands attached to hooks, (see Figure 5.12). They were asked to place different objects on the elastic bands and to measure the length to which the elastic band stretched (see Figure 5.13). Establishing a link between the length of the elastic band and the pull of each object was no easy task. The teacher questioned children about their results and tried to help them appreciate the relationship between the pull of the object illustrated by the stretched elastic band and the weight of each object. As well as offering experience of a perceptible outcome of the effects of different weights, children would also be helped to consider the parallels between the elastic band and the spring in the force-meter.

A teacher of a Year 3 class planned a sequence of activities which supported the development of children's ideas from an awareness of pushes and pulls, to an appreciation that forces could be measured. Firstly, children rank-ordered a selection of pushes and pulls. They then made a push/pull meter which enabled them to take non-standard measures of those same pushes and pulls. The teacher's account indicated that children used this device in a variety of situations, just one of which was weighing.

Encouraging children to make and use a push/pull meter was valuable in two respects. Firstly, it provided the possibility of measuring pushes and pulls using non-standard measures. Secondly, it offered the possibility of measuring pushes *and* pulls in contrast to conventional spring-balance type newton-meters which measure only *pulls.* Using a push/pull meter provides a bridge between the qualitative terms such as big/little push used by younger children to discriminate sizes of pushes and pulls and the more formal measurements in newtons offered by a newton-meter. Non-standard measurement helps children understand what they are measuring, how the measuring device works and the need for standard quantification of measurements. It is anticipated that this sequence enhances the possibility of children being more receptive to the introduction of newton-meters. The teacher reported that, when they children were introduced to the newton-meter, they were in a position to understand the function of the device and the need for accurate standard measurements in their investigations of forces. Records of children's investigations show their appreciation that the newton-meter was measuring the pull of an object. (See Figure 5.14).

In a Year 6 class, children made the push/pull meter according to the suggestions of the researchers and used it to investigate how much push was needed to make different objects start moving. The children developed this investigation themselves as a result of making the device. Children's ideas could be further developed by using their new-found awareness of the uses of standard measurement of pushes and pulls to calibrate their own device against a standard one. (Alternatively, they could be helped by the provision of the information that a force meter pulls upwards with a force of 1N when a mass of 100 g is suspended from it. Activities of this kind can help scaffold the transition to measurement using newton-meters).

Figure 5.14


Using a Force-meter.

Object.	Predict the force of the pull.	The force of the pull when measured in newtons.
Apple	5 Newtones	2 newtones
Sand	1 newtone	3 newtones
Potato	8 newtones	7 newtones
rice Pudding	9 newtones	10 newtones
Pack of cards	5 newtones	$4\frac{1}{2}$ newtons

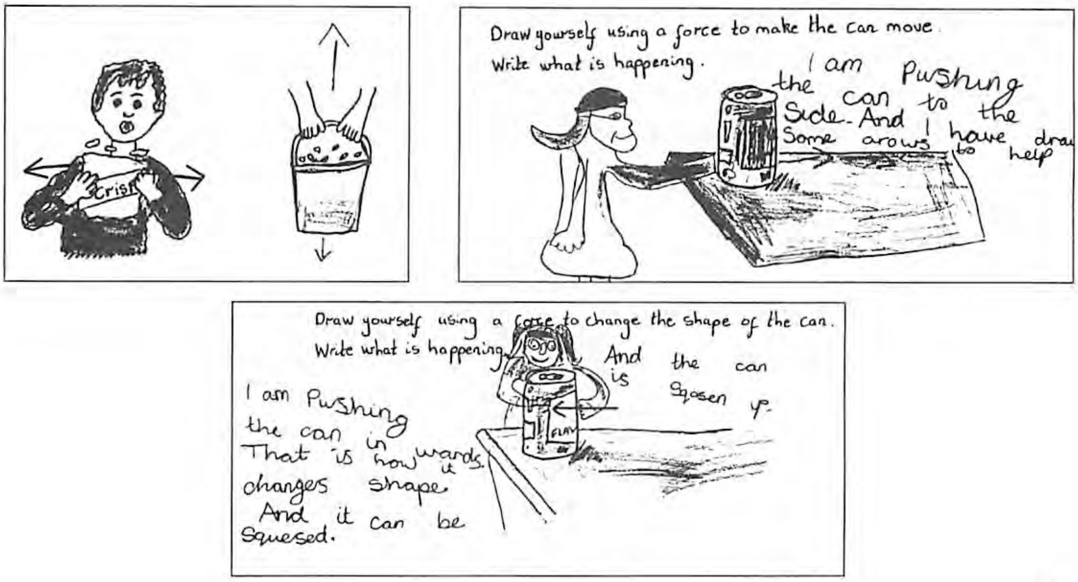
What is the force-meter used for?
mesureing forces

Y3 G H

Introducing children to formal systems for *measuring* forces is one aspect of conceptual development. Another is to introduce children to the culturally accepted symbols for *representing* the size and direction of forces. Many children used arrows to show what they believed to be the *location* of a force rather than to indicate its *direction* or *magnitude*. In a Year 3 class, the teacher asked children to show what they believed to be the direction of forces using arrows. The drawings show children's ability to represent direction of their own pushes and pulls (see Figure 5.15).

The teacher believed that consideration of the *direction* of forces was at the limits of the Year 3 children's understanding and that representation of the *magnitude* could wait until children had much greater experience of measuring forces.

Figure 5.15



Y3 G M

5.5 Helping children to develop ideas about gravitational forces

During the elicitation phase, children offered a variety of explanations as to how the Earth's gravitational force works. They suggested it could either pull or push or both pull *and* push . Most understood the effect of gravity in that it keeps them on the ground, or stops them floating away. A few Upper Key Stage 2 and Key Stage 3 children understood that the direction of gravity is towards the centre of the Earth. However, most felt that there was no gravity in space and most did not appreciate gravity as something acting *between* two objects. Children's explanations of how gravity works revealed aspects of their understanding which needed further support. Some of the children believed gravity operated on land but not in water and ideas that gravity was linked to air were also revealed. One of the ways of helping children to develop their ideas about gravity was considered to be to help them appreciate gravity as a force that is directional. A Year 3 and 4 teacher asked children to draw pictures and show the direction of gravity using arrows. To help children appreciate that the force due to the Earth's gravity is towards the centre of the Earth, children were given globes and stuck figures at different points on the Earth's surface. The teacher felt that the discussion around these models was useful in helping children towards more Earth-centred notions of gravity appropriate to the age group.

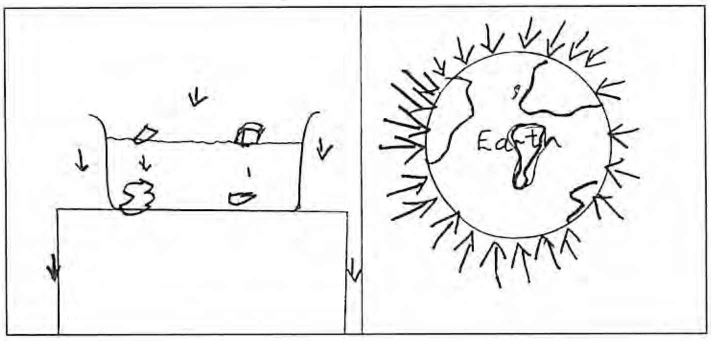
We used a globe and stuck model figures on it in different places and I asked, 'What is it that makes people stay on the Earth in different parts of the world?' They said that it was gravity, coming from the centre of the Earth.

Year 3/4 Teacher

To check their appreciation that the Earth's gravitational attraction operates towards the centre of the Earth, she gave children two pictures, one of a tank of water and one of the Earth. Children were encouraged to draw arrows on both pictures to show the direction of gravity.

The child's drawings reproduced in Figure 5.16 demonstrate his appreciation that gravity acts towards the centre of the Earth.

Figure 5.16



Y4 B H

In a Year 5 and 6 class, a teacher used the analogy of magnetic attraction to suggest that gravity was a force of attraction pulling down. The teacher explained:

This level of teaching input and teacher directed activity was necessary as a foundation for the next experiences.

Year 5/6 teacher

The teacher's notes indicate a later sense of dissatisfaction with some aspects of this direct teaching. As with all analogies and models, some attributes of the analogy map across usefully to support science understanding. However, not all attributes of the model are equally useful. On balance, this teacher came to the conclusion that the analogy between the gravitational attraction of the Earth and magnetic attraction was not entirely helpful. Some children, she felt, were confused by the parallel.

I did use the idea of magnets to talk about attraction and this is the idea that has stuck in their minds. This is something I must remember as I feel it has confused the children.

Year 5/6 teacher

There are some aspects of the analogy which the child was able to cling to and which are useful, children might need further discussion of some aspects, such as whether gravity is an artefact like a magnet, or a force between two objects. On balance, the analogy linked some familiar experiences to the newly presented knowledge. In addition, both magnetism and gravity are examples of non-contact forces. While the analogy was limited in many respects it led to some developments in understanding, such as gravity being conceptualised as a pull *towards* the Earth.

Teaching and learning activities adopted in these Key Stage 2 classrooms aimed to help children to understand the direction in which the Earth's gravitational force acts, perhaps helping them move from a 'ground-centred' to an 'Earth-centred' view. The idea of gravity as the force of attraction between two masses tended not to be addressed by teachers at Key Stage 2.

A preliminary stage might be to help children distinguish between mass and weight. A teacher of a Year 5 and 6 held a class discussion to elicit ideas about the nature of weight and mass in the course of which, children's everyday understandings emerged. The teacher introduced children directly to the idea that mass is 'how much stuff something is made of'. Children's everyday sense of weight was used as an introduction to weight as a force downwards.

Interventions addressing the mass/weight distinction at Key Stage 3 tended to be in the form of class discussions in which new ideas were introduced and existing ideas put to public scrutiny. In some lessons, teachers were able to use direct experiences, video evidence or children's investigations to provide the evidence to fuel the debates. In one Year 7 class, children were encouraged to 'weigh' themselves using kilograms and newtons. Their task was then to consider how the two measurements might change if they took the same measurements on the Moon. The teacher hoped that students might be helped to understand that they were measuring different properties. Children worked individually on this task, followed by a whole class discussion which provided an opportunity to share results and interpret data.

5.6 *Helping children to develop their ideas about friction and air resistance*

During the elicitation phase Key Stage 2 and 3 children showed awareness of friction when they mentioned it as a force. They tended, however, to associate it with particular objects, almost as though it were a property of those objects. There was some confusion about whether friction was operating in different instances and how friction worked. The intervention aimed to follow up these ideas through direct experiences of instances of friction. In one Year 5 and 6 class, the teacher provided some direct experiences of friction for children to experience directly and tangibly and reflect upon. One of the instances was a rubber pad designed to help the elderly or those with problems in gripping to open the lids on jars. Children were asked to explore whether there was a difference in opening the jar with wet hands and with the pad. While all the children noted the ease with which the jar opened using the pad compared to wet hands, they differed in the extent to which they understood friction as playing a role. Children recorded some of their ideas in writing (see Figure 5.17).

Figure 5.17

Example 1

The pad for opening the Jar helps by
because if you have wet hands it will be
easier to turn.

Y5 G L

Example 2

The rubber pad helps you if you wet hands because I think rubber provides more grip

Y6 B M

Example 3

The pad decreces the griction on the jar lid making it eysier to open and close tightly. Rubber is the best type of material to use because it is glexable and bendy.

Y6 G M

Example 4

The pad for opening the lids of jar work by the rubber and the lid rubbing together and causing friction and therefore making it easier to open the jar. Rubber is a good material for bending, it is flexible for small jar & big jar lids.

Y6 G H

The children's written responses records the different ways in which they interpreted the experience and their explanation as to why they thought that the pad makes the lid easier to turn. Many suggested that the rubber provides more 'grip' an expression which might be interpreted as an approximation to the idea that friction is operating. If this is so, it might be helpful to provide the scientific label as an alternative to, or substitute for, the vernacular expression of the idea. Indeed one teacher commented upon the need to use both 'grip' and 'friction' during discussions in order to help children label their understanding as friction.

I had to maybe reinforce the idea that more friction meant more grip, just by giving examples and using the word 'friction' as well as 'grip' all the way through.

Year 5/6 teacher

The child who offered Example 1 in Figure 5.17 does not use the word 'grip', though Example 2 does. The latter might be an example of a response from a child who is ready for the correct scientific vocabulary. Example 3 is more difficult to interpret because the respondent refers to a *decrease* in friction, and there is indeed friction between the lid and the glass of the jar. Such responses can provide the stimulus for fruitful class discussion. Example 4 is the only one of those reproduced here which introduces the idea of friction as a force operating *between* two surfaces.

The teacher helped children generalise their ideas by considering a second context, that of the brakes on a bicycle. Pupils had an opportunity to experience the cycle brakes in operation before making explicit their ideas in response to the instruction, 'Describe how a brake block on a bicycle manages to stop the wheel turning.' (See Figure 5.18).

Figure 5.18

The rubber block presses against the rubber tyre and causes the tyre to slow down and finaly stop.

Y6 G M

The brake block also made of rubber has little zig zag lines which when slammed down on the wheel which increases friction and pulls the wheel to a halt

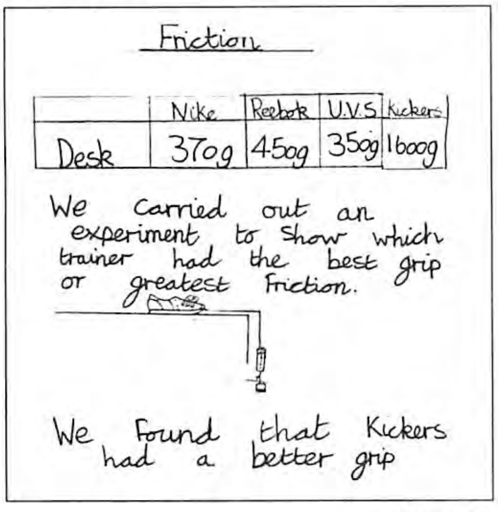
Y6 B M

The first piece of writing describes observations of the effect of the brake block on the movement of the wheel. These observations are important since they could lead to a later appreciation that slowing down and stopping the movement of an object requires a force and that in this instance the force is termed 'friction'. The second reports that the indentations in the brake block increase friction and slow down movement. It is interesting that friction is described as a pull. Further work might focus on this belief and help the child begin to appreciate friction as a force acting in the direction opposite to the movement of the wheel. While it is useful to explore instances of the same concept in different contexts, the cycle context presents some counter-intuitive complexity because the friction force between the road and the moving wheels is in the same direction as the movement of the bicycle. It might be that other instances which are more closely linked to intermediate understandings might be introduced prior to examination of frictional forces on a wheeled vehicle.

Following a suggestion offered by the research team the teacher encouraged children to reflect on imaginary events in order to help them develop their ideas about friction. As a creative writing exercise, she asked them to write about a world with no friction. They were encouraged to consider the effects this would have. It was anticipated that, in order to consider a world without friction, children would first need to reflect upon their understanding of how friction works and the effects of friction in the real world. The creative writing provided a supportive context for this imaginative leap. Often, children's first thoughts were of examples associated with their direct classroom experiences. This demonstrated that they were linking their ideas from these earlier experiences with the demands of the new task. Many children generated instances linked to their experience of the effects of the brake on a moving cycle, suggesting that in a frictionless world, cars and other vehicles would not stop. Interestingly, there is no evidence to suggest children believed friction was needed to start wheels turning. Others thought of events which would affect their own physical actions. Hands would slide rather than rub together, movement would be uncontrolled and chaotic. The teacher used a class discussion to share the range of instances about the effects of having no friction. These creative writings were effective in encouraging children to recognise instances in which friction *does* operate and to consider its effects. The class discussion drew some of these ideas together and a composite story was constructed. This practice allowed children to make explicit their ideas and reflect on the ideas of others. Frictionless events and their effects were considered, inconsistencies in descriptions of effects were exposed and reformulated within the discussion.

One particular way in which children were helped to understand friction was by collecting evidence from investigations of their ideas. Several Key Stage 2 teachers encouraged children to explore the movement of objects across different surfaces or the movement of different objects across the same surface. The arrangement illustrated in the example drawn from a Year 3 class (reproduced as Figure 5.19 below) allowed children to gather data which they then used to help them in drawing conclusions.

Figure 5.19



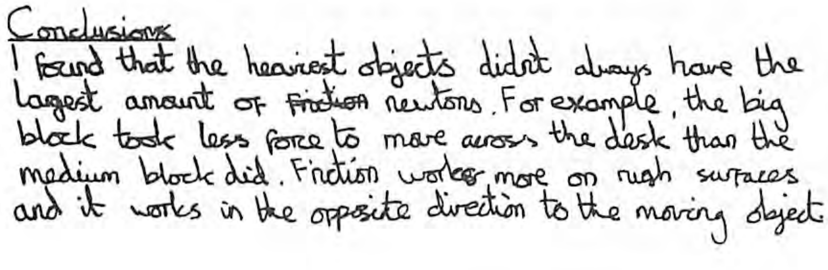
Y3 B M

Figure 5.20

A Year 6 teacher encouraged the development of children's use of the term 'grip' through the means of an investigation to see which trainer had the best grip. (See Figure 5.20). Children compared the movement of trainers down a smooth slope. Some of the children explained that particular trainers had more grip and therefore more friction. They seemed to believe friction was an intrinsic property of the rough sole. These kind of activities could further develop children's understanding by inviting them to consider the outcomes of their investigations in terms of forces opposing movement.

In another Year 6 class, the teacher asked children to investigate the movement of wooden blocks across different surfaces. They were encouraged to measure the force required to pull the blocks along. Some of the children linked their results to the texture of the different surfaces. A few, like the child below, were able to link their results to friction caused by movement between two surfaces. (See Figure 5.21).

Figure 5.21



Y6 G H

Investigations such as these provided children with evidence about the variations in frictional force. Some of their causal explanations showed an appreciation of forces shift away from a notion of grip as an intrinsic property of only one of the surfaces. Once children appreciated that friction occurs between surfaces moving against each other, they needed further support to understand those instances of friction without movement, such as a stationary book on a slope.

Within the elicitation phase, children were asked to describe why a can dropped from a moving car falls in a particular manner. Many children used 'wind resistance' as a core idea in their explanations of the movement of the can. A Year 5 and 6 teacher attempted to extend children's understanding of stopping forces by asking them to consider the effects of air resistance on objects moving through air. She wanted children to gain an appreciation that movement might be slowed down by the air. Children investigated what happened when a large piece of cardboard was dropped, first on its edge (with a small area of the leading surface) then with its largest surface area falling first. The investigation was carried out by children using the organisational structure of a whole class lesson. Children decided how they would measure the height from which the cardboard needed to be dropped and any difference in the time taken to reach the ground. Other concerns of fair testing, such as controlling the height and point of release and number of trials needed were discussed and selected by the children. Children timed how long the card took to fall, in each trial. Recordings were made on the blackboard and shared with the class. A discussion was organised to reflect on the evidence and for the generation of explanations as to why the card fell at different speeds.

In another Year 5 and 6 class, the teacher followed the investigation of the falling card with other opportunities to investigate air resistance. Two pieces of paper (both pieces were of the same mass, one crumpled into a ball and one open) were released and allowed to fall through the air. The teacher dropped both pieces of paper simultaneously from a height of two metres. Children observed which landed first. All the children correctly observed that the crumpled paper landed first but, they found it difficult to generate an explanation for this observation. A few suggested that the smaller paper weighed more. Interestingly, a few suggested that the crumpled paper was smaller and therefore lighter. These responses suggest a failure to conserve the mass of the paper. The second view is contrary to widespread beliefs expressed in the elicitation that heavy things fall faster. The teacher's description shows her attempts to provide further evidence to challenge some of the children's ideas.

The children seemed to grasp the reason why the card on its side fell more quickly. But with the paper many of the group said it was because the scrunched paper was heavier. I unscrewed the ball and showed them it was the same piece of paper but they still said that when you scrunch it, it still gets a bit heavier. We talked about the hammer and the feather and I said there was no air on the Moon and which did they think would hit the ground first. James said, 'At the same time.' The others said, 'The hammer because it is heavier.'

Year 5/6 teacher

The teacher helped the children make links between the evidence from their investigations and the video evidence of Neil Armstrong's hammer and feather experiment on the Moon, in which both land at the same time. They were urged to consider the link between the absence of air on the Moon and the role of air in slowing down objects moving on Earth. The teacher's description shows that these ideas are accessible to some children. It also shows the powerful influence of their intermediate understandings on children's interpretation of evidence. For these children, associations between the differing contexts were difficult to make and further evidence of the movement of objects might be needed before notions of air resistance become accessible. Until children are able to understand the role of gravity on falling objects, movement downwards might not be the most effective context in which to consider the effects of air resistance. The ideas and practices of this teacher exemplify how a diversity of approaches might be used to help children develop their ideas within a concept area. The different approaches used different modes of activity, with the teacher helping children to construct and access representations through different cognitive modes. Her constant comparison of different instances illustrates one way in which children might be helped to link events and redescribe their representations.

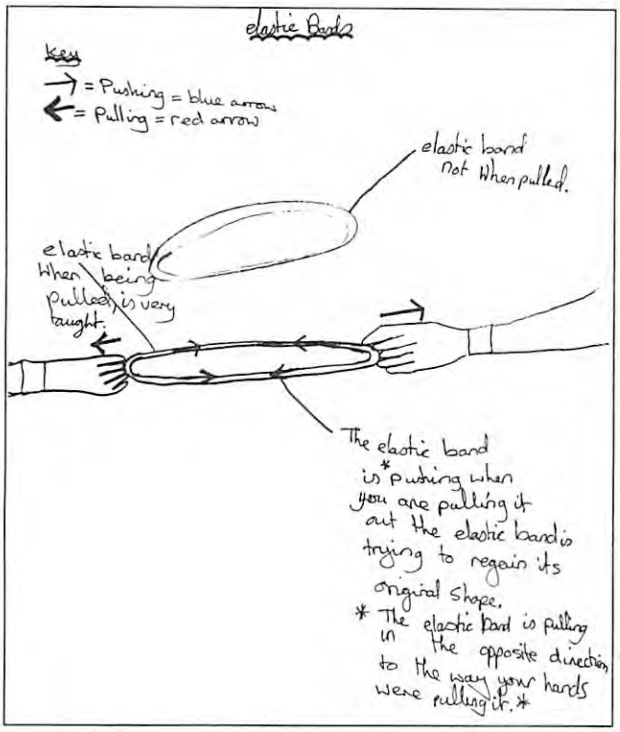
5.7 Helping children develop their ideas about reaction forces

During the elicitation, reaction forces were rarely mentioned by any children. Intervention in this area tended to be addressed by teachers at the Upper end of Key Stage 2 and at Key Stage 3. However, there were some instances of teachers in Years 3 and 4 attempting some introductory work in this area. In general, teachers tended to use whole body experiences to help children understand that the object being pushed pushes back on the thing doing the pushing. It was believed that awareness might be increased if children, when they pushed an object, felt, or gained the sensation of, the object pushing back on them. In a Year 3 and 4, class children were encouraged to pay attention to the feeling of pushing upwards on a book held at arm's length in order to explore the complementary sense of the book pushing downwards on their hand. The teacher felt that this was one way on making reaction forces accessible to young children.

They seemed to be happy with the idea that the book was pushing down and went around the room looking for other objects that might be pushing or pulling.

Year 3/4 teacher

Figure 5.22



Some teachers asked children to pull an elastic band and consider whether they could feel the elastic band pulling back. A Year 6 teacher asked children to contrast this with what would happen if they moved their hands away from each other without the elastic band. Many of the children recognised that the band was also pulling their hands back together. Children were encouraged to draw their ideas and share these with the rest of the class. Interesting differences emerged in children's beliefs about whether the elastic band pushed or pulled. When children drew their ideas on the blackboard, some showed arrows in the correct direction but were confused in their descriptions of pushes and pulls. Others confused both arrows and descriptions. The class was asked to show their commitment to one of a selection of five drawings and explanations made by their fellow class members. In this way, the teacher helped the children to reflect on their own ideas. Asking children to choose a drawing helped the teacher monitor the changes in ideas following the discussion. The drawing (see Figure 5.22) shows one child's understanding following this sharing of ideas.

Y6 G H

Figure 5.23

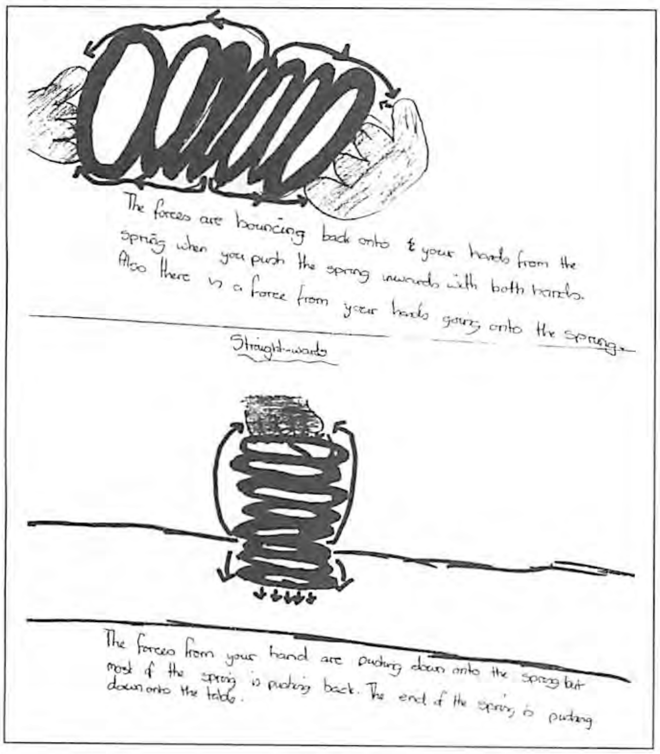
Other practical experiences were explored with the aim of helping children to appreciate reaction forces. In groups, children experienced a sequence of three activities. One at a time children sat in a large trolley or wheeled box and pressed their feet or hands on an outside wall (see Figure 5.23). They observed what happened to the movement of the box and tried to explain this event in terms of forces. Some children focused on forces such as friction while others showed that they had at least an intuitive understanding of the wall pushing back.

Figure 5.24

A second activity was for children to explore a range of springs. (See Figure 5.24). These springs varied in size but included some large mattress springs. Children squeezed the springs and considered what forces were acting. They focused on the spring both in a horizontal position (pushing the spring together with both hands) and vertically, (on a table, and pressed down with the hands).

The teacher's questions then probed whether they could feel anything pushing back up. The drawing below (see Figure 5.25) shows how Claire (Year 6) was able to appreciate that forces were pushing back on her hand and also on the table below the spring.

Figure 5.25



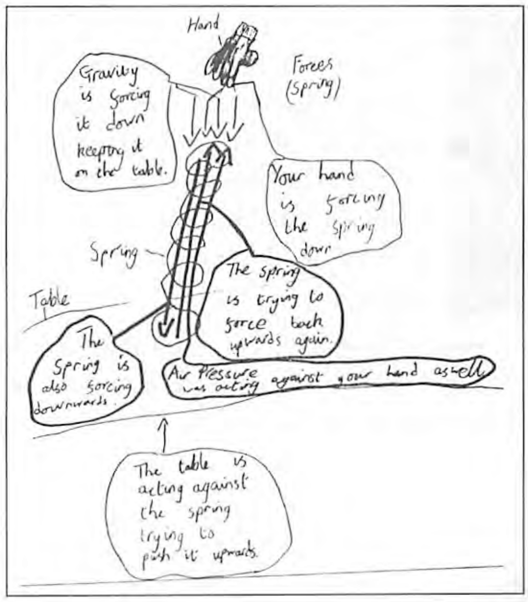
The forces are bouncing back onto your hands from the spring when you push the spring inwards with both hands. Also, there is a force from your hands going into the spring.

The forces from your hand are pushing down onto the spring but most of the spring is pushing back. The end of the spring is pushing down onto the table.

Y6 G M

Daniel reveals an increased appreciation of the reaction forces. (See Figure 5.26). His drawing shows he can conceptualise and represent several pairs of reaction forces. His complex description of the forces together with the drawing indicates the accessibility of these ideas to some pupils at Key Stage 2.

Figure 5.26



Y6 B H

A third activity was for children to sit on a chair, with and without a foam cushion. They were then asked to consider what forces were operating. Children interpreted this activity in different ways. Some described sitting on the chair in terms of rearrangement of the contents of the cushion:

When you sit on the cushion the beans go to the sides.

Others, like Sara (see Figure 5.27) identified one force, gravity, pulling down and suggested the chair kept a person up. Laura (see Figure 5.28) suggested two forces: gravity pulling down and the chair pushing up. On its own, this activity was less useful than the spring in helping children to access the idea of reaction forces. It may be that the spring provided a more direct sensation of something pushing back than did sitting on the chair. The everyday experience of the chair as providing support may have also led to a failure to appreciate the possibility of the chair pushing up.

Figure 5.27

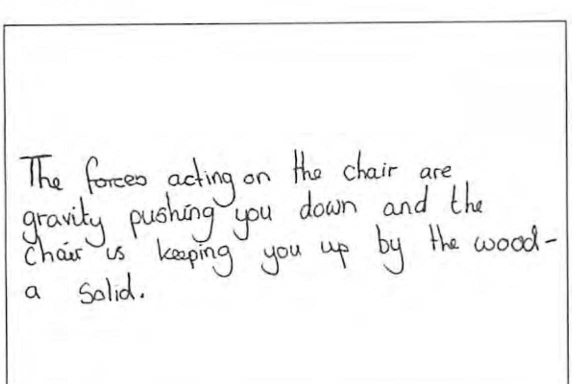
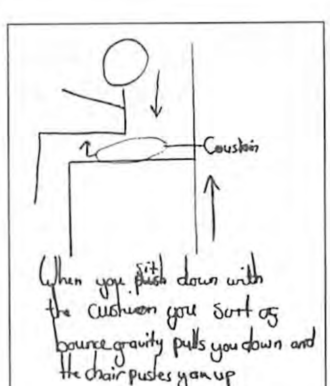


Figure 5.28



Y6 G M

Figure 5.29

The mattress spring compression activity and pushing off from a wall while seated in a wheeled box provided useful bridging analogies to understanding reaction forces. When linked to the activity of sitting on a chair, children could be helped by their teacher to make links in their understanding of the three events. An important aspect of these three practical experiences was the teacher's support in helping children to interpret the events in terms of forces. The teacher moved around the groups posing questions and challenges as new intermediate understandings were expressed. Sometimes, these questions focused on the abstract representations of the forces involved in the form of children's drawings. (See Figure 5.29). At other times, questions focused on the more tangible and intuitive aspects of the experiences, such as whether children could feel anything pushing back. Discussions tried to help children to make conceptual links between the three activities. For instance, interactions around the spring would encourage children to consider whether pressing down on the spring was similar in some way to sitting on the foam cushion. Direct links were made in these interactions between the push up of the spring and the possibility of the cushion pushing up. In each case, children were being encouraged by the teacher to make links and re-think existing representations. The extent to which children made these links was illustrated in one child's response which records the suggestion that the spring is something like the elastic band. Children's drawings of their ideas reveals insights into their developing appreciation of pairs of forces. An important aspect of promoting conceptual development was, according to the teacher, helping children to label their sensory experiences as 'reaction forces'. With some hesitation, she introduced the term to some children anticipating that they understood the concept.

> *I hope it's right I've told them it's called reaction forces. They seemed to understand the concept so I gave them the words.*
>
> Year 6 teacher

The link between language development and conceptual development in science was explicit in the practice of some of the teachers. The comment above shows the teacher's sensitivity to the development of personal understandings. During her interactions with pupils, the teacher is searching for evidence of conceptual understandings and trying to determine the point at which it is important to label such new understandings with the correct technical words.

5.8 Helping children to develop their understanding of multiple forces.

During the elicitation, children at Key Stages 2 and 3 tended to over-estimate the number of forces they represented as acting on an object. This was the result of the tendency to nominate the *objects* which they associated with forces rather than the abstraction of the forces themselves. The effects of each force was most often considered separately with few children recognising that forces could be understood in combination. Although some children at

Key Stage 3 used the terms 'unbalanced' and 'balanced' forces, they had little appreciation of the implications of these terms. For example, they could not relate balanced and unbalanced forces to their differing effects on movement. Intervention aimed to help children firstly, to gain more understanding of the forces acting on objects: secondly, to help them understand that forces have a combined effect on the movement of objects. Intervention in this area was mainly approached in Key Stage 2 classrooms.

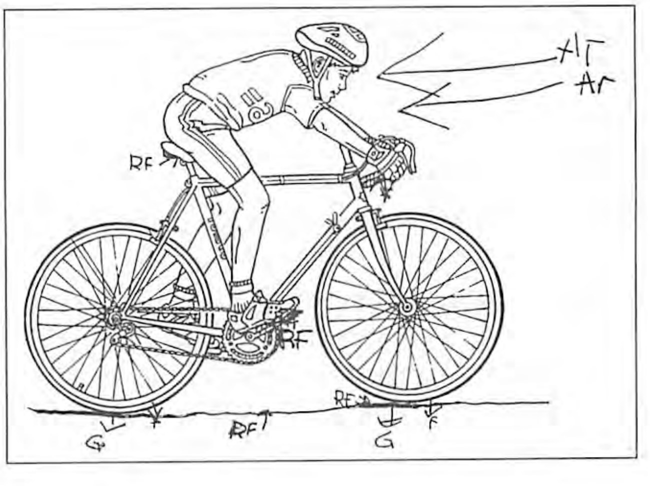
A Year 3/4 teacher used intervention to explore the effects of various forces separately. She asked children to explain how gravitational force, friction, air resistance and reaction forces work and then record which forces would act on a child on a moving bicycle. Children were encouraged to use arrows to show the direction of each force and to label each arrow. Individual drawings provided a focus for group discussions of their expressed ideas. This strategy revealed areas where children were making some progress and some points of difficulty. The work below illustrated as Figure 5.30 exemplifies an idea held by some children, that air resistance keeps things in the air. The drawing shows the deliberately constrained selection of forces nominated by the teacher for the purposes of this intervention.

Figure 5.30

<u>Multiple Forces</u>

Can you explain what these forces do?

Gravity	Keeps everything one the ground.
Friction	Stops things moveing
Air resistance	it trys Keep thing in the air.
Reaction force	thiags pashingback.



Y4 B M

In one Year 6 class, children regarded as able by the teacher addressed the effects of combined forces on movement. The children investigated the forces on a block moving at a steady speed and forces on a block moving at increasing speed. The children attached a newton-meter to the block to quantify their results. Children's work shows the interest they had in this activity. Many reported results systematically. Children varied in their ability to relate the results of their investigations to the concept of balanced and unbalanced forces. Some described their investigations but offered little in terms of interpretation.

At Key Stage 3, intervention focused on the effects of forces in combination. Children were encouraged to add and subtract forces. One teacher's journal comment suggests that children were working at the limits of their ability with only a few grasping the idea of resultant forces.

A few managed to add, subtract and obtain resultant forces.

Year 7 teacher

5.9 Some general issues arising from the intervention experience.

As well as the specific and precisely targeted issues which have been discussed in the earlier sections of this chapter, there are some more general points which arise from a review of intervention activities.

The whole programme of collaborative research into the learning and teaching of forces was exploratory in nature. One consequence was that all activities required careful planning, perhaps with very little precedent to build upon. Such planning for first time usage is much more time-consuming than the implementation of well-honed familiar activities where the spread of possible pupil outcomes is familiar. Teachers valued the suggestions which emerged as the result of group discussion and reflection, but only a fraction of possible activities were actually put into practice. Interventions were prioritised to address just some of the areas in which children might be helped to make progress. Consequently, the point made elsewhere is re-emphasised: the outcomes in terms of pupils' developing understanding resulting from the activities described in this chapter could not be described as optimal. Only a sub-set of ideas was addressed, with a small selection of the activities, conducted without prior experience. The next time around, teachers will be able to call on these experiences, pupils' expressed ideas will be less surprising and judgements about matching intervention activities to pupils' developmental needs will be made with greater confidence.

The idea of progression in understanding is incompatible with a dichotomous view that pupils either know, or do not know, the science. Progression in understanding, by definition, must include an acceptance of at least three points in understanding to accommodate something between complete ignorance and complete knowledge. The term we use for understandings in this middle range is 'intermediate understanding' and descriptions of progression identify possible sequences which pupils move through in learning pathways or 'trajectories'. At the project intervention meeting, teachers were concerned about their lack of overview, both of where the science was leading and of pupils' developing understanding. Such subject knowledge and knowledge of typical progression in pupils' understanding combine to inform 'pedagogical subject knowledge'. This chapter specifically, and the report generally, do not claim to present the last word on this subject. However, it is suggested that the reported activities are necessary and represent movement in the direction of a researched curriculum.

Much more could be said about the role of language in the development of pupils' conceptual understanding, but this is not the place to do so. Instances of teachers checking children's conceptual understanding before offering the correct technical label for an idea must suffice to make the point that the role of language in the socio-cultural transmission of science ideas is critical. Children's own circumlocutions and vernacular expressions are adequate until they outstrip their conceptual needs. The use of the terms 'push' and 'pull', for example, are sufficient to label a great deal of useful groundwork prior to the introduction of the abstraction of 'force' as a general label.

The rationale of validating understanding of science ideas by reference to evidence was one that seemed to gain acceptance amongst the participating teachers. Occasionally, there is a tension between this view and the pressure which insufficient time imposes on teachers. The limited time available in the intervention phases meant that there was little opportunity for lengthy interventions. There was evidence of attempts to link the evidence from several contexts and also to share a range of ideas through the medium of class discussion.

The university-based researchers were interested in the range of different representational forms which teachers would encourage children to use, since the theoretical underpinning of the model of conceptual change was one of Representational Redescription, (Karmiloff--Smith, 1992). This theoretical position suggests that pupils represent their knowledge in a variety of ways, with the central co-ordinating modality of language 'redescribing' that knowledge in a conscious, self-aware or metacognitive manner. Knowing about forces thus might entail whole-body kinaesthetic knowing, as for example, knowing intuitively about balance, or co-ordinating velocities of vehicles moving in different directions when crossing the road safely. Quantification is another mode of knowing, as is two-dimensional drawing using arrow conventions or narrative sequences which describe causal chains. The formalism of scientific investigation in which variables are defined, controlled and measured adds another dimension. Knowledge of forces might entail the representation of several such sources of internalised information which is co-ordinated into a coherent, multi-faceted account which give us that confident sense which we call 'understanding'. The important point is that this theoretical stance was entirely compatible with teachers' inclination to adopting a range of experiences using different perspectives to sharpen or bolster children's knowledge.

The next chapter documents in more quantitative form the shifts in understanding about forces which have been introduced in more descriptive terms in this chapter.