6. CHANGES IN CHILDREN'S IDEAS

This chapter presents and interprets data summarising shifts in children's ideas about forces. The data are drawn from written classroom-based assessments, most of which had been associated with physical events and phenomena managed in their classrooms by teachers during earlier phases of the project. Children recorded their ideas in booklets which contained the stimulus questions and relevant illustrations. Every child in each participating class completed the booklets. (In one or two cases, where teachers of younger children experienced time pressures, not all children completed the booklets.) The same sub-sample as was interviewed prior to the intervention activities was re-interviewed. This sub-sample comprised, as far as possible, six children from each participating class, three boys and three girls, one each of high, medium and low overall scholastic achievement according to their teacher's judgement. (This ideal distribution was adjusted and roughly balanced across the sample to accommodate the participation of single-sex schools or small schools in which the representation of pupils was particularly uneven.) The interview sample was 42 children at Key Stage 1 (5-7 years); 29 at Lower Key Stage 2 (7-9 years); 29 at Upper Key Stage 2 (10-11 years) and 18 at Key Stage 3 (11-14 years).

Each pupil was interviewed with his or her responses in the booklet being the initial stimulus for discussion. The booklet provided a focused agenda and the interview offered the opportunity to clarify the ideas already presented, as well as a chance to probe further. The minimal outcome was a clearer understanding of each child's thinking with respect to the ideas which had been targeted. In some cases, children were unable to offer any well-developed views. This was accepted in the knowledge that the requirement to make a written response was not the hurdle. In other cases, children actually changed their ideas significantly, or in emphasis, in their interview responses as compared with their written expression. When this happened, the more recent idea was recorded and coded. It was also possible for children to articulate their ideas more fully, perhaps by elaborating or providing instances or evidence. These more extensive comments provide a rich qualitative resource to illustrate and validate the more compact written responses.

All interviews were recorded in note form, using available space in the pupils' booklets. They were also audio-recorded and some were video-recorded. The latter occurred when opportunity arose, depending on the level of ambient noise and available space. All interviews were conducted during researchers' pre-arranged visits to schools, children being withdrawn singly to a quiet room or corner in the school for this purpose.

In order to make the mass of data collected comprehensible to readers, the initial discussion is presented in three sections. Any such division is to some degree arbitrary. Our decision was based on the notion of children's starting points and increasing complexity of ideas. The three sections are thus:

6.1 Some general ideas about forces;

6.2 Ideas about some specific forces;

6.3 Balanced and unbalanced forces.

There may be an understandable temptation to think of the data presented in this chapter as the outcome of a precisely targeted intervention, in the manner of an experimental treatment.

The data are emphatically not the outcome of such an experimental design. It is extremely difficult, if not impossible, for practical purposes, to match learning outcomes to the kinds of intervention to which individual children were exposed since most activities were conducted as normal classroom interactions with no outside observer or other means of recording detail. Also, from a practical perspective, we know that every teacher was not able to review children's pre-intervention responses thoroughly and match the suggested repertoire of intervention techniques to the particular ideas prevailing in their classrooms in the time available. The virtue of ecological validity – working with real teachers in their classrooms – also has its downside. The demands of the National Curriculum on teachers' time remained during this piece of research.

For the reasons suggested above, the data can be expected to be conservative in the extent to which they capture the possibilities of conceptual change. A more precise targeting of interventions to expressed ideas might be assumed to be more likely to result in optimal levels of conceptual change. What is reported here are the far more amorphous shifts within a group comprising pupils of different ages who have been subjected to a range of experiences which cannot be precisely reconstructed or reported. Nonetheless, there are shifts to be seen. Such shifts are informative, pointing to susceptibilities to development within the age group studied which might be more widely exploited.

6.1 Some general ideas about forces

The preliminary explorations with children gave indications that for many of them the scientific meaning of the word 'force' was not well understood. In consequence, questions which included the word 'force' led to responses of severely limited validity. It therefore seemed more appropriate to explore and assess children's understandings of the effects of forces through the deliberate use of the words 'push' and 'pull' within some of the intervention activities and post-intervention questioning.

6.1.1 Defining pushes and pulls

Children were asked to, 'Write how you decide whether you are pushing something or pulling it'. 'Push' is an everyday word in most children's vocabulary from an early age. The common meaning of the word is to exert a force on a body to move it away from the self (or from whatever else it is that exerts the force). At Key Stage 1 and 2, roughly twice as many children described a push as a movement forward as referred to a movement away. (See Table 6.1)

A push is when I push a draw

Interview response: *Pushing is when it goes forward (push a drawer).*

A pull is when I pull my shos on

Interview response: *Pulling is when it goes backwards (pull my shoes on).*

Y2 B M

This pattern was reversed at Key Stage 3, the notion of movement away from the self predominating. About one fifth of Key Stage 3 subjects also appreciated that the arm could be extended to provide a push on an object *towards* the self. A small number of children (two KS1 pupils and one KS2) confused push with pull. This was not the more sophisticated realisation described by Key Stage 3 children. These younger children used a pulling movement to define a push.

Most younger children defined a pull as an action which caused a movement *backwards,* with far fewer describing it as causing a movement *towards* the self. As with responses to push, this pattern was reversed in the Key Stage 3 responses where the *towards* the self response predominated. Again, about one fifth revealed the appreciation that the arm could be extended and an object could be pulled away from the self. One Key Stage 1 child demonstrated a clear confusion of pull with push.

Table 6.1 Distinguishing between a push and a pull

	Post-Intervention			
	KS1 n=42	**LKS2** n=29	**UKS2** n=29	**KS3** n=18
Push				
correct position of agent	-	-	-	22 (4)
forwards	43* (18)	45 (13)	59 (17)	28 (5)
away	21 (9)	31 (9)	24 (7)	44 (8)
backwards/towards	5 (2)	3 (1)	-	-
other	31 (13)	21 (6)	17 (5)	6 (1)
Pull				
correct position of agent	-	-	-	22 (4)
backwards	48 (20)	48 (14)	55 (16)	28 (5)
towards	24 (10)	31 (9)	38 (11)	44 (8)
forwards/away	2 (1)	-	-	-
other	26 (11)	21 (6)	7 (2)	6 (1)

* Pecentages, raw numbers in brackets.

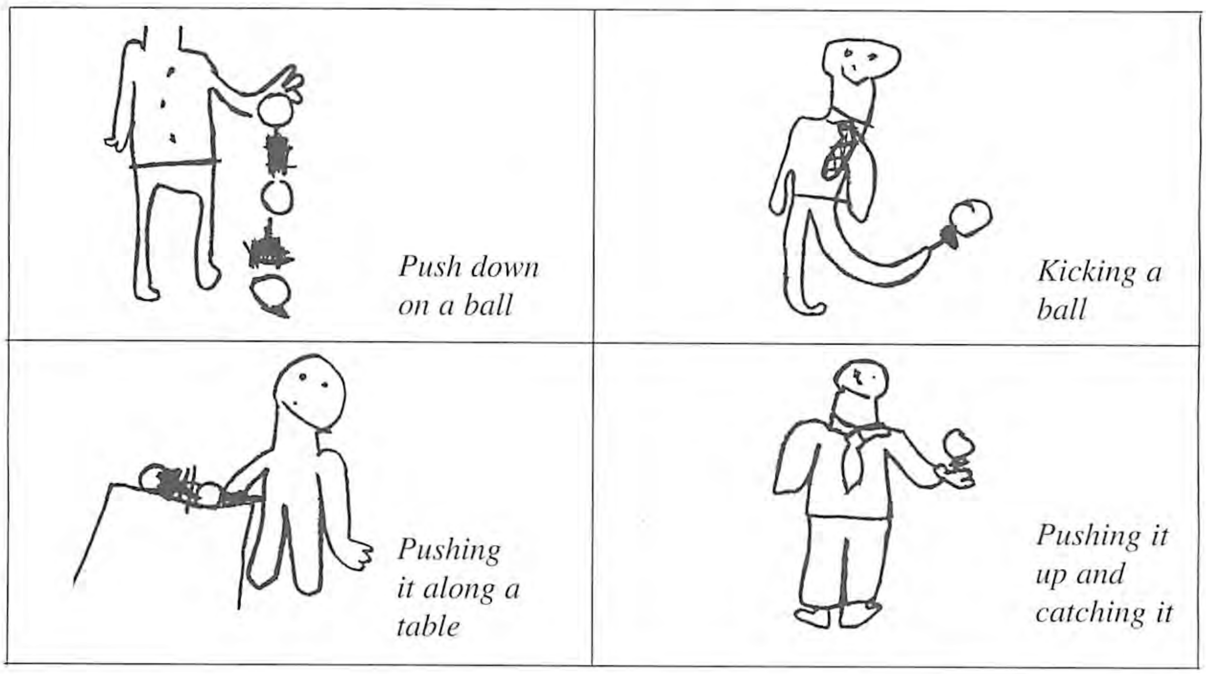
In summary, most children understand the distinction between push and pull actions which cause movement, though a few of the younger children in the sample confused the two. Mostly, this understanding is egocentric, being defined as something done by people in relation to the position of the self. (An instance was observed amongst KS1 children of confusion that it was possible for one object – a trolley - to be moved by two people, one pushing and one pulling.) About a fifth of Key Stage 3 pupils appreciated that a push could be towards the self and that a pull could be away from the self.

6.1.2 Examples of pushes and pull

Key Stage 1 children were asked to think about what they do when they push and pull and to then write or draw four things they do which are pushes and four things they do which are pulls.

The pattern of responses was very similar for push and pull examples. About two thirds of the Key Stage 1 interview sample were able to provide four examples, as requested. Only one child was unable to give any examples. The remaining third of the sample was able to provide three, two or one examples of a push or pull.

Figure 6.1 Examples of pushes.

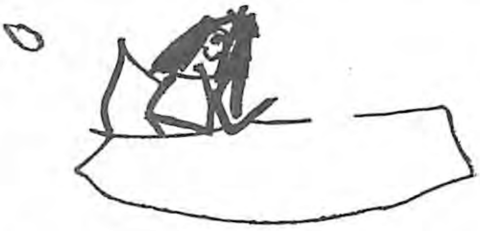


Y1 G H

This example drawn from the Year 1 sample is interesting because it shows a child's recognition that actions such as kicking and throwing a ball can be understood as pushes.

Figure 6.2 Examples of pulls.

my dog is pulling me across the road



Sophie is pulling her bed sheet off

Pulling my bike because it is not working

I'm putting my dolly into the air and pulling it down

RGM

Confusions between pushes and pulls were in evidence in about one fifth of the sample. This might prompt the question whether it is important for young children to be able to distinguish between pushes and pulls. In their early dealings with forces, we want children to begin to think about and understand some fundamental causal relationships. Specifically, we want them to understand that if something changes its movement, it does so *only* as the result of a force acting, very often the result of some other object moving. (Forces acting at a distance - magnetism and gravity, for example - also have to be considered at some later point.)

The verb 'to move' confuses the picture to some degree, because it is used both transitively and intransitively. We can say, 'I move the object' or, 'I move', meaning 'I move myself'. As we will see, children's ideas of movement tend to be, initially at least, preoccupied with their own and others' *intentional* movements, (using the intransitive sense of 'to move'). This has to be taken into account in the context of our efforts to encourage children to begin to think analytically about the nature of the relationship between 'bodies' in the sense in which physicists use the term. This includes distinguishing between pushes and pulls and recognising that forces occur not in isolation but between at least two objects. The issue of who or what is doing the pushing and pulling is a theme which recurs over time in the study of forces as well as in other areas of the National Curriculum. In the part of the curriculum which deals with *Materials and their Properties*, for example, the properties of materials as capable of being deformed by a push (squeezing) or a pull (stretching) are considered. Such ideas may be seen as moving the ideas of push and pull from the subjective to the objective.

6.1.3 Examples of one push and one pull by non-human agents.

Young children seem predisposed to be interested in active involvement, especially whole-body movement. This characteristic is often exploited by teachers. Indeed, the question requiring children to distinguish between pushing and pulling was framed in terms of children's own actions. The question thus arose as to the extent to which children were able to think of pushes and pulls as something which might happen between non-human or inanimate agents. To address this issue, children were asked directly, 'Can you think of a push that is not done by a person?', followed by a parallel question relating to pulls.

Table 6.2 One example of a push by a non-human agent.

	Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
Living Things				
person	10 (4)	3 (1)	-	-
non-human animal	21 (9)	17 (5)	7 (2)	-
plant	2 (1)	-	-	-
Natural events				
wind	21 (9)	34 (10)	28 (8)	11 (2)
other natural phenomena	2 (1)	7 (2)	-	-
Human artifacts				
wheeled vehicle	14 (6)	10 (3)	17 (5)	6 (1)
mechanical	12 (5)	10 (3)	14 (4)	11 (2)
Specific named forces				
friction	-	3 (1)	3 (1)	11 (2)
upthrust	-	-	1 (3)	6 (1)
magnetic repulsion	-	-	-	17 (3)
air/resistance	-	-	3 (1)	22 (4)
gravity	-	3 (1)	3 (1)	-
Don't know,' other responses or non-instances	17 (7)	10 (3)	14 (4)	17 (3)

Table 6.2 summarises responses. It must be noted that children were required to provide only one example, so the the distribution of responses across the various response categories might be thought of as an indication of what first comes to children's minds when asked to think of a push which is not done by a person.

The proportion of children across all age groups who failed to provide a response meeting the criterion of a push by a non-human agent was higher than expected, ranging from 10 to 17 per cent. This does not include those for whom it appears to have been irresistible (five of the younger children in the sample) to include a human agent in their example, despite the clear restriction in the request. Younger children were more inclined to include examples involving animals. One example referred to a plant.

a flow pushing its selfs up

A flower pushing itself up.

Y2 G M

an animal can push a box with it's head.

An animal can push a box with its head.

Y3 B H

my Bude ~~krets~~ gets the Ball with its Beack and Brings is to him.

My budgie gets its ball with its beak and pulls it up

Y1 G H

Natural events, especially the wind, were identified as capable of exerting a push by more than a quarter of children in the three younger age groups, being the predominant form of response of the Lower Key Stage 2 group. Water and geological events were mentioned by a very small minority.

when the wind blows the branches of the trees

When the wind blows the branches of the trees.

Y3 B H

A rock pushing another rock. It might happen if it's dead rainy. Thunder and lightning would hit a rock and move another rock.

Y2 B L

Human artifacts were mentioned by between one fifth and one third of children in each of the three lower age groups. This was the most common category of response amongst the Upper Key Stage 2 group. Examples in this category showed roughly equal representation of wheeled vehicles and other forms of machinery or mechanical devices.

a car can Force it self Forward.

A car can force itself forwards. The engine pushes the car.

Y4 B H

We have to bear in mind that such expressions as 'the engine pushes the car' are only part of the story, perhaps sufficient to convey meaning in an everyday sense. In physics language, the story has to continue, to describe the role of the road in pushing the car, provided the wheels are turning. Such issues will be considered more fully in Section 6.3 of this chapter.

Specific named forces were the most common form of response offered by the Key Stage 3 pupils, with just a sprinkling from Key Stage 2 and no such offerings from Key Stage 1. As well as a growing technical awareness, the older pupils were no doubt more conscious of the scientific context of the probe and follow-up interviews and this possibly steered them towards a more formal exemplification. The distribution of the most frequently named forces is recorded in Table 6.2.

Air resistance

Y9 B L

In the light of these data, a tentative progression in children's thinking about pushing agents is suggested. Key Stage 1 children think of themselves and others as capable of pushing, and this is generalised to other living things. They seem to favour the intransitive use of 'to move' with its connotations of 'capable of movement', an attribute of living things. Lower Key Stage 2 children reveal more awareness of pushes happening in the natural world, especially associations with the pushing of the wind. There are strong reminders of Piaget's (1929) and Laurendau and Pinard's (1962) descriptions of children's animistic beliefs about the wind here. Upper Key Stage 2 children's responses are weighted more towards machines. We might see this as a move from subjective to objective. At Key Stage 3, the examples of pushes are abstracted and depersonalised, using technical terms for forces, in particular 'air resistance', 'magnetic repulsion', 'friction' and 'upthrust'.

The picture emerging from the parallel data concerned with identifying one pull has many similarities with the above discussion with the exception that natural events diminished dramatically. This diminution in citing of natural events is chiefly attributable to the absence of references to wind, as compared with the push examples. A small number cited wind exerting a pull, (three children at KS1 and two at KS2.) As with pushes, the youngest age group referred most frequently to pulls by living things. At Lower Key Stage 2, since natural events were scarcely mentioned, living things continued to predominate in the examples offered. The Upper Key Stage 2 children referred more to human artifacts than to any of the other response categories. (Examples of human artifacts were offered only by KS1 and KS2 pupils, with wheeled vehicles and other forms of machinery once again mentioned in equal numbers.) Key Stage 3 pupils favoured technical examples once again, though gravity (being offered by two thirds of this age group) tended to overwhelm any other possibility. It was interesting to note that gravity was also suggested by about one fifth of Upper Key Stage 2 pupils and about half as many at Lower Key Stage 2. The shift towards more formal and abstract instances of forces is in evidence at Key Stage 2, no doubt as the result of formal instruction.

In general, the age-related shift from egocentric examples through other living things, to examples in the physical world, human artifacts and specific named abstract forces is confirmed. This progression might be a useful way of structuring teaching experiences and reviewing children's learning outcomes.

Table 6.3 One example of a pull by a non-human agent.

	Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
Living things				
person	5 (2)	3 (1)	-	-
non-human animal	31 (13)	34 (10)	17 (5)	6 (1)
Human artifacts				
wheeled vehicle	12 (5)	10 (3)	17 (5)	-
mechanical	12 (5)	14 (4)	17 (5)	- -
Natural events				
wind	7 (3)	3 (1)	3 (1)	-
other natural phenomena	2 (1)	-	-	-
Specific named forces				
gravity	-	14 (4)	21 (6)	67 (12)
friction	-	-	7 (2)	-
magnetic attraction	-	3 (1)	3 (1)	6 (1)
'Don't know,' other responses or non-instances	33 (14)	17 (5)	14 (4)	22 (4)

6.1.4 'Force' as the term for pushes and pulls.

Children were asked, 'What name do we use in science for all kinds of pushes and pulls?'. The idea behind this question was to discern at what point (and how extensively) the ideas of pushes and pulls were abstracted into the more generalised understanding to which we assign the label 'force'. Table 6.4 shows that older children, in particular, responded with a range of technical words (for example, 'gravity,' 'friction,' 'power'). At Key Stage 1, only one fifth of the sample produced the word 'force'. At Key Stage 2, around half the sample was able to make the generalisation while at Key Stage 3 the figure rose to about 90 per cent. The following responses illustrate the elaborations offered by two children who used the word 'force'.

Int *What does a force do?*

Ch *It makes things move.*

Int *Does it do anything else?*

Ch *Makes it move more. It can make it stop.*

Y2 B H

Ch *[Forces] change the nature of things around them. Gravity keeps us down. Friction slows us down. Magnetic forces attract some metal objects.*

Y7 B H

Table 6.4 'Force' as the term for pushes and pulls

	Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
force	21 (9)	59 (17)	48 (14)	89 (16)
other technical names	2 (1)	14 (4)	45 (13)	11 (2)
word related to force	2 (1)	3 (1)	-	-
description of action	-	3 (1)	-	-
Don't know,' and other responses	74 (31)	21 (6)	7 (2)	-

This finding underlines the age-appropriateness of dealing with specific events to be referred to as 'pushes' and 'pulls' at Key Stage 1. It became apparent as the result of talking to young children that the term 'force' actually constitutes a difficult abstraction, one that is not easily accessible to children at Key Stage 1.

6.1.5 Pushes and pulls in order of magnitude.

Quantification is central to scientific enquiry. In the course of the research, consideration was given to the manner in which children might be encouraged to think about forces as phenomena having magnitude. The logico-mathematical operations explored by Piaget (1929) offered a useful precedent, especially when coupled with the practices, commonly adopted in Key Stage 1 and Key Stage 2 classrooms, used to introduce other concepts of measurement. Putting examples in order of magnitude was one of the starting points decided upon. Children were asked to think of a very small push, then a very big push and finally a medium-sized push, writing or drawing their choices for each in the boxes provided. Results are summarised in Table 6.5. A parallel set of questions was presented with respect to pulls and the results of that aspect of the enquiry are presented in Table 6.6.

Table 6.5 Examples of pushes in order of magnitude.

	Post Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
3 pushes, ordinal	45 (19)	55 (16)	34 (10)	28 (5)
3 pushes, not ordinal	36 (15)	31 (9)	38 (11)	22 (4)
pushes and pulls	5 (2)	-	-	11 (2)
ambiguous responses	2 (1)	3 (1)	3 (1)	22 (4)
2 pulls, ordinal	7 (3)	10 (3)	10 (3)	6 (1)
other responses	5 (2)	-	14 (4)	11 (2)

Table 6.6 Examples of pulls in order of magnitude

	Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
3 pulls, ordinal	38 (16)	59 (17)	31 (9)	33 (6)
3 pulls, not ordinal	33 (14)	21 (6)	21 (6)	11 (2)
pulls and pushes	2 (1)	7 (2)	7 (2)	-
ambiguous responses	5 (2)	7 (2)	17 (5)	39 (7)
2 pulls, ordinal	10 (4)	3 (1)	10 (3)	11 (2)
other responses	12 (5)	3 (1)	14 (4)	6 (1)

Results show some surprising features which might lead one to question the reliability of the data were it not for the similarities between the two sets of results. There is not a trend of increasing success with age. In both instances, the two younger groups perform better than the two older ones, with the peak of performance at Lower Key Stage 2. (See Figure 6.3).

Figure 6.3 Pulls and pushes in order of magnitude

	very big	medium sized	very small
pull	*pulling a wagon across the road*	*pulling a toy*	*pulling a a leaf off a tree* 
push	*pushing a lampost over* 	*pushing my dad out of bed*	*pushing a teddy over*

Y2 G H

There is a very high incidence in all groups of the three examples given being valid cases of pushes or pulls but not ordinal in magnitude. This tendency was slightly less amongst the Key Stage 3 respondents who were more likely to offer ambiguous responses. That is, the order of magnitude of the pushes or pulls which they suggested could not be judged by an independent assessor. This was due to a tendency to include named forces of unspecified magnitude. (See Figure 6.4).

Figure 6.4 Pulls and pushes in order of magnitude

	very big	medium sized	very small
pull	gravity	person	apple
push	rocket	person	piston

Y7 G H

A significant proportion of pupils offered only two instances of pushes and two instances of pulls: eight per cent of the total sample in each case, while a similar proportion offered other responses not meeting the questions' criteria.

How might these patterns of success (and lack of success) be explained? There is no doubting that the older pupils knew more about forces in a formal sense, for this is confirmed by their responses to many of the other questions posed. On this occasion, it seems likely that the Lower Key Stage 2 children responded in an intuitive manner and succeeded in making unambiguous qualitative distinctions. It is possible that knowing more about forces interfered with the Key Stage 3 pupils' willingness to respond in a similarly direct qualitative fashion. Responding by reference to named forces required that differences in magnitude needed to be equally explicit, in formal terms. These tended not to be explicit, so many of the Key Stage 3 responses could not be said to describe an unambiguous ordinal relationship in the values suggested.

6.1.6 Identification of a force-meter and understanding its uses

A consideration of forces in the curriculum would be expected, at some point, to deal with the issue of how force is quantified and measured. In the course of the research work with teachers, the team came to realise the part that children's own non-standard measuring devices might play. The construction and use of such devices was more developed as an idea rather than an actuality in the research schedule, but it was of interest to ascertain the extent of the sample's familiarity with standard devices for measuring force, namely force-meters (or newton-meters). The manner in which familiarity with such devices was tapped was through the use of a photograph accompanied by the question, 'What is this measurer called?' Responses to this question before and after intervention are summarised in Table 6.7. (Since use of force-meters at KS1 was not expected, the question was not presented to the youngest age group.)

Figure 6.5

Post-intervention, about half of the Lower Key Stage 2 sample named the pictured measuring device as a newton-meter or force-meter.

This represented an increase in comparison with the same sample's responses pre-intervention. Of course, a number of children referred to the device as a 'spring balance', which it undeniably is, often being graduated in grams as well as in newtons.

Table 6.7 Identification of a newton-meter

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
newton-meter		24 (7)	37 (11)	56 (10)		45 (13)	34 (10)	61 (11)
force-meter		-	-	-		7 (2)	-	17 (3)
pull-meter		-	-	-		3 (1)	-	-
spring balance		14 (4)	-	22 (4)		10 (3)	-	17 (1)
weigher		14 (4)	-	6 (1)		-	-	-
other named instrument		10 (3)	7 (2)	-		3 (1)	7 (2)	-
'Don't know,' and other responses		37 (11)	55 (16)	17 (3)		31 (9)	59 (17)	6 (1)

The question following the identification of the force-meter asked children, 'What does it measure?'. The most generalised and accurate response might be expected to take the form, 'It measures force', or 'It measures force in newtons'. Since newton-meters often double as devices for weighing things, responses referring to 'weight' or units of mass were also expected. Responses are summarised in Table 6.8.

Pre-intervention, younger pupils' responses referred predominantly to 'weight' or 'grams' with none mentioning 'force' and only a few mentioning 'newtons'. From the Key Stage 3 pupils (who would be expected to have had some experience of measuring forces) about one quarter of responses referred to 'force', one quarter to 'newtons' and one quarter to 'weight'.

The post-intervention data strongly suggest that some modification of ideas took place. 'Force' or 'newtons' accounted for about one quarter of the Lower Key Stage 2 responses, about one third of the Upper Key Stage 2 responses and three quarters of those at Key Stage 3. Responses referring to the measurement of 'force' arguably suggest awareness of a continuous physical quantity whereas the specification of units might connote a more limited understanding of discrete categories.

Table 6.8 Property measured by newton-meter

	Pre-Intervention				Post-Intervention			
	KS1 n.a	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**	**KS1 n.a.**	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**
force		-	-	28 (5)		10 (3)	14 (4)	50 (9)
pulls		3 (1)	-	6 (1)		10 (3)	3 (1)	11 (2)
weight		48 (14)	24 (7)	28 (5)		28 (8)	21 (6)	6 (1)
other named force		-	-	6 (1)		3 (1)	-	-
newtons		3 (1)	21 (6)	28 (5)		14 (4)	21 (6)	28 (5)
grams		10 (3)	17 (5)	-		7 (2)	3 (1)	-
mass		-	-	-		-	-	6 (1)
named objects		21 (6)	14 (4)	-		14 (4)	10 (3)	-
other physical quantities		7 (2)	3 (1)	-		7 (2)	10 (3)	-
Don't know' and other responses		7 (2)	21 (6)	6 (1)		7 (2)	17 (5)	-

Pupils were further asked to, 'Give two different ways that it can be used to measure'. The idea behind this request was to point up the distinction between horizontal and vertical uses of the instrument. Those pupils who thought in terms of measuring 'weight' would be unlikely to do this with the meter in the horizontal position. The question thus offered a strong invitation to express ideas about measuring forces more generally, since this would be the most likely reason to use the meter in the horizontal orientation. Table 6.9 summarises the results of this part of the enquiry.

Pre-intervention, more than half of the students at both Key Stage 2 and Key Stage 3 suggested a *vertical* use of *hanging things* on the meter or *pulling down* on it in the vertical position. Many referred to the possibility of using the meter to weigh objects. Post-intervention, references to vertical use of the meter actually diminished.

You can put it on something and lift it up and see what it weighs. You could try and lift sugar.
If it goes down to 10 you've got loads in it.

Y3 B M

You can put something on the hook and it will pull down and it will measure.

Y4 G L

You put weights on the hook and hold it and read the newtons.

Y9 B H

You pull it from the end. You can measure how big the pulling force is.

Y9 B H

Table 6.9 Using newton-meter vertically and horizontally

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
Indication of vertical use								
hang/pull down		55 (16)	55 (16)	61 (11)		34 (10)	41 (12)	28 (5)
weight		28 (8)	10 (3)	33 (6)		17 (5)	14 (4)	33 (6)
Indication of horizontal use								
pull along		3 (1)	3 (1)	28 (5)		10 (3)	34 (10)	17 (3)
Summary of responses								
vertical and horizontal uses suggested		3 (1)	3 (1)	28 (5)		7 (2)	28 (8)	17 (3)
vertical use only		79 (23)	66 (19)	67 (12)		45 (13)	32 (9)	44 (8)
horizontal use only		-	-	-		3 (1)	3 (1)	-
other responses		17 (5)	31 (9)	6 (1)		45 (13)	38 (11)	39 (7)

A suggestion for the horizontal use of the force-meter was comparatively rare amongst Key Stage 2 pupils pre-intervention, while a quarter of Key Stage 3 subjects indicated that it could be used in the horizontal position to *pull* things. This awareness increased in the Key Stage 2 sample following intervention activities, but diminished amongst those at Key Stage 3.

It seems that the use of the force-meter for measuring forces was not at all well established or understood in any of the age groups participating in the study. This may be attributable to a lack of experience. This situation is not helped by the fact that there are few commercially available force-meters which have been designed to measure pushes. It is tempting to suggest that Key Stage 3 pupils' uncertainties were actually increased as the result of further activities, perhaps their confidence about its use as an instrument for weighing things having been put on hold.

Table 6.10 indicates that, in contrast to their lack of knowledge about how to use a force-meter and for what purpose, many pupils could name the unit in which the force-meter measures. About one fifth of Key Stage 2 pupils hazarded the guess that the meter measured in units of length, possibly cued by the linear scale (visible in the photograph of the meter).

Table 6.10 Unit in which newton-meter measures

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
newtons		14 (4)	34 (10)	94 (17)		48 (14)	31 (9)	100 (18)
gram/kg/mass unit		31 (9)	34 (10)	-		-	14 (4)	-
newton and gram		-	-	-		3 (1)	3 (1)	-
other units		21 (6)	3 (1)	-		21 (6)	28 (8)	-
Don't know' and other responses		34 (10)	28 (8)	6 (1)		28 (8)	24 (7)	-

6.1.7 Representing forces using the arrow convention

Several questions invited the use of arrows to identify and label forces acting in various situations. Responses reveal, to some extent, pupils' understanding of the use of arrow conventions to describe the direction and magnitude of forces though not all cues to use arrows made an explicit request for a formal representation. More general issues associated with the use and interpretation of arrows will also be discussed in later sections. (See for example, Section 6.3.2.1). At this point, a specific and focused requirement to *interpret* the use of given arrows is discussed. The reference is to a question showing a milk bottle held by a hand. A long arrow points vertically upwards while a short arrow points vertically downwards. Children are asked, 'What exactly do the arrows on the drawing tell you about the forces acting?'. The responses were analysed for references to *direction* and *magnitude* (*Movement* represented by the arrow convention is discussed in later sections.) While it was possible to interpret the drawing as representing a bottle decelerating towards the ground, this was not an expected response in the age group under consideration. (Another explanation which is consistent with the drawing is that the bottle is accelerating away from the ground, or more simply, moving upwards. It was the interpretation of the magnitude and direction of the arrows which was drawn from responses for the purpose of this discussion even though pupils might have volunteered information about the resultant movement).

This question was presented to the Key Stage 2 and Key Stage 3 pupils as a pre-intervention activity. The results were that only about one third of each age group referred to the direction of the force while even fewer (one pupil each at Upper KS2 and KS3) referred to magnitude. Data are summarised in Table 6.11. The inference was drawn that Key Stage 2 and Key Stage 3 children in the research sample, for whatever reason, had not been exposed to teaching of this particular convention, prior to intervention. The view was that these conventions were certainly appropriate to the Key Stage 3 sample pupils, so the question was posed a second time to this group, post-intervention, but not to the Key Stage 2 group. Judgement as to the appropriateness for Key Stage 2 was suspended.

Table 6.11 Arrow representation of forces - direction and magnitude

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=n.a.	LKS2 n.a.	UKS2 n.a.	KS3 n=18
Direction								
direction, general		3 (1)	10 (3)	28 (5)				-
upward and downward force		14 (4)	7 (2)	6 (1)				83 (15)
upward force only		10 (3)	3 (1)	-				-
downward force only		3 (1)	3 (1)	-				6 (1)
direction not mentioned		69 (20)	76 (22)	67 (12)				11 (2)
Magnitude								
upward force greater		-	-	6 (1)				50 (9)
upward force same size		-	3 (1)	-				6 (1)
size not mentioned		100 (29)	97 (28)	94 (17)				44 (8)

The post-intervention responses of the Key Stage 3 group showed a dramatic positive shift in the appreciation of the directional information about forces conveyed by the arrows on the milk bottle. There was also a very significant positive shift in their appreciation of magnitude, but not quite to the same degree as the shift in understanding with respect to direction.

The down arrow is the force of gravity and the up arrow is the force of the person's hand on the bottle. The upward arrow is longer so the upward force is greater than the downward force so the bottle is being picked up or lifted.

Y9 B M

The boy is picking up the milk bottle. You can tell because the force pulling up is more than the force of gravity.

Y7 B H

Forty-four per cent of the Key Stage 3 sample did not link the size of the arrows to the magnitude of the forces on the bottle.

There is one arrow which means gravity and one arrow which means weight.

Y7 G L

The dramatic shifts apparent in the data in Table 6.11 suggest that, when directly addressed, the arrow conventions of direction and magnitude of forces seems to be fairly readily accessible to Key Stage 3 pupils. This fact, together with some Key Stage 2 teachers' success in helping children to represent forces using arrows, suggests that the convention is worth exploring with Key Stage 2 pupils also.

6.2 Ideas about some specific forces

6.2.1 Ideas about the gravitational force of the Earth

The Key Stage 2 Programmes of Study in the National Curriculum refer to the knowledge '*that objects have weight because of the gravitational attraction between them and the Earth*'. This carefully worded expression acknowledges the necessity of conceptualising gravitational attraction as something that happens *between* objects. In time, children will be expected to move to an appreciation of the role of mass and distance in such relationships, but our focus was on direction only. Asking whether the Earth's gravitational attraction is a push or a pull presupposes that it is understood as a force between two objects. This fact justifies presenting such a question but does not imply a belief on the part of the researchers that children universally shared such a view. Indeed, an important developmental issue seems to be a movement away from the personalising of forces towards an objective view. An *intermediate understanding* might be that forces are seen as the properties of objects.

While a view that gravity is a property of the Earth to attract objects to its surface would be less than correct in the physicist's understanding, in an educational and developmental context, we have to make decisions as to whether such stated beliefs constitute positive progress in the direction of a more complete conventional scientific understanding. If we believe such ideas constitute conceptual progress, we must decide how to treat them as useful while stopping short of validating them, for all time, as correct beliefs.

Children's confusion as to whether the effect of the Earth's gravitational force on objects is a push or a pull is established in the literature concerned with ideas about forces. The finding that some children might describe gravity as *both* a push and a pull adds another dimension. The push/pull confusion with respect to gravity became apparent in the research reported here during initial explorations of children's thinking. Once recognised, the issue was specifically addressed. Children were asked, 'Is the effect of gravity on objects a push, a pull or both?'. They were then asked to tick one of the three boxes matching these options, followed by the request to, 'Explain how gravity works'.

Table 6.12 summarises children's choices of the direction in which the force of gravity acts on objects. Pre-intervention data reveal about the same proportion of Lower Key Stage 2 children describing gravity as a push as described it as a pull. Both of these reduced in frequency post-intervention, with choices shifting towards 'push *and* pull'. This group may be influenced by context-specific ideas about gravitational forces which are assumed to work in different directions in different situations.

Table 6.12 Effect of gravity on objects in terms of push and pull

	Pre-Intervention				**Post-Intervention**			
	KS1 n.a.	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**	**KS1 n.a.**	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**
gravity is a pull		41 (12)	41 (12)	72 (13)		31 (9)	55 (16)	83 (15)
gravity is a push		45 (13)	55 (16)	22 (4)		21 (6)	24 (7)	6 (1)
gravity is a push and a pull		7 (2)	3 (1)	6 (1)		45 (13)	17 (5)	11 (2)
no response		7 (2)	-	-		3 (1)	3 (1)	-

The Upper Key Stage 2 post-intervention data show an additional 14 per cent defining the force of gravity as a pull with the 'push' responses declining. As with the younger group, the tendency to define gravity as both a push and a pull increased.

At Key Stage 3, the already high proportion of pupils defining gravity as a pull increased from 72 per cent to 83 per cent.

The post-intervention summary is that the Earth's gravitational force on objects was correctly defined as a pull by about one third at Lower Key Stage 2, about half at Upper Key Stage 2 and about four fifths at Key Stage 3. If these cross-sectional data are taken as offering a clue to progression in understanding, the development is relatively steady across the seven years under consideration. It is nonetheless the case that a significant number of children of all ages viewed the Earth's gravitational force as a push, the figure remaining at six per cent even at Key Stage 3.

The follow-up question, 'Explain how gravity works.', was designed to encourage children to elaborate their basic statement about direction towards description or explanation of the *mechanism* of the Earth's gravitational force. Results are summarised in Table 6.13.

Table 6.13 How gravity works

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
gravity is:								
attraction between masses		-	-	-		-	3 (1)	6 (1)
force between Earth and masses		-	-	-		3 (1)	-	11 (2)
pull of Earth		-	-	39 (7)		3 (1)	17 (5)	44 (8)
due to spin of Earth		3 (1)	-	-		3 (1)	3 (1)	6 (1)
keeps things down		14 (4)	10 (3)	11 (2)		21 (6)	38 (11)	28 (5)
stops floating away		3 (1)	17 (5)	22 (4)		3 (1)	7 (2)	-
pulls things down		-	7 (2)	6 (1)		24 (7)	17 (5)	-
pushes things down		3 (1)	-	6 (1)		10 (3)	3 (1)	-
caused by push of air		7 (2)	3 (1)	-		3 (1)	3 (1)	-
because Earth like a magnet		-	-	-		3 (1)	-	6 (1)
Don't know,' and other responses		69 (20)	62 (18)	17 (3)		24 (7)	7 (2)	-

Before intervention activities, no children expressed an understanding of gravitational force in the most generalised manner, as an attraction *between masses*, or more specifically, as an attractive force *between* the Earth and other masses. About one third of Key Stage 3 pupils described gravity as a property of the Earth.

Gravity pulls things to the centre of the Earth

Y9 B L

Two thirds of Key Stage 2 children could not begin to explain how gravity works. Those who were able to formulate a response tended to describe gravity in terms of its effects - something which keeps things down or stops things floating away. About one third of Key Stage 3 pupils used similar descriptions to explain how gravity works.

Because gravity pulls you down so you don't float

Y7 G H

Gravity stops things floating and keeps them on the ground.

Y7 B M

Though we cannot specify precisely what form they took for individual pupils, it seems that intervention activities had a significant impact on children's thinking. A very small number of children reformulated gravitational force as a force *between* bodies (or more specifically, between the Earth and other bodies).

Gravity is the force which acts upon masses to pull them down to the ground. It is the the force of attraction between two masses.

Y9 B H

The Earth attracts different masses to it. The attraction is called gravity. Heavier objects attract objects with greater force. Jupiter has more gravity than Earth.

Y9 B H

Gravity comes from the core of the space bodies and pulls thing to it. The Moon has gravity but it is weaker.

Y6 H B

The more limited explanation of gravity being 'the pull of the Earth' increased in popularity as did the description of it as something that 'keeps things down'.

Ch *Gravity pushes and pulls and makes you stay on the ground.*
Gravity is in space. No, not in space. Space has no gravity.

Int *Where would you find gravity if you were to look for it?*

Ch *On the Earth there is gravity that keeps us down. You find it on the floor because gravity keeps us down. No, gravity is up in the air because you stay down it's pushing you down to stay on the floor. If you bounce a ball on the floor gravity pushes it back up.*

Y6 B M

This example and the one that follows are examples of children describing gravity as a push and a pull within the same explanation.

Ch *Gravity is a pull. It goes in a straight line. On light people the gravitational pull is not big. On fat people the gravitational pull is big.*

Int *How does this happen like that?*

Ch *They have a bigger mass. More weight than a thinner person or a fat person. So* *there would be more weight adding, pushing down when you stand up. All your weight is down at the bottom. If you have something heavy in your pockets your pants will fall down.*

Y6 B M

gravity eminates from the centre of the Earth. Round the Earth there is a gravitational field and anything under that is pulled towards the Earth.

Y9 B M

There is evidence that children were testing some causal ideas, which is pleasing, even though these were erroneous. For example, some referred to the spin of the Earth

Ch *The Earth spins at a very fast speed and the spinning pulls objects down. Astronauts would go to different planets. Earth has a very strong pull and the Moon has a light pull. The Earth's gravity holds the Moon where it is and it (Moon) can only move slowly because the Earth's gravity stops it moving.*

Int *Why does the Moon have less gravity?*

Ch *The Earth's gravity holds the moon in orbit and stops the Moon spinning fast and that's why it has less spin and less gravity.*

Y3 B H

Others talked of the push of air.

Ch *Gravity pushes you down to be able to stay on the Earth. You can force things up but gravity pushes them back down.*

Int *Where would you find gravity on the Earth?*
Ch *All round us. In the air. Inside things - can. You throw the can up it will come back down because you've got gravity in the air pushing down on top of the can.*

Y6 B L

Ch *You find gravity down here. Walking on paths, floor, ground. If it wasn't there you would just float up.*

Int *How does it keep you on the ground?*

Ch *Down here there is air. Smoke rises like air because there is no air up there. There is air on the floor. Gravity is just like air. There is no air in space. Air keeps you down.*

Y4 G M

The simile of the gravitational force of the Earth being like magnetic attraction was also in evidence.

Ch *The centre of the Earth is magnetic and it pulls everything towards it. It brings anything with mass towards it. Everything that has mass has gravity on. The bigger it is, the bigger the force of gravity.*

Int *How does gravity work then?*

Ch *It is like a magnet. A magnet attracts other metal. The nearer the metal is to the magnet the bigger the attraction. The nearer the two things are the bigger the pull. If you get too far away they won't attract each other.*

Y7 B H

One might sympathise with children's struggles to make sense of this pervasive force which is so much part of daily life that we cease to notice it. Beyond such everyday experience we have very little direct evidence of gravitational attraction between masses. So we tend to use the word 'gravity' as shorthand to name the gravitational attraction between objects and the Earth. Taking a wider perspective we may point to the effect of the Moon's gravitational attraction on the Earth's oceans and where these forces are even greater, between planets. We have to accept that this is simply the way the universe appears to work. Those pupils who have stated that gravity is an attraction between masses (or between the Earth and other objects) have taken their thinking as far as could be hoped, and we should perhaps be delighted that seven per cent of the sample achieved this level of understanding. The fact that these five pupils included one each at Lower and Upper Key Stage 2 is reason for optimism that this important idea might be made more widely accessible.

Children's explanations as to how gravity works were also analysed for directionality, for this aspect was deemed to be an important indicator of the degree of generality (or 'depth') of their understanding. The following levels, indicating movement in understanding towards increasing generality, can be defined:

1. If we lack a sense of living on the surface of a planet, we can still operate a definition in which *gravity causes objects to fall to the ground*. Perhaps even less abstracted, more local still, is the notion that *gravity causes objects to fall downwards*.

2. Still fairly parochial, gravitational force can be thought of as a force acting *between the Earth and other bodies near the Earth*. An elaboration of this idea is an appreciation of the importance of the centre of the Earth as the notional point towards which objects are attracted.

3. At its most general, gravity is a force which might be imagined to operate between two masses anywhere in the universe.

All of these ideas in their various degrees of completeness incorporate some understanding of the force of gravity. Pre-intervention, the most common outcome was no clear indication of downward attraction (see Table 6.14). Of the responses which indicated direction, the most common was the most local, least abstracted idea of 'downwards'. Next most frequent, though seen only at Key Stage 3 and even there, in small numbers, was the idea of gravity as a force of attraction towards the centre of the Earth. Least common was the most abstract level of definition of attraction between the centres of masses. This same pattern recurred post-intervention, though with far more pupils indicating the direction in which they believed the force of gravity to be acting, and large increases in the direction of scientifically more accurate (and more abstracted) responses.

Table 6.14 Direction of force due to gravity

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
1. towards centres of masses		3 (1)	-	-		-	3 (1)	6 (1)
2. towards centre of Earth		-	-	17 (3)		7 (2)	7 (2)	33 (6)
3. downwards, towards ground		21 (6)	21 (6)	56 (10)		59 (17)	72 (21)	33 (6)
No clear indication of downward attraction		76 (22)	79 (23)	28 (5)		35 (10)	17 (5)	28 (5)

Another question which probed ideas about gravity used the activity of a ball thrown up in the air. Children were asked whether gravity is acting on the ball, (i) when it is moving upwards and (ii) just when it reaches its highest point. In this instance, children have to be clear about the interaction between the two forces, that of the hand making the throw and that of gravity. They may also be aware of other forces acting, such as air resistance. The interacting forces in this context cause us to become aware of some wider aspects of children's understanding of how gravity works. For example, it becomes apparent that the Earth's gravitational force is not always treated by them as a constant force on the ball, but as a variable interaction between the force upwards exerted by the hand and the force downwards of gravity. While the ball was moving upwards, half the Lower Key Stage 2, about a third of the Upper Key Stage 2 and about a fifth of Key Stage 3 pupils thought that gravity was *not* acting. The movement upwards seems to have precluded the possibility, in their minds, that a force downwards could be acting. A small minority suggested that gravity would be acting but to a reduced extent during the ball's upward movement. In contrast, at the apex of the trajectory, all the Key Stage 3 children believed that gravity was acting, together with the majority of their Key Stage 2 counterparts.

There's another force which is stronger while it is going upwards. It's up in the air. It's always there if you push the ball upwards then the force in the air is helping the ball upwards. It's stronger than gravity. When it's at its highest point gravity and the other force are equal. Gravity will eventually pull it back down. When it went up it used its strength against gravity. When it was at its highest point they were equal. When it was coming down it has lost its strength.

Y6 G M

Ch	*Because you give it a push force which makes it go up gravity is still acting when it goes up. When it gets to its highest point it just drops. The force of your hand throwing it really hard makes it go up and it just drops when the gravity gets too strong.*
Int	*Why does gravity get too strong? Why is it stronger when the ball is at its highest point?*
Ch	*The weight of the ball, it gets too heavy to go high any more. The speed of the ball pushes air out of the way so the air can make way for the ball. On different planets, the stronger the gravity, the ball would go to a different height. Where there is less gravity the ball would go quite high, about 25ft. Where there is no spin at all the ball would go high and may not come down. Gravity is always the same on Earth, it is always spinning. When the ball stops, gravity has a chance to pull it down.*
	Y3 B H
Ch	*Nothing is being pulled down because gravity is not acting. It won't go down. When it gets to its height it can't stay there because gravity pulls it down.*
Int	*How does it happen to be at that height?*
Ch	*Gravity is there, no matter how high, it is still there. It's not very high but as high, as you can throw something.*
	Y4 B L

In another question, a car with driver and passenger were illustrated. The passenger was described as 'just letting go of the can' with her arm extended through the car's window. The further information was offered that, 'The car is being driven forwards quite fast.' Children were asked to mark the drawing to show the point where they thought the can would first hit the road. They were then asked to explain why they thought the can hit the road at the point which they had marked. Responses to this question are discussed more fully in Section 6.3. For the moment, attention will focus on the incidence with which pupils chose to make references to gravity as the force which caused the can to hit the road. Such references to gravity were, in the context of the can dropped from a moving car, rare.

Seven pupils in the two oldest age groups mentioned gravity pre-intervention, increasing to eleven pupils across the entire age span post-intervention. This total included only about one fifth of the Key Stage 3 pupils. A dropped object from a moving vehicle appears not to suggest the force of gravity. As with the vertically thrown ball discussed above, it seems that other forces which are acting on an object moving through the air readily dominate children's thinking and may be deemed to negate the effects of gravity.

A brief video clip (not at all clear in quality) of Neil Armstrong's hammer and feather experiment on the Moon was shown to all children. Aspects of children's responses are reported here since many of them invoked the concept of gravity to explain what they saw on the video-recording. Armstrong is shown holding each object at arm's length before releasing them. It was confirmed that, 'They both hit the surface of the Moon at the same time.' and children were asked to explain, 'Why does this happen on the Moon but not on Earth?'. The Key Stage 1 sample was initially included but was omitted post-intervention since they seemed to make so little sense of what was shown in the film. (The visual quality of the evidence presented in the film made acceptance of the objects and the event an act of faith.)

About one third of the entire Key Stage 2 and 3 sample, both before and after intervention, suggested that the result occurred as it did because there is no gravity on the Moon, (see Table 6.15).

Ch *On the Earth there is gravity to pull things down like the hammer.*

Int *What happens on the moon?*

Ch *Moon? No gravity. On Earth heavier things move down first, but on the moon they are both the same weight. Gravity pulls things down on Earth. No gravity makes the hammer lighter.*

Y4 B L

It is difficult to understand how children are thinking to arrive at this sense which they made of the Armstrong experiment. Pre-intervention, about one third of the Key Stage 3 sample suggested that the outcome was because of *less* gravity on the Moon; this proportion almost doubled in the post-intervention interview responses. The example above shows one example of the kind of complete chain of reasoning needed to arrive at the 'no gravity' reasoning.

Table 6.15 Hammer and feather falling on Moon - role of gravity.

	Pre-Intervention				**Post-Intervention**			
	KS1 n=42	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**	**KS1 n.a.**	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**
no gravity on Moon	8 (3)	28 (8)	52 (15)	28 (5)		48 (14)	41 (12)	22 (4)
less gravity on Moon	-	14 (4)	17 (5)	33 (6)		17 (5)	17 (5)	61 (11)
more gravity on Moon	-	-	-	6 (1)		10 (3)	7 (2)	-
other responses	-	24 (7)	21 (6)	11 (2)		10 (3)	3 (1)	-
gravity not mentioned	92 (39)	34 (10)	10 (3)	22 (4)		14 (4)	31 (9)	17 (3)

One Lower Key Stage 2 child explained a supposed absence of gravity on the Moon as attributable to the lack of air.

The hammer is heavier than the feather but in space there is no gravity so everything would fall at the same rate. Down here the hammer would fall first because there is air so there is gravity. Gravity and air are just like brothers and sisters.

Y4 G M

About one fifth of the Key Stage 2 and Key Stage 3 samples combined explained the simultaneous impact of the hammer and feather on the Moon correctly, in terms of an absence of air resistance. There was no strong age association with this response and the frequency rose only very slightly in the post-intervention responses.

Ch *On Earth the hammer would go first because the feather would float down.*

Int *Why does it float like that?*

Ch *It's light so there's an upwards force from the air.*

Y7 B M

Another question in the context of astronauts on the Moon has some relevance to this discussion of gravity. The question was posed, (cued by video footage of Moon-walking in which astronauts are seen moving gracefully if ponderously, wearing bulky suits, helmets and boots), 'Why do astronauts wear big boots when they walk around on the Moon?'. Only the Key Stage 3 sample was presented with this question before and after intervention and none answered in terms of the large boots offering grip or protection. Fifty-six per cent suggested that the boots were to give added *weight,* though without any reference to the gravitational force of the Moon.

They wear big boots to help them to stay down better so they don't float away into space.

Y9 B H

Twenty-eight per cent suggested that the boots added weight in the context of there being *less* gravity on the Moon (as compared with the Earth).

Because there is less gravity on the moon and the boots keep them down. Because it is higher up than Earth so there is less gravity.

Y7 G L

Seventeen per cent of this same Key Stage 3 group suggested that the boots added weight because of an *absence* of gravity on the Moon.

Because the is no gravity on the moon the weight of the boots pull them downwards.

Y7 G H

The line of argument seems to be that in the absence of gravity, extremely heavy boots are needed. It appears that these respondents have completely separated weight from the force of gravitational attraction and advocate 'heaviness' as a substitute for the absent gravity.

Ch *On Earth you have weight but on the Moon you don't have weight, you only have mass. So where there is gravity, there is weight.*

Y7 B H

Perhaps insufficient attention had been paid to weight or heaviness as the result of gravitational attraction in the course of the intervention activities to which these pupils were exposed.

The distinction between measuring mass and force in appropriate units was directly addressed with Key Stage 3 pupils only. The problem was set by describing someone having a 500 gram pack of butter which, when hung on a newton-meter, gave a reading of five. The question was posed, 'Why does it read 5 and not 500?'. Half of the responses suggested that the same property was being measured, but using different units. That is, no distinction was made between mass and weight.

Because it's measured in Newtons and 1N =100g.

Y9 G M

1N is the equivalent of 100g. They are measuring something in different units.

Y7 G M

About ten per cent gave responses which included 'weight' or 'force' as the property being measured in newtons. We cannot be certain that such responses incorporate a clear distinction between weight and mass, a recurrently problematic distinction for pupils.

The force is five and it is measured in newtons. It is not measured in g, it is measuring in newtons. It is measuring the force. If it is in g it is measuring weight.

Y7 B H

Another question inviting references to gravity was that which asked simply, 'What forces are acting on you when you sit on a stool?'. This was an invitation to describe balanced forces in a static system, but the majority of responses which referred to relevant forces mentioned only gravity or weight. This was the case both before and after intervention. Table 6.16 summarises references to gravity and makes clear how extensive is the appreciation of gravity as a force acting on a sitting person, especially post-intervention. The contrast with the low incidence of references to gravity in dynamic situations of other than downward movement the situation in which the ball is moving upwards and the can moving forwards for example - is very apparent.

When you sit on a stool your mass is pulled downward by gravity.

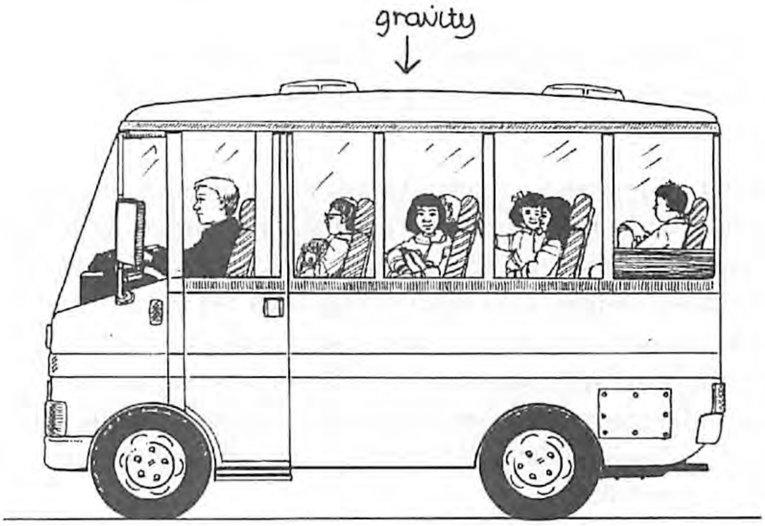
Y9 B H

Table 6.16 Gravity acting on seated child

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
gravity is acting		17 (5)	41 (12)	67 (12)		45 (13)	59 (17)	89 (16)
weight is acting		7 (2)	7 (2)	22 (4)		3 (3)	3 (1)	11 (2)
gravity/weight not mentioned		75 (22)	52 (15)	11 (2)		45 (13)	38 (11)	-

Another opportunity to examine assumptions about the gravitational force of the Earth arose in the question which showed a school bus moving along the road and asked pupils to, 'Draw arrows on the picture to show the forces acting on the bus.', and 'Put labels on the arrows to show what the forces are.' (The various forces which were identified and some indication of their interactions are described more fully in Section 6.3. The present discussion is limited to a consideration of gravitational force.) The data suggest an age-related increase in the number of children representing gravity as a force in this dynamic situation (31 per cent lower KS2, 59 per cent upper KS2 and 83 per cent KS3). It is of some interest that a sizeable proportion of children at all Key Stages failed to mention gravity or weight in this context (62 per cent lower KS2, 41 per cent upper KS2, 11 per cent KS3).

Figure 6.6



It stops the bus from floating.

Y9 G H

A further opportunity to examine children's appreciation of gravity was available within children's causal explanations of the movement of a floating helium-filled balloon. Children were invited to attach paper clips to the balloon and asked to explain why the balloon moved in the way it did, i.e. horizontally rather than in an upward direction. (The forces on the balloon had been balanced.) At pre-intervention the concept probe was posed to all children in the sample. Children across the three Key Stages tended to focus on the paper clips as preventing the balloon moving upward. Few responded in terms of gravity. Following intervention, it was judged to be inappropriate to probe the very young children's understanding of balanced forces so the concept probe was posed to children at Key Stages 2 and 3 only. Across Key Stage 2 and 3 there was an increase in the number of children using gravity correctly in their explanations. Over one third of the children in Upper Key Stage 2 and Key Stage 3 identified gravity as one of two forces operating on the balloon. At Key Stage Three, one quarter of the children reasoned that gravity was one of a pair of balanced forces.

Table 6.17 Gravity mentioned in connection with helium balloon.

	Pre-Intervention				Post-Intervention			
	KS1 n = 42.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
Gravity mentioned as one of a pair of balanced forces.						3 (1)	3 (1)	28 (5)
gravity mentioned correctly as one of two forces. Not necessarily correct forces, not necessarily balanced	-	-	3 (1)	11 (2)		7 (2)	31 (9)	39 (7)
Gravity mentioned by itself.	-	-	-	11 (2)		-	10 (3)	-
Gravity used incorrectly.	-	-	3 (1)	6 (1)		3 (1)	3 (1)	-
No mention of gravity.	100 (42)	100 (29)	93 (27)	72 (13)		86 (25)	51 (15)	33 (6)

6.2.2 Ideas about friction

The same caveats apply to the following discussion of friction as to the previous consideration of pupils' ideas about gravitational force. Friction needs to be considered by pupils in the context of the system in which movement between two surfaces occurs. For the sake of simplicity and clarity, aspects of beliefs about friction are considered more or less in isolation in this section. The understanding of friction as a force interacting with other forces is considered in Section 6.3.

The first question which precisely targeted the concept of friction was set in the context of riding a bicycle, a pastime assumed to be familiar to all children both in general and in the specifics of how it feels to pedal across different surfaces. It was explained that when a boy rode across a field (contrasted with riding across the playground) he had to pedal harder. 'Why is it harder to ride across grass?', was the question posed to the Key Stage 2 and Key Stage 3 groups, post-intervention only. Table 6.18 summarises the outcomes.

Table 6.18 Difficulty of riding bicycle on grass

	Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
more friction on grass		41 (12)	48 (14)	72 (13)
otherwise expressed		-	7 (2)	-
playground smooth		-	3 (1)	11 (2)
grass bumpy		24 (7)	17 (5)	6 (1)
more gravity on grass		7 (2)	7 (2)	-
less friction on grass		-	-	11 (2)
other responses		28 (8)	17 (5)	-

Familiarity with the idea and the word 'friction' was surprisingly extensive: about two fifths at Lower Key Stage 2, half the pupils at Upper Key Stage 2 and almost three quarters at Key Stage 3 used the term in their explanations. Only two Key Stage 2 pupils expressed the idea of an opposing force on grass with an apparent lack of access to the technical vocabulary.

Ch *There is more grip on the grass.*

Int *How does that work?*

Ch *It interferes with the tyres, wheels.*

Y5 B L

However, amongst the younger children about one quarter were more drawn to the uneven nature of the grassy surface than to the abstraction of 'friction'.

An interesting idea to ponder is the suggestion from some children that there is *more* gravity when riding on grass. Gravity seems to be treated in such instances as a force which opposes movement.

The gravity on the grass tries to pull the bike back.

Y3 B H

Because the gravity is pushing harder. The gravity is acting on his head and his bike, on the handle bars and on the wheels.

Y3 B M

More puzzling is the suggestion by two Key Stage 3 pupils that there was *less* friction associated with riding over the grass. Perhaps for those who think that friction enables or causes movement, greater difficulty in movement results from less friction.

Ch *Because the playground is smooth and the grass is rough and there is less friction on the grass.*

Int *What makes you think there is less friction?*

Ch *Grass isn't very hard. I don't know I've just found it hard to pedal when I've done it.*

Y7 G L

Friction was also directly addressed by a question which presented the situation of a book on a plank in three orientations (see Figure 6.7). Firstly the plank was shown as level and the book still; secondly, the plank was raised a little, the book remaining still; thirdly, the plank was raised higher and the book was shown sliding. Pupils were instructed, 'Write under each drawing if you think that the force of friction is acting on the book.' Table 6.19 presents a summary of responses.

Figure 6.7

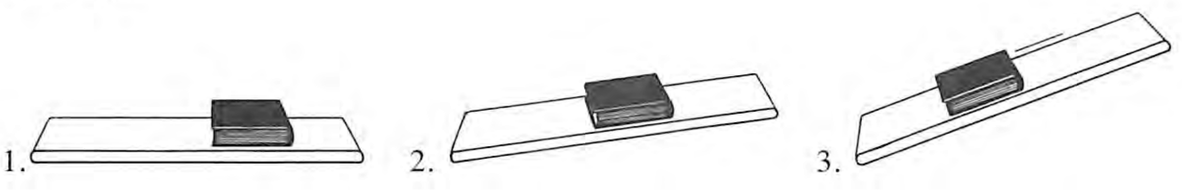


Table 6.19 Frictional force between book and plank - summary of responses

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
1. no, 2. yes, 3. yes - friction opposes movement		24 (7)	21 (6)	44 (8)		52 (15)	28 (8)	56 (10)
1. no, 2. no, 3. yes - no friction without movement		24 (7)	28 (8)	22 (4)		28 (8)	31 (9)	17 (3)
1. yes, 2. yes, 3. no - no friction with movement		7 (2)	3 (1)	6 (1)		7 (2)	10 (3)	11 (2)
1. yes, 2. yes, 3. yes - always friction between surfaces		3 (1)	-	11 (2)		3 (1)	21 (6)	11 (2)
other		41 (12)	48 (14)	17 (3)		10 (3)	10 (3)	6 (1)

The scientifically accurate response, one which recognised that friction is a force which opposes movement between surfaces, was the majority response in the post-intervention interviews. About half the sample at Lower Key Stage 2 and Key Stage 3 suggested that no friction would be acting in the first case (book stationary, plank horizontal), but that friction would be operating when the plank was raised in both cases. The substantial increase in the success rate of the lower Key Stage 2 pupils is worthy of further investigation.

1. *Friction is not acting.*

2 *Friction is acting. Two sides are rubbing together and that creates friction. If friction is greater than the gravity force pulling downwards it stays still. If gravity force is greater it moves.*

3. *Friction is acting.*

Y9 B M

The second group of responses is consistent with the idea that there is no friction without movement, a belief that was fairly widespread but which decreased in incidence quite sharply in the Key Stage 3 group.

1. *No. It is not moving.*

2. *No it is not moving.*

3. *Yes the book was moving, friction is things moving.*

Y4 G L

Many children who indicated no friction associated with the sliding book failed to give any explanation. This reasoning may be influenced by consideration of friction as a force which *impedes* movement. Within this view the instance of a sliding book might suggest no friction. Others asserted that friction *caused* the movement of the book.

Int *What does friction do?*

Ch *Friction makes the book go very fast.*

Int *How does it do that?*

Ch *Friction helps things move.*

Y5 B L

We have to be very careful in interpreting these responses. In the case of a wheeled vehicle, it would be correct to assert that 'the road pushes the car'. The force exerted by the road as the wheel rotates against it would not be possible without friction. It would be like attempting to drive on ice. This understanding may have confounded pupils' understanding of friction in the context of the sliding book.

Some Key Stage 2 and Key Stage 3 pupils expressed awareness that friction would be acting in the case of the sliding book and also knew that this force would be less than in the example of the stationary book.

The fourth group summarised in Table 6.19 offered judgements consistent with the view that there is always some friction between surfaces in contact. This view was most likely to have been made explicit in the case of the stationary book on the horizontal plank.

1. *There is friction because if there was no friction it would be sliding. Friction is in between the table and the book. It keeps it steady.*

2. *Yes, friction has to stop it moving.*

3. *Yes, friction is trying to stop it moving.*

Y6 B M

Ch *There is, but it won't be able to move because there is no slope, friction is all along the plank of wood.*

Int *Is it there when there is no book?*

Ch *Yes it's there when there is no book.*

Y6 G M

The question which asked, 'What forces are acting when you sit on a stool?' also elicited some ideas about friction. In this context, interpretation of responses is complicated by the fact that the forces operating on a seated person might be thought of in more than one way. For example, if a person is seated in a stationary position, the forces acting on the body are gravitational force and the force exerted in return by the stool. Alternatively, the person may be thought of as sitting in a less stable position or even as twisting or otherwise moving, in which case friction most certainly will oppose the movement between the body and the surface of the stool. Because of these two possible viewpoints, the references to friction in Table 6.20 distinguish between those which offer justification for the force of friction and those which mention it without such justification.

There were no justifications amongst the pre-intervention responses, but these did occur post-intervention.

Ch *Friction between you and the stool .*

Int *How does it work?*

Ch *It keeps you steady.*

Int *Is there friction anywhere else?*

Ch *Friction between the stool and the floor.*

Int *How does that work?*

Ch *It stops you sliding.*

Y7 B H

More commonly obtained from the younger pupils in the sample were suggestions that friction would be operating without any correct justification.

The chair is a surface and you're sitting on it and it's stopping you from falling. Friction is straight up.

Y3 G M

Table 6.20 Friction acting on seated child.

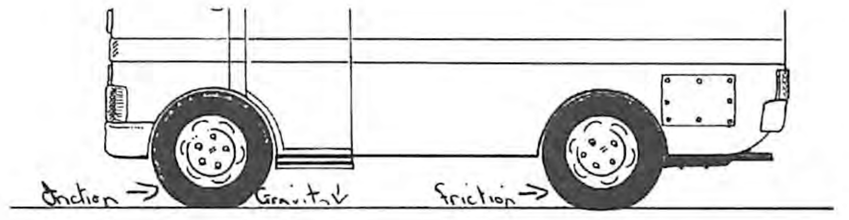
	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
friction with explanation	-	-	-	-		-	3 (1)	22 (4)
friction without explanation			7 (2)	28 (5)		10 (3)	21 (6)	22 (4)
friction not mentioned		100 (29)	93 (27)	72 (13)		90 (26)	75 (22)	56 (10)

Responses referring to friction will be considered next by returning to the question about the forces acting on the bus (discussed in relation to gravity in section 6.2.1 above and in the context of interacting forces in Section 6.3.2.5 below). Firstly, arrows drawn to represent friction acting in association with the body of the bus will be considered. The main feature of this form of response was its sporadic occurrence. Only five pupils (six per cent of the combined KS2 and KS3 sample to whom this question was posed) drew arrows labelled 'friction' in their pre-intervention responses, and five post-intervention. Remarkably, there were no pupils in common between the two sets of five, which seems to confirm the elusiveness of appreciation of frictional force in this form.

An arrow drawn to represent friction associated with the wheels was slightly more common than those associated with the body of the bus, (six per cent of KS2/3 pupils pre-intervention, compared with 50 per cent post-intervention). In situations such as the book on the plank the force of friction acts in the opposite direction to any movement. However, for wheeled vehicles, the frictional force opposes the movement of the *tyres* in contact with the road and is, therefore in the *same* direction as the movement of the vehicle. No pupil offered a forward pointing arrow unequivocally associated with the force of friction on a wheel.

A surprisingly small proportion of children drew their arrows pointing backwards, (three per cent Lower KS2, 14 per cent Upper KS2 and 17 per cent KS3), i.e in the direction from which the bus has travelled.

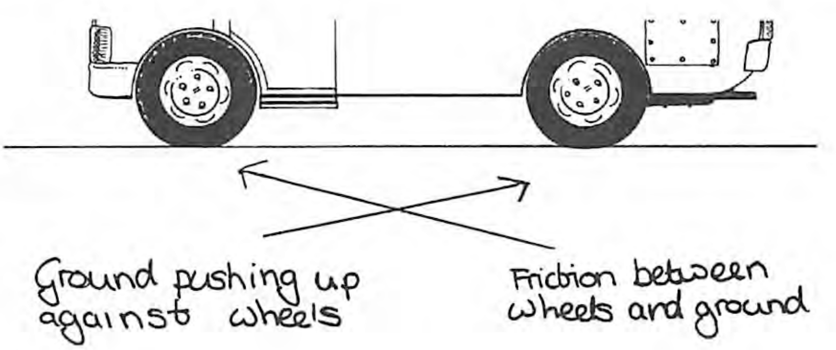
Figure 6.8



Y6 B H

Many more pupils (seven per cent Lower KS2, 28 per cent Upper KS2 and 67 per cent KS3) drew their arrows pointing in some other direction than clearly horizontal (forwards or backwards) or vertical.

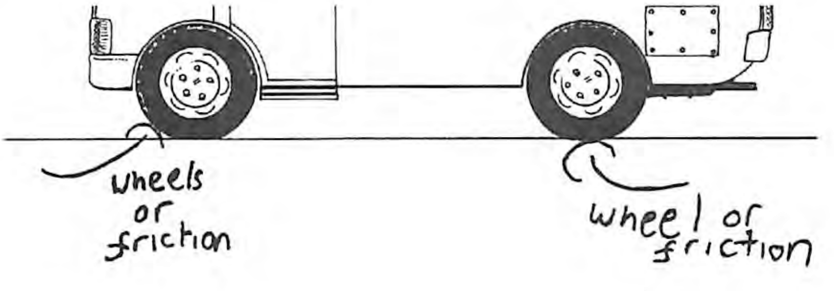
Figure 6.9



Y9 B M

A small proportion of pupils drew curved arrows. Whereas such a representation violates the fundamental Newtonian notion that forces act in straight lines, in these responses, it more likely indicated a lack of understanding of the conventional use of arrows to represent forces.

Figure 6.10



Y3 G H

Some of the more extended verbal responses obtained during interviews enabled pupils to elaborate their ideas beyond what it was possible to illustrate in drawings alone. One idea that emerged was that a frictional force depends on the *speed* at which an object is travelling. When stationary or moving slowly, friction was not believed to be acting (or was thought to be acting only minimally).

Because the wheels are going fast, the wheels start rubbing. It comes from the wheels and the ground. The bus driver has his foot on the pedals. The wheels are going so fast it causes friction. If it goes slowly there is not so much friction. When two things rub together the air begins to cause friction as well.

Y3 G H

In summary, it is apparent that children did not show much evidence of understanding of the frictional forces associated with the turning wheels of a bus. Most of those who drew arrows labelled as representing friction presented them at various angles around the wheels, some even curved. This lack of conceptual understanding was further confounded by the lack of understanding of the conventions associated with representing forces with arrows.

6.2.3 Air resistance

The *caveats* about treating air resistance independently of other forces with which inevitably, it would be interacting, apply as much as was the case in the discussion above of gravity and friction. As a particular instance of a frictional force, this discussion of air resistance must also be related to the ideas discussed in the previous section. Nevertheless, for the sake of clarity of focus, there are some issues associated with this concept which will benefit from a separate discussion.

In the context of the question about the can dropped from the moving car, children were asked, 'Why do you think the can first hit the road at the place where you put the letter c?'. This question posed a complex problem because of the changing co-ordinates of the relative positions of car, can and road. Nonetheless, what was presented was a situation which most children could readily imagine as real.

In their pre-intervention responses, no children used 'air resistance' as a scientist would, to describe a force that would slow the forward movement of the can. Those children who mentioned air resistance at all, described it as a force which would move the can backwards.

Because its going fast the can will blow back. Air resistance forces it back.

Y6 G H

The pressure is against the car because the car is moving. Air resistance, when something is moving the can will always have some resistance in the opposite direction and when the can is dropped it doesn't have any engine of its own so the can is forced back.

Y6 B H

The post-intervention interview responses suggest that reasoning in terms of air resistance was not very stable amongst the Lower Key Stage 2 pupils, while the Upper Key Stage 2 pattern remained more consistent. There were some shifts at Key Stage 3 which, while of small percentages, are interesting in providing insights as to the kinds of movement in understanding that might be achieved. Only four of the 18 Key Stage 3 pupils referred to air resistance. One stayed with the idea of air resistance being responsible for the can moving backwards. The other three showed appreciation that the force and movement of the can would be slowed although one was of the opinion that the air resistance would exactly cancel out the forward movement of the can.

Ch *Because it will drop straight down because it is still moving with the car.*

Int *How will that happen?*

Ch *When it is released it will start slowing down with the air resistance.*

Y7 B H

Ch *When you drop the can it doesn't drop directly down, it drops forward and then air resistance pushes it, for example, acts on it so it goes down straight. The vehicle is moving forward so the can moves forward and because there is no more energy getting to the can, so force take over.*

Int *What are these forces?*

Ch *Air resistance and gravity take over.*

Y9 B L

The can is pushed forward by the speed and pulled back by air resistance resulting in the can dropping roughly below where it was dropped from.

Y9 B M

It had been noticed that many pupils used the expression 'wind' or 'wind resistance' when describing opposition to the can's forward movement through the air. This form of wording was recorded when responses were coded; outcomes are summarised in the lower half of Table 6.21. It can be seen immediately that 'wind' was a far more popular interpretation of the phenomenon than 'air resistance'.

The distinction between 'air resistance' and 'wind' (or 'wind resistance') is not a trivial one in terms of the sense which children impose on this event. When physicists objectify the event of movement across two surfaces in contact, the important consideration is that the movement is in different directions (or at different speeds in the same direction). For example, air resistance between a car and the air is the same whether the car moves through the air (as when it is driven on a road), or the air moves across the car (as in a 'wind tunnel'). The latter is often the more convenient method of testing a car's body or an aeroplane's wing for its aerodynamic characteristics. (Similarly, boat hulls are tested in a flume.) Children clearly take time to achieve understanding of this equivalence, though their use of the word 'streamlined' is not uncommon. A moving body of air is felt because it exerts a force as it passes across and around a person. If the wind is strong enough, children will have felt the need to brace themselves or may even have been caused to stagger. They may have seen umbrellas blown inside out or even more extreme damage caused by the wind: trees uprooted, buildings damaged. In contrast stationary air is intangible. The results summarised in the lower half of Table 6.21 suggest that the ideas of the force of a moving body of air (i.e. what we commonly call 'wind') and the force opposing the movement of a body through a static body of air (i.e. 'air resistance') are frequently confounded in children's thinking.

Table 6.21 Dropping can from moving car-effects associated with movement through air

	Pre-Intervention				Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
References to air resistance								
a.r. slows can	-	-	-	-	-	-	-	11 (2)
a.r. cancels forward momentum	-	-	-	-	-	-	-	6 (1)
a.r. moves can backwards	-	17 (5)	7 (2)	11 (2)	-	7 (2)	7 (2)	6 (1)
a.r. not mentioned	100 (42)	83 (24)	93 (27)	89 (16)	100 (42)	93 (27)	93 (27)	78 (14)
References to wind								
wind blows can forwards	7 (2)	7 (2)	7 (2)	-	-	7 (2)	3 (1)	6 (1)
wind blows can backwards	17 (5)	28 (8)	55 (16)	39 (7)	19 (8)	66 (19)	69 (20)	39 (7)
wind/wind resistance not mentioned	83 (35)	66 (19)	38 (11)	61 (11)	81 (34)	28 (8)	28 (8)	56 (10)

Because the movement through the air would be sensed against the skin in this context, it is interpreted as wind. The frequencies in Table 6.21 show that most children describe this 'wind' as blowing the can *backwards*.

Ch *If the car's going fast the can is going to be pushed back. The force will push it back.*

Int *What force?*

Ch *The wind would be pushing the car and it would come off the wind shield down the side of the car and it would push the can. The car is going through the wind and pushing it either side of the car.*

Y9 G L

Ch *Because the force acting on the wind is pulling it back. If it's going fast it will go right back because the wind gets stronger and pushes it.*

Y6 G H

About two thirds of the Key Stage 2 responses were of this kind, compared with one third at Key Stage 3. This was an increase compared with the Key Stage 2 responses of the same kind pre-intervention, while the Key Stage 3 proportion of this form of response remained static.

A small number of children described 'wind' as blowing the can 'forwards'.

Ch *It will drop to the front because they are going fast so the can will drop. They are going fast and the push force of the wind will push it to the front.*

Int *Where does this wind come from?*

Ch *It comes from the back of the car. It's called 'push thrust'.*

Y5 G H

Ch *Because the wind pushes it forward.*

Y7 B L

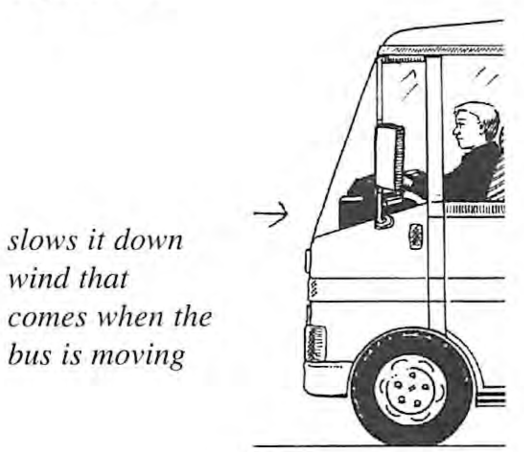
Because of the shifting co-ordinates between the forward-moving car, the falling can and the road, there is the potential for ambiguity over the net directions which children understand and intend to communicate. For example, when the can was described as moving 'backwards', interviewers probed to ensure that what was intended was more than the forward movement being slowed.

The question which asked children to, 'Draw arrows on the picture to show the forces acting on the bus.' had the potential to elicit similar ideas to those described in relation to the can dropped from the moving car.

Figure 6.11

Y9 G M

Figure 6.12



Y5 B M

References to 'wind' or 'wind resistance' were almost totally absent in the post-intervention responses, with just a single Lower Key Stage 2 pupil offering the idea that 'wind resistance' operated at the front of the bus to oppose its forward movement. The incidence of 'air resistance' responses, compared with those for the dropped can, was greatly increased, all associated with an arrow pointing towards the front of the bus, opposing it's forward movement. This form of response was offered by three per cent of pupils at Lower Key Stage 2, ten per cent at Upper Key Stage 2 and 56 per cent at Key Stage 3.

Care was taken to code 'wind resistance' and 'wind' responses separately, and the latter are summarised at the bottom of Table 6.22. Twenty seven per cent of lower Key Stage 2, twenty per cent of Upper Key Stage 2 and eleven per cent of Key Stage 3 drew arrows labelled 'wind'. A greater proportion of these arrows were drawn at the front of the bus, (opposing its forward movement) post-intervention.

The differences in responses when the can and the bus are the subject of consideration may be attributable to the very different sizes and masses involved, as well as the fact that the bus has its own mode of propulsion while the can does not.

Table 6.22 Forces on moving vehicle - effects associated with movement through air

	Post-Intervention			
	KS1 n.a.	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**
Reference to 'air resistance'				
a.r arrow, front, opposing		3 (1)	10 (3)	56 (10)
a.r. arrow, front, assisting		-	-	-
a.r. arrow, rear, assisting		- -	- -	- -
no a.r. arrow		97 (28)	90 (26)	44 (8)
Reference to 'wind resistance'				
w.r. arrow, front, opposing		3 (1)	-	-
w.r. arrow, rear, assisting		-	-	-
no w.r. arrow		97 (28)	100 (29)	100 (18)
Reference to 'wind'				
wind arrow, front, opposing		14 (4)	17 (5)	11 (2)
wind arrow, side, opposing		3 (1)	-	-
wind arrow, front, assisting		-	-	-
wind arrow, rear, assisting		10 (3)	3 (1)	-
no wind arrow		72 (21)	79 (23)	89 (16)

6.3 Balanced and Unbalanced Forces

This section explores the extent to which children apply their knowledge and understanding of forces and the associated scientific language to a number of everyday events and experiences. In so doing it considers their appreciation of the fact that, in these events and experiences, objects are acted upon by several forces simultaneously. It sets, therefore, their understanding of specific forces, considered in Sections 1 and 2, into more complex situations.

For the purposes of initial discussion of the data the section has been sub-divided into:

6.3.1 Balanced forces acting on stationary objects

6.3.2 Unbalanced forces acting on moving objects

6.3.3 Balanced forces acting on moving objects

6.3.1 Balanced forces acting on stationary objects

6.3.1.1 Size of the reaction force

Previous research (Erikson and Hobbs, 1978; Minstrell, 1982) has indicated that the concept of reaction force presents children with considerable difficulty. The assumption underlying the particular probe discussed here (which made use of a top-pan balance) was that children would be able to appreciate a reaction force most readily if they were to receive a direct tactile experience of one. In consequence, at the pre-intervention stage the children were provided with a top-pan balance, asked to press down on it to give a reading of 10N, then to say whether the pan was exerting a force on the pressing hand. If so, they were asked to predict the size of this force. About 40 per cent of the children at Key Stage 2 recognised that there was a force on the hand from the pan but of these, only a half were able to predict its size accurately. All but one of the Key Stage 3 children accepted that a force was acting and three quarters of them were able to indicate an understanding that its size was equal to that of the push from the hand.

The sizeable proportion of Key Stage 2 children (90 per cent Lower KS2 and 60 per cent Upper KS2) *not* able to confirm the perception of a reaction force of equal magnitude in these most favourable circumstances emphasises the difficulty experienced with this concept. The extent of the difficulty does appear, in this context, to be age-related, as the details of Table 6.23 show. However, the data from the seated child probe (discussed next) are much less clear in this regard.

Following the intervention activities the probe was repeated at Key Stage 3 only, but without the direct experience of pushing on a balance. No improvement in the number accepting the equality of the reaction force was recorded.

This probe highlights the difficulties many children experience in conceptualising the idea of reaction force even when presented in its most tangible, perceptible manifestation. Amongst those able to confirm the existence of reaction force as a phenomenon, the probe reveals that most are not able to recognise that a static situation requires the forces acting to be in *balance*.

Table 6.23 Size of reaction force

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n.a.	UKS2 n.a.	KS3 n=18
reaction force equal		10 (3)	38 (11)	72 (13)				67 (12)
reaction force less		17 (5)	3 (1)	11 (2)				17 (3)
reaction force more		7 (2)	7 (2)	11 (2)				11 (2)
no reaction force		34 (10)	3 (1)	-				-
no response		31 (9)	48 (14)	6 (1)				6 (1)

6.3.1.2 Forces acting on a seated child

Children's experience of sitting on a chair was used to probe their understanding of the forces acting in this static situation. It was anticipated that, particularly for the younger children, the whole-body experience would enhance a more correct interpretation of the downward force on the body due to gravity being balanced by the upward reaction force of the chair.

Table 6.24 shows the responses to the question 'What forces are acting on you when you sit on a chair?'. Gravity or weight was the most commonly mentioned force. However, prior to the intervention a significant number failed to include it. This omission was clearly age-related, being 75 per cent at lower Key Stage 2 falling to 11 per cent at Key Stage 3. This perhaps reflects the view that gravity ceases to act when objects stop moving downwards. The intervention activities resulted in a substantial reduction in these figures to 45 per cent and zero respectively.

At the pre-intervention stage only one child (KS3) indicated that there is a force from the stool. Possibly sitting is experienced too frequently for it to invoke the idea of a reaction force. The intervention activities, involving quantification and force diagrams, appear to have induced a recognition of such a force in about one quarter of all of the children. Surprisingly, this improvement in understanding did not increase with age.

On the chair: the forces push down to keep the chair steady

On you: The force keeping you up

Y7 B M

Table 6.24 Forces acting on seated child

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
Gravity								
gravity is acting		17 (5)	41 (12)	67 (12)		45 (13)	59 (17)	70 (16)
weight is acting		7 (2)	7 (2)	23 (4)		10 (3)	3 (1)	11 (2)
gravity/weight not mentioned		75 (22)	52 (15)	11 (2)		45 (13)	38 (11)	-
Reaction Force								
'reaction force' mentioned		-	-	-		-	3 (1)	-
reaction force otherwise expressed		-	-	6 (1)		24 (7)	24 (7)	22 (4)
reaction force not mentioned		100 (29)	100 (29)	94 (17)		76 (22)	72 (21)	78 (14)
Balanced Forces								
two correct forces, balance mentioned		-	-	-		3 (1)	7 (2)	-
incorrect forces, balance mentioned		3 (1)	-	6 (1)		10 (3)	10 (3)	6 (1)
two correct forces, balance not mentioned		-	-	6 (1)		7 (2)	17 (5)	22 (4)
only weight/gravity, balance not mentioned		28 (8)	48 (14)	83 (15)		41 (12)	31 (9)	72 (13)
only reaction force, balance not mentioned		-	-	-		3 (1)	-	-
no correct forces, balance not mentioned		69 (20)	52 (15)	6 (1)		34 (10)	34 (10)	-

A comparison of the data from this probe with those discussed earlier in relation to the top-pan balance suggests that not all of the children who were able to predict the size of a reaction force once such a force had been pointed out to them would, in the absence of prompting, have considered the existence of such a force in the context of sitting on a stool. Nevertheless, the implication from the data is that with appropriate intervention the concept of reaction force can be made accessible to children.

For the large proportion of children considering that only a single force is acting in this situation there can be no question of balance.

Gravity - No more forces. Gravity pushes you down so you don't float off.

Y7 G H

When you sit on a stool your mass is pulled down by gravity. The stool just keeps you up.

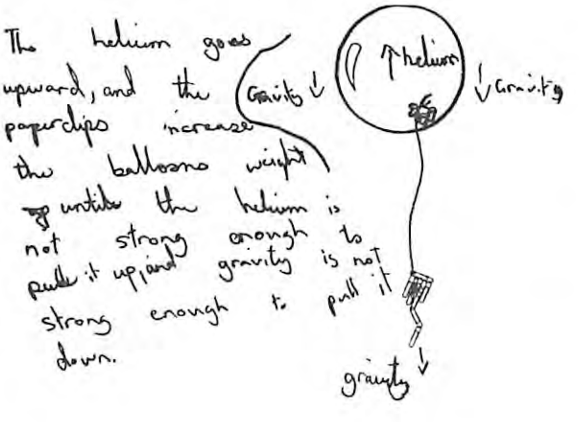
Y9 B H

Even those who responded with both correct forces, in most cases did not mention the balance between them. It may be that a more productive teaching sequence would place an understanding of the need for *balanced* forces in static situations somewhat earlier than is common in order to use the logic of this idea to dictate a need for *reaction* forces.

6.3.1.3 Forces acting on a helium-filled balloon

Children were provided with a helium-filled balloon with a string attached. They were then challenged to add to the string small objects (e.g. paper clips) in just sufficient numbers to prevent the balloon from moving either upwards or downwards. When they had succeeded in this task, the question was posed, 'What can you say about the forces acting on the balloon when it is like this?'.

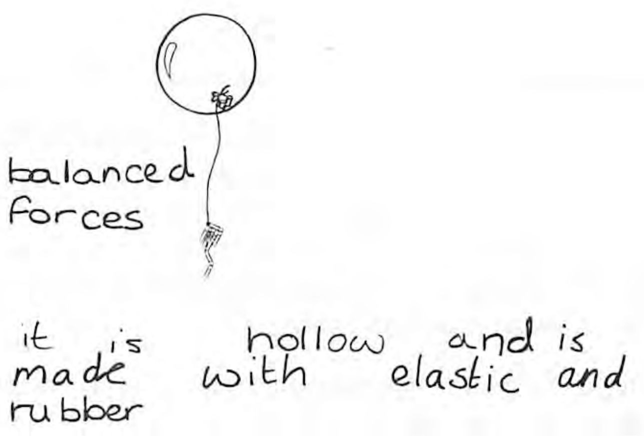
Figure 6.13



Y6 B H

The helium wants to go up and it can do that until it hits the ceiling. But when you have paperclips, the weight pulls it down slowly, or it will hang in mid air if you hang the right amount.

Fig 6.14



Y6 G M

Table 6.25 Forces acting on helium-filled balloon

	Pre-Intervention				Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
Two Forces								
two correct forces/objects, balance mentioned	-	10 (3)	17 (5)	22 (4)		14 (4)	24 (7)	34 (6)
two incorrect forces, balance mentioned	-	-	3 (1)	6 (1)		21 (6)	7 (2)	50 (9)
two correct forces/objects, balance mentioned	3 (1)	21 (6)	24 (7)	22 (4)		17 (5)	28 (8)	6 (1)
Single Force								
gravity/weight only acting	3 (1)	21 (6)	31 (9)	39 (7)		-	10 (3)	6 (1)
paper clips hold it down	55 (23)	24 (7)	14 (4)	6 (1)		24 (7)	14 (4)	6 (1)
air supports balloon	5 (2)	10 (3)	-	-		3 (1)	7 (2)	-
helium holds it up	-	-	3 (1)	-		7 (2)	-	-
Other Explanations								
no forces acting	-	-	-	-		3 (1)	-	-
nature of balloon	-	-	3 (1)	-		3 (1)	-	-
other responses	31 (13)	3 (1)	3 (1)	6 (1)		3 (1)	3 (1)	
don't know	-	-	-	-		3 (1)	7 (2)	-
no response	5 (2)	10 (3)	-	-		-	-	-

The data in Table 6.25 suggest that being physically involved in the act of countering the upward force of the balloon by adding objects in just the right quantity resulted in a significantly greater proportion of children with the notion of a balance in this static situation, even at the pre-intervention stage, as compared with the top-pan balance and stool situations. Post-intervention, many of those who were unable correctly to identify the forces involved were nevertheless aware of the necessity of balance.

However, this concentration on the added objects proved so powerfully attractive to many that they excluded all other forces from their interpretations both pre-and post-intervention. Perhaps some of these respondents felt that it is simply the nature of helium-filled balloons to rise. This attribute seems not to be considered to be in need of a name. On the other hand, a force to counteract this tendency of the balloon to rise is more familiar.

An understanding of the helium balloon behaving in the way it did as the result of its interaction with its environment - the air in which it floated - is an abstract idea. The helium and the air are both invisible. It was unlikely that children would draw analogies with objects floating in water without specific support from their teachers. Upthrust, as a phenomenon common to all fluids, was understandably not well understood by these children and this lack of awareness led to many describing the upward force on the balloon as the 'balloon force' or the 'force of the helium', etc. Such responses were accepted as legitimate at this level. A few, however, referred to the upward force as 'air resistance'.

6.3.2 Unbalanced forces acting on objects

6.3.2.1 Forces on a bottle using the arrow convention

The children were asked to interpret a line diagram of a bottle showing the forces acting upon it (gravity and a lift from a hand) represented by arrows. The arrows were in accordance with the convention regarding size and direction. Section 6.1.7 discussed the children's responses in terms of their appreciation of the direction and magnitude of the forces represented by arrows.

In addition, however, it is possible to use their responses as indications of their understanding of the probable *nature* of the forces acting and the resulting *movement* of the bottle.

Figure 6.15

The fact, noted previously, that children frequently omit to mention gravity or weight as a force, is exemplified again in the responses summarised in Table 6.27. However, the intervention activities here effected a considerable change at Key Stage 3 - from 39 per cent to 89 per cent. For the younger children, the most plausible interpretation of the data is that they were unfamiliar with the arrow convention.

This unfamiliarity almost certainly also accounts for the failure of the majority of younger children to name the upward force on the bottle. It appears to have been less of a problem for those at Key Stage 3 as correct responses were given by 44 per cent at pre-intervention and 67 per cent following intervention.

Table 6.26 summarises data elicited regarding children's ideas as to what the two arrows represent in the sense of what quality of force they assumed to be acting.

Table 6.26 Arrow representation of forces

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n.a.	UKS2 n.a.	KS3 n=18
Nature of downward force								
gravity/weight		17 (5)	28 (8)	39 (7)				89 (16)
air resistance		-	3 (1)	-				-
push from hand		-	-	11 (2)				-
force not named		83 (24)	69 (20)	50 (9)				11 (2)
Nature of upward force								
pull from hand		14 (4)	7 (2)	44 (8)				67 (12)
friction		-	-	6 (1)				6 (1)
air resistance		7 (2)	3 (1)	-				6 (1)
gravity/weight		-	-	6 (1)				6 (1)
push from liquid		-	7 (2)	-				-
force not named		79 (23)	83 (24)	44 (8)				17 (3)

Table 6.27 Arrow representation of forces - resultant movement.

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n.a.	UKS2 n.a.	KS3 n=18
bottle moves upwards		7 (2)	7 (2)	28 (5)				44 (8)
bottle moves downwards		-	-	-				6 (1)
bottle does not move		-	3 (1)	-				-
bottle moves up and down		3 (1)	3 (1)	6 (1)				6 (1)
movement not mentioned		90 (26)	86 (25)	67 (12)				44 (8)

The children's lack of knowledge of the convention also prevents the data concerning the movement of the bottle from being reliably informative for those at Key Stage 2. The intervention activities for Key Stage 3 children were able to effect a significant increase in correct movement responses (i.e. responses consistent with the fact of the longer upward arrow) from 28 per cent to 44 per cent. (See Table 6.27).

The down arrow is the force of gravity and the
up arrow is the force of the persons hand
on the bottle. The upward arrow
is longer so the upward force is greater
than the downward force so the bottle is
being picked up or lifted.

Y9 B H

If knowledge of the convention is assumed for the remainder (which is by no means a certainty), then the fact that unbalanced forces cause changes to movement was not well understood.

It was noted by teachers that once the arrow convention of representing the direction and magnitude of the forces is understood by children, it can be used as an extremely helpful assessment tool. Indeed, the arrow convention is an excellent example of Representational Redescription: movement in space can be represented graphically, in two dimensions, as an explicit check on interpretations of the outcomes of various forces acting.

6.3.2.2 Starting to move on a bicycle

Children were asked, 'What do you have to do to make your bicycle start moving?'. This was one of the earliest questions posed. The thinking behind it was to offer an open opportunity to children to describe a familiar, whole body activity in terms of motion and forces, or other vernacular descriptions which they might favour. Prior to intervention, less than half of the children at Key Stages 1 and 2 used 'push' or 'force' in their responses. The most common descriptions referred to movements of their legs or parts of the bicycle. On the other hand, nearly three quarters of the Key Stage 3 children provided responses which recognised that a force is needed to initiate movement.

The recommended intervention activities provided opportunities and encouragement for children to describe everyday activities using more specifically force-related words. The evidence gathered during the pre-intervention interviews gave strong indications that younger children, in particular, were experiencing difficulties with the word 'force'.

Table 6.28 Starting to move on bicycle

	Pre-Intervention				Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n.a.	UKS2 n.a.	KS3 n.a.
use force	-	-	14 (4)	-	-			
push pedal/ground	14 (6)	48 (14)	28 (8)	72 (13)	71 (30)			
ride/move legs	57 (24)	45 (13)	38 (11)	28 (5)	24 (10)			
wheel/chain turns	12 (5)	-	14 (4)	-	-			
other responses	14 (6)	7 (2)	7 (2)	-	5 (2)			
no response	3 (1)	-	-	-	-			

Subsequent discussion led to an agreement that Key Stage 1 children should be encouraged to continue to use words such as 'push' and 'pull' in their explanations with no expectation of an early introduction of 'force'. The repeat of the bicycle question at post-intervention for Key Stage 1 children revealed a considerable increase in responses using 'push', from 14 per cent to 71 per cent. (See Table 6.28). These children were thinking of the activity in a manner which revealed a closer focus on the *causes* of movement, using an age-appropriate vocabulary.

What do you have to do to make your bicycle start moving?

You Push The paddels with your feet.

Y2 G M

What do you have to do to make your bicycle start moving?

you puch the pedle and the chan mov and the well go

You push the pedal and the chain moves and the wheel goes

Y2 G M

The above example illustrates the kind of observation-related reasoning which even five to six year old pupils can be encouraged to use. Such complete sequences of causal reasoning are by no means commonplace in this age group.

6.3.2.3 Forces on a can dropped from a moving car.

The children were presented with a line drawing of a car which they were told was travelling 'forwards quite fast'. The children were invited to mark on the drawing the position of first impact on the road of a can dropped from the car and to give their reasoning. Their responses were categorised as 'ahead of', 'directly beneath' or 'behind' the point of release and are summarised in Table 6.29.

Table 6.29 Dropping can from moving car - position of impact on road.

	Pre-Intervention				Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
ahead	21 (9)	10 (3)	14 (4)	17 (3)	17 (7)	7 (2)	3 (1)	33 (6)
directly beneath	55 (23)	28 (8)	7 (2)	17 (3)	67 (28)	24 (7)	3 (1)	11 (2)
behind	21 (9)	62 (18)	79 (23)	67 (12)	17 (7)	69 (20)	93 (27)	56 (10)
no response	3 (1)	-	-	-	-	-	-	-

Intervention for the Key Stage 3 sample doubled the number of children with correct impact predictions, taking the proportion from one sixth to one third. Although the data in Table 6.30 indicate that approximately one fifth of Key Stage 1 children at both pre-and post-intervention stages correctly predicted an 'ahead' impact, closer scrutiny of their responses showed that their reasoning did not involve consideration of the forward momentum of the can. For the majority of these children, the can went where it rolled or was thrown (see Table 6.32). The very small proportion of Key Stage 2 children who at pre-intervention had 'ahead' predictions was reduced yet further (from 12 per cent to five per cent) by the readjustments in their thinking brought about by the intervention activities.

Prior to intervention, a little more than a half of Key Stage 1 children indicated that the can would land directly beneath its point of release. This fraction was increased to two thirds post-intervention. It appears that the drop was considered by them in isolation from the other influential factors.

The overwhelmingly popular response, at both pre- and post-intervention stages, was that the can would land in the 'behind' position. The reasons given in the vast majority of cases were based upon a misinterpretation of the direct experience of air hitting a hand or face protruding from a moving vehicle. This interpretation has air moving backwards past the car rather than the car passing through (relatively) static air. The logical conclusion of thinking based on this misinterpretation is that the 'wind' will blow the can backwards. This form of reasoning was discussed previously in Section 6.2.3.

Although in other situations pupil's seemed intuitively to use ideas in a manner which closely approximates the scientific idea of momentum, in this instance, the idea of 'wind' or 'air resistance' seemed to overwhelm any other consideration. Momentum responses are summarised in Table 6.30.

Table 6.30 Dropping can from moving car - can has momentum

	Pre-Intervention				Post-Intervention			
	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
can has forward momentum	-	-	-	-	-	-	-	11 (2)
can continues to move forward	-	-	3 (1)	17 (3)	-	-	-	28 (5)
car is moving fast	-	-	3 (1)	-	2 (1)	3 (1)	3 (1)	-
no mention of momentum idea	100 (42)	100 (29)	93 (27)	83 (15)	98 (41)	97 (28)	97 (28)	61 (11)

Even after intervention, very few at the lower Key Stages and about two fifths at Key Stage 3 were able to base their thinking on the fact that the forward movement of the can prior to release would continue after it. This is another example of children's tendency to think of forces coming into play only when threshold levels have been reached. In this instance, the threshold might be thought of as being limited or held back by the opposing effect of movement through air. It is likely that the experience of empty drinks cans as very light, low density objects, capable of being blown along a street has strongly influenced chidren's judgements. It may be possible that an introduction of the concept of momentum at an appropriate stage in teaching would assist understanding of phenomena such as dropped 'passively moving' objects.

The dropped can question provided more evidence of mention of gravity being omitted in instances where more than one force needs to be considered. Even after intervention, very few children in the earlier Key Stages and only 22 per cent at Key Stage 3 included gravity in their explanations. Again, it is possible that children think of the effects of gravity being suppressed by other, more powerful, forces. In other words, it could be that gravity has not been overlooked so much as been deemed not to have been brought into play. Children frequently used the metaphor of war, battle or struggle between forces. In this instance, gravity might have been considered to be overwhelmed by more active and powerful forces. If gravity is considered to have been 'beaten' by other forces, it is unlikely that it will be mentioned.

A sizeable minority both pre-and post-intervention provided explanations that did not include consideration of the forces acting. The responses of this kind at Key Stage 1, involving throwing and rolling, were mentioned above. The most common of such responses at the other Key Stages considered the position of the can relative to the car, not the road. In consequence children gave 'behind' answers because they had in mind that the car had moved forwards as the can was falling. Even careful probing at interview could not deflect some children (for example 31 per cent at upper KS2) from this viewpoint.

Ch *The car is going forwards and the can is going down. So it goes at an angle.*

Int *Why does it go backwards?*

Ch *Because the can isn't moving backwards it is going down because the car is going forwards. It goes at an angle.*

Int *Why does it do that I wonder? You've said - 'The can is going backwards. The car is going forwards.'*

Int *It (the can) is just going down. Because the car is going forwards it seems as if it is moving backwards.*

Table 6.31 Dropping can from moving car - explanations not mentioning forces.

	Pre-Intervention				**Post-Intervention**			
	KS1 n=42	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**	**KS1 n=42**	**LKS2 n=29**	**UKS2 n=29**	**KS3 n=18**
can thrown	43 (18)	7 (2)	-	-	36 (15)	-	-	-
can rolls	12 (5)	-		-	5 (2)	7 (2)	-	-
can goes there	12 (5)	7 (2)		-	29 (12)	7 (2)	-	-
car moves forward	5 (2)	24 (7)	34 (10)	22 (4)	7 (3)	21 (6)	31 (9)	11 (2)
can is heavy	3 (1)	7 (2)	3 (1)	-	2 (1)	3 (1)	-	-
no response of this kind	26 (11)	55 (16)	62 (18)	78 (14)	21 (9)	62 (18)	69 (20)	89 (16)

6.3.2.4 Forces causing a ball to bounce

The children were asked to explain what makes a ball bounce when it is dropped onto the playground. The important attributes of the content of this situation were deemed (by the research team) to be the familiarity of the experience and the visible and tangible elasticity of the ball. It was anticipated that these aspects would encourage and enable children to envisage and discuss reaction force by reference to the visible compression of the ball on impact with the hard playground surface. In the event, this dynamic situation appeared not to be any more effective than the static 'seated' child in eliciting the idea of a reaction force. Only a handful of pupils at both interview stages gave responses which indicated an awareness of the playground's role in the bouncing reaction of the ball.

Gravity pulls it down but the force applied at the other side isenough to send it back

Gravity pulls it down but the force applied at the other side is enough to send it back.

Y9 B H

Table 6.32 Bouncing ball - reaction force

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
'reaction force' mentioned		-	-	-	-	-	3 (1)	6 (1)
reaction force otherwise expressed		10 (3)	6 (2)	6 (1)	2 (1)	17 (5)	7 (2)	6 (1)
'bounce' force		3 (1)	-	-	2 (1)	-	-	-
reaction force not mentioned		86 (25)	93 (27)	94 (17)	95 (40)	83 (24)	90 (26)	89 (16)

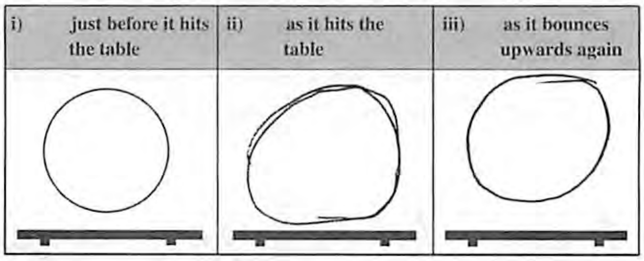
However, in marked contrast to the older children, 33 per cent of those at Key Stage 1 and 24 per cent at lower Key Stage 2 recognised the need for the playground to be *hard*. This is arguably as a result of the younger children responding from their personal experience that the harder the surface the better the bounce. There may be a similar reason for these same children considering that the 'bounce' is related to the force of the downward throw.

when the ball hits a hard surface
it will come up again Because
of the Strong Downward force

Y3 B H

At the pre-intervention stage this probe asked Key Stage 2 and 3 children to draw the ball at and just after the point of impact with the playground and then to explain their drawings.

One fifth of the Key Stage 2 children and two thirds at Key Stage 3 demonstrated an understanding that the ball was deformed and then reformed.



Explain why you drew the balls the way you did.
It is because when you drop it, it bends in and then expanded.
You can hardly see the little dint where it squashes up a tiny bit.
When it comes back out it causes it to go back in the air again.

Y6 B H

After intervention children at all Key Stages were asked to explain why a ball bounces. There was no requirement for any drawing. In these circumstances the percentages of those mentioning the changing shape of the ball or the consequential effects on the air pressure inside it fell dramatically. No Key Stage 1 child mentioned the change; less than 10 per cent at Key Stage 2 and only 28 per cent at Key Stage 3 did so. These data (Table 6.33) would seem to suggest that the use of appropriate drawings greatly enhances understanding of this phenomenon.

A side colapses in and pushes back
out again, forcing it back up into the air.

A side collapses in and pushes back out again, forcing it back up into the air.

Y6 B H

Table 6.33 Bouncing ball - change of shape

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n=42	LKS2 n=29	UKS2 n=29	KS3 n=18
ball deformed then reformed		17 (5)	24 (7)	61 (11)	-	-	3 (1)	11 (2)
inside air compressed and decompressed		-	-	6 (1)	-	7 (2)	3 (1)	17 (3)
ball deformed		-	3 (1)	-	-	-	-	-
change of shape not mentioned		83 (24)	72 (21)	33 (6)	100 (42)	93 (27)	93 (27)	72 (13)

A sizeable minority, from a third to a half across all Key Stages, gave explanations which made no mention of forces but invoked the round, hollow, rubbery or bouncy nature of the ball itself.

it is hollow and is
made with elastic and
rubber

Y6 G M

the ball has boncey rubber
inside it and it makes the ball
bonce.

Y3 B H

It is made of rubbir and is round.

Y5 B M

This kind of explanation reveals a focus on some very situation-specific, intrinsic qualities of the object under consideration: in this case, a rubber ball. This kind of response is lacking in generality. It does not refer to the more universal and abstract concepts of force and motion, springiness, elasticity or reaction force

6.3.2.5 Forces on a moving vehicle

Key Stage 2 and 3 children were provided with a line drawing of a moving vehicle and asked to draw and label arrows on it to show the forces acting. For the first part of this probe there was no requirement that the children should consider the *interaction* between the forces they mentioned. It was possible, therefore, for them to think of the forces individually at this stage. The force accounting for the forward movement of the bus was considered separately in the analysis and is reported first. At pre-intervention no child drew a forward-pointing arrow labelled 'engine' or 'wheels', though one third of Key Stage 2 children and a half of those at Key Stage 3 labelled such an arrow pointing in the direction in which the bus was moving 'push'. There was a very small increase in the incidence of such arrows being drawn post-intervention and Key Stage 3 children, in particular, changed to an 'engine' label.

As in some of the probes discussed earlier, it was noticeable that arrows labelled either 'gravity' or 'weight' were lacking in many children's responses. The age-related omissions of any references to gravitational force or weight were in the proportions of two-thirds, a half and one tenth of pupils for Key Stages 1, 2 and 3 respectively. The fact that this discounting of the force due to gravity was apparent in many of the probes used has serious implications for teachers.

Table 6.34 Forces on moving vehicle - from engine

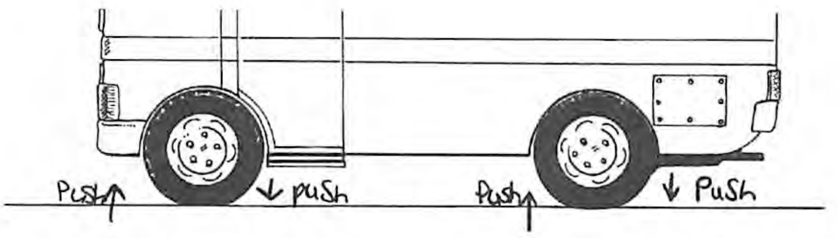
	Post-Intervention			
	KS1 n.a.	**LKS2** n=29	**UKS2** n=29	**KS3** n=18
arrow forwards - engine / wheels		3 (1)	17 (5)	56 (10)
arrow forwards - push		28 (8)	21 (6)	6 (1)
arrow forwards - pull		-	3 (1)	-
no forwards arrow		69 (20)	59 (17)	39 (7)

The problems associated with children's understanding of air resistance were discussed in detail in Section 6.2.3. Their difficulties were clearly revealed in their responses to this moving vehicle probe. There is possibly less confusion on display in this task than there was in the dropped can probe but clearly the use of the words 'wind' or 'wind resistance', with their connotations of moving air, need to be subjected to explicit discussion and reflection in classrooms, in the interests of better understanding of air resistance.

It was not clear in all cases whether children used arrows to indicate the point of action of the force or its direction. Prior to the introduction of the arrow convention to represent forces, many children used arrows as devices to indicate *where* forces were thought to be acting. Such responses cannot be assumed to include ideas about direction, magnitude or movement. Elsewhere in the curriculum, arrows are used in precisely this more limited manner – simply to indicate where objects are, as a labelling device. The probe, as it was presented, might have cued children more precisely to the fact that it was the formal scientific ideas about forces that was the object of enquiry. Equally, such a request might have bewildered those children who did not have such an understanding and it was left to those who did to demonstrate as much. Children's 'friction' arrows highlight this difficulty, for most arrows seem most validly interpreted as indications of *where* friction was thought to be acting, in a rather more general sense than the arrow convention, used more precisely, would enable them to communicate.

The school bus probe was not used, pre-intervention, so data concerning children's awareness of friction can only be compared with other tasks. In these other pre-intervention tasks, friction was not commonly mentioned by children in any of the Key Stages from which the sample was drawn. The friction arrows drawn post-intervention in relation to the moving bus probe occurred with greater frequency than had been the case in other pre-intervention tasks: about one quarter of pupils at Lower KS2, about one half at Upper KS2 and four fifths at KS3. However, the warning that the majority of arrows drawn might have been intended to indicate the *location* of friction rather than the direction in which the frictional force was acting, must be carefully heeded. Arrows were drawn at various angles to the horizontal. Not a single pupil at any Key Stage drew an arrow to represent unequivocally the frictional force acting at the wheel in the same direction as the forward movement of the bus. This is not altogether surprising, since it is a counter-intuitive idea as well as being difficult to reconcile with the notion that might have been promulgated, that friction *opposes* movement. It seems to be safe to conclude that teachers had not addressed this specific issue with pupils, and indeed, there was no imperative that they should have done. The direction of frictional force at the wheels requires a careful and detailed consideration of what parts are moving against what surfaces. Once it is appreciated that the wheels are rotating against the surface of the road, pushing the bus forwards against the purchase on the road surface, it becomes easier to appreciate that the frictional force between tyres and road acts in the direction in which the bus is moving. The example of tyres failing to grip, resulting in spinning on an icy road surface, helps to amplify this understanding.

Figure 6.16



Y6 B L

Pupils were asked explicitly to comment on the changing size of the forces while the bus was increasing its speed.

About one quarter of the KS3 sample suggested that, under the condition of the bus increasing its speed, *all* the forces would be increasing.

They will get bigger and bigger.

Y7 B H

the friction, engine power, and air resistance increase

Y7 B H

About one quarter offered the view that while the bus was increasing its speed, the force attributed to the engine would *increase* while all opposing forces would remain *unchanged*.

the force at the front increases and
the force at the back stayed the same

Y9 G L

Another quarter of the KS3 sample mentioned changes only in the forces opposing movement.

Fiction becomes less and air resistance becomes less

Friction becomes less and air resistance becomes less because you are getting at a faster speed.

Y9 B L

As discussed in earlier sections (see 6.3.1.1 and 6.3.1.2) the evidence suggests that the idea of reaction force is not well developed. In labelling the forces acting on the moving bus, the indications were that pupils had not thought systematically in terms of forces acting in pairs. The moving bus probe confirmed that most children were not thinking about reaction forces, the incidence of reaction force arrows being only ten per cent overall. Most of these references to reaction forces were from KS2 children, suggesting that their teachers had spent some time attending to this aspect of their understanding during intervention. There is thus reason for optimism that KS3 pupils are capable of even greater gains, given appropriate guidance.

Table 6.35 Forces on accelerating vehicle

	Post-Intervention			
	KS1 **n.a.**	**LKS2** **n.a.**	**UKS2** **n.a.**	**KS3** **n=18**
Balance of forces				
engine force greater				44 (8)
no size comparison				56 (10)
Changes in size of Forces				
all forces increasing				28 (5)
engine force increasing, opposing same				22 (4)
engine force increasing, opposing decreasing				6 (1)
all forces decreasing				6 (1)
only opposing forces mentioned				28 (5)
changes in size not mentioned				11 (2)

At the post-intervention stage, KS3 pupils were additionally asked, 'What can you say about the forces on the bus while it is increasing its speed?'. Just under half the KS3 sample indicated that the force from the engine would need to be greater than the forces opposing the forward motion of the bus. The remainder of the sample made no comparison of the sizes of forces. (Section, 6.3.3.1, reviews ideas about the forces acting on the bus while it is moving at a constant speed.)

One lone voice suggested that all the forces would be decreasing. No pupils suggested that all the forces would stay the same, though a minority offered no suggestions about any forces changing in size.

The relationship between forces in the direction of movement and those opposing movement when a vehicle is accelerating is conceptually complex and linguistically demanding to articulate. The force in the direction of movement increases, but so too do the forces opposing that movement, but the increase in the forward force is greater than the increase in the opposing forces. In this sense, the quarter of the sample which asserted that *all* the forces were increasing was correct. The single pupil who suggested that the force of the engine was increasing while the opposing force was decreasing was not literally correct, though it would be true to say that the opposing force was decreasing *relative* to the forward-acting force. The essential idea of the necessity for forces to be *unbalanced* in order for acceleration to be achieved by a moving vehicle was appreciated by less than half of this KS3 sample. It seems likely that pupils would benefit from class debate about the forces acting in various situations such as that presented in the moving bus probe. Such activities would encourage the articulation of ideas and more analytical thinking stimulated by a critical reflection on their own and others' expressed ideas.

6.3.3 Balanced forces on moving objects

It is important to point out at this point that the National Curriculum draws a firm distinction between balanced forces acting on *stationary* objects and balanced forces acting on *moving* objects. While the former are part of the Programme of Study for KS2, the latter are not expected to be addressed until KS3.

6.3.3.1 Forces on a vehicle moving at a constant speed

The probe centred on the subject of the moving bus discussed in section 6.3.2.5 was extended at the post-intervention stage, with KS3 pupils only, to include the question, 'What can you say about the forces on the bus when it is moving at a steady 30 miles per hour?'. (Incidentally, metric units were not used in posing this question in view of the fact that road signs and everyday usage in the UK refers to m.p.h. rather than k.p.h.)

Starting with the essential idea, that of the necessity of appreciating that the forces acting on a body moving at a steady speed must be *balanced*, it is evident that this understanding was not at all well established in the interview sample. Only three children responded in a manner which indicated awareness that, under the condition of constant speed, the forces acting must be balanced (see Table 6.36).

The force that makes the bus move is equal
the air resistance and friction

Y9 B M

Over half of the sample did not explicitly articulate any relationship which could be interpreted as a view on the balance between the forces causing the bus to move in a forward direction and forces opposing such movement. As such, these pupils did not show awareness of the essential feature of the physicists view of a body moving at constant speed.

Table 6.36 Forces on vehicle moving at steady speed.

	Post-Intervention			
	KS1 n.a.	LKS2 n.a.	UKS2 n.a.	KS3 n=18
Balance of Forces				
forces 'balanced'				6 (1)
engine force same as opposing				11 (2)
forces unbalanced				28 (5)
no size comparison				56 (10)
Changing Size of Forces				
all forces stay same				28 (5)
engine force decreases, opposing stay same				6 (1)
all forces decreasing				17 (3)
only opposing forces mentioned				17 (3)
changes in size not mentioned				33 (6)

Just over one quarter of this KS3 sample suggested that all the forces would stay the same. This response, albeit tacitly, might be inferred to incorporate a notion that the forces which are acting are balanced.

Ch *The force that makes the bus move is equal to air resistance and friction.*

Y9 B M

Ch *The engine force will be the same as friction and air resistance.*

Y9 B M

Slightly under one fifth of the sample suggested that all forces would be decreasing.

Ch *The force slows down friction would slow down because the bus is at a steady 30 mph.*

Y7 B L

It is possible that everyday experience of the sound of the high rate of engine revolutions required to accelerate a vehicle to the nominal speed are being contrasted, by these pupils, with the relatively lower rpm at constant velocity. This is apparent to drivers and passengers alike as the result of the sound of the engine though, or course, the vehicle will be operating in a higher gear. Thus they may conclude that the force to move a vehicle at steady speed is decreasing, or the vehicle is 'coasting'. This may also explain the single pupil who suggested that the engine force decreases while opposing forces stay the same.

The remaining 40 per cent of this KS3 sample either did not mention forces at all, or made reference only to opposing forces.

Under frictionless conditions, Newtonian views of forces become more lucid, their relevance and utility become more apparent. On the surface of the Earth, the Newtonian ideal is veiled; a force has to be provided in order to maintain a movement of any kind. This is because the frictional forces which oppose movement are pervasive, whether it be the result of an object moving across the ground, through the air or across the surface (or below the surface) of water. Pupils lack first-hand experience of frictionless conditions. In situations involving interacting forces such as that of the bus moving at constant velocity, the necessity of balanced forces for a steady speed to be maintained is likely to be counter-intuitive, even at KS3.

6.3.3.2 Stopping a spacecraft in space

It was suggested in the previous section that some of the difficulties children have with envisaging the forces acting on a moving body on Earth are related to their lack of direct experience of frictionless environments. Though Newton's laws of motion predict that an object will continue to move in a straight line in the direction in which a force is applied until something else happens to change that state, this is not the experience on Earth. Moving objects slow down very rapidly as the result of opposing frictional forces. The power of Newton's laws of motion is that they have applicability far beyond the parochial conditions pertaining on the Earth's surface. Indeed, it is on a planetary scale and beyond that the laws are particularly useful, and also, where they can be verified. The modern era of space exploration is not just *helpful* in supporting pupils' understanding of the laws of motion; such a perspective is *essential*. Historically, hypothesis generation and verification of the laws was conducted by means of astronomical observation and it is no coincidence that the period of rapid theoretical advances coincides with the development of the technology of telescopy. In the modern era, images of space exploration, Moon walking and weightlessness are familiar to most children through the secondary source of video material. Children can be invited to engage in thought experiments in which they consider the consequences of various actions in a hypothetical gravity-free, frictionless environment. Children's awareness of and fascination with space travel permitted the use of such a context to probe their understanding of movement and balanced forces. The question posed to KS2 and Ks3 children was, 'If astronauts want to bring their spaceship to a stop in space, what do they do?'.

As expected, children took this question in their stride. No child pointed out that it would be most unlikely that an astronaut should want to bring a spaceship to a halt in space, nor attempted to question what 'stop' would mean in these circumstances.

Table 6.37 Stopping a spacecraft in space.

	Pre-Intervention				Post-Intervention			
	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18	KS1 n.a.	LKS2 n=29	UKS2 n=29	KS3 n=18
reverse thrust		-	7 (2)	28 (5)		10 (3)	10 (3)	28 (5)
create stopping force		3 (1)	3 (1)	11 (2)		3 (1)	-	6 (1)
stop engine		31 (9)	24 (7)	33 (6)		17 (5)	38 (11)	39 (7)
push button		41 (12)	20 (6)	17 (3)		41 (12)	14 (4)	6 (1)
land		10 (3)	-	-		10 (3)	3 (1)	-
stopping impossible		3 (1)	7 (2)	6 (1)		3 (1)	3 (1)	6 (1)
stopping mechanism not known		10 (3)	38 (11)	6 (1)		14 (4)	31 (9)	17 (3)

In order to consider the problem in terms of forces, it was necessary to recognise that most frequently, spacecraft travel through space with rockets or engines switched off, no force being necessary to maintain movement at a constant speed in the frictionless environment of space. Stopping therefore requires a force to be applied in the direction opposite to the movement of the craft.

As might be expected, most children generalised their experience of moving and stopping a vehicle on Earth. The responses of the youngest children in the sample tended not to be able to specify a causal chain of events which would cause the spacecraft to stop: they suggested pushing a button or some similar act of faith.

Ch *They turn the gears off with a switch.*

Y3 B H

Ch *Press a button.*

Y3 B M

One third of the total sample suggested that the spacecraft could be brought to a halt by 'stopping the engine'.

turn the engine off and then they chain it to the pland

Y9 B H

they turn off the engine

Y9 B H

Four children in the course of the pre-intervention interviews and two during post-intervention demonstrated their awareness that stopping a movement requires a force to be applied, though without being able to suggest a means of applying such a force.

During pre-intervention interviews, a sprinkling of KS2 pupils and a quarter of the KS3 sample gave a 'reverse thrust' form of response.

To bring them to a stop they put on their rockets which fire forward to slow them down.

To bring them to a stop they put on their rockets which fire forward to slow them down.

Y9 B H

The number of KS2 children offering a response of this kind increased slight post-intervention, while the KS3 level of accurate response remained unchanged.

The fact that pupils readily accepted this form of problem and gave serious thought to their responses is encouraging. There are many hypothetical situations which could be discussed by a class which are likely to stretch and enhance their thinking about forces and motion. It is increasingly the case that massive objects need to be manoeuvred in space; occasionally there are accidents which make the news and challenge pupils' assumptions about 'weightlessness' and the relationship between gravity, weight and mass. Such examples are both stimulating and instructive and confirm that science must be an imaginative as well as an empirical discipline.

Summary

The responses of pupils representing the age-range 5-14 years to a wide range of concept probes have been summarised. Shifts in their thinking have been identified and some tentative hypotheses as to why (or why not) ideas might have changed have been very briefly rehearsed. The next chapter reviews the qualitative and quantitative evidence which has been assembled, relates this evidence to the published literature and offers some suggestions for consequent action to support teaching and learning in this area.

7. *SUMMARY AND CONCLUSIONS DRAWN*

7.0. Introduction

The programme of research reported here was dynamic and exploratory; it built on previous published data and did not expect to provide the last word on the subject of teaching and learning about forces. It is claimed, nonetheless, that some new insights were gained – about the sequence in the emergence of ideas, about specific teaching strategies which seem likely to enhance the possibility of pupils making progress with their knowledge, about approaches to the notation specific to understanding and communicating ideas about forces and about possible sequencing of the curriculum. These ideas are preceded by some more general points about teaching forces from a position of being informed by a constructivist rationale. It is planned to produce some support materials for teachers following a more exhaustive review of our own and other researchers' evidence and recommendations.

The structure of the chapter is as follows:

Section 7.1 Some general assumptions
Section 7.2 The notation of forces
Section 7.3 Evidence of progression in ideas
Section 7.4 Some initial thoughts on sequencing

The programme was a demanding one for all participants – researchers, teachers and pupils. In the circumstances, there could only be indications of possibilities for enhancing pupils' understanding arising from particular insights in individual classrooms. In the course of the research itself, there was discussion and reflection, but the possibility of a wide dissemination and implementation of emerging best practices was severely constrained, both by the demanding research schedule and by teachers' wider curricular responsibilities. This report begins the process of reflecting on the insights gained; there was not the opportunity for teachers to re-visit topics, to explore some of the emerging strategies, to attempt to improve on their practices in the light of what had been learned. Such modifications of approach will need to await the next time in which they approach the teaching of forces – for most, the next academic year with the next year's cohort of pupils. At that time, effective elicitation strategies will be familiar and available rather than novel; pupils' ideas might make more sense in terms of the developmental sequences discussed below; possibilities for intervention strategies as means of guiding and supporting pupils' developing ideas will have been rehearsed and prepared. Teachers will be in a stronger position to optimise pupils' progression as the result of the more precise targeting of intervention to pupils' expressed ideas.

The results reported in the previous chapter were described as 'conservative' in the sense that the measured changes in pupils' understanding suggested particular areas in which there seemed to be scope for action. This chapter reviews what we regard as the more significant outcomes of the research which would be expected to carry forward into implications for practice.

7.1 Some general assumptions

- ***Starting early***

  We fully endorse the view of the Waikato group that we must start early: '...if children are to understand important ideas in physics it is essential that many change their ideas about force. We believe this can be done and suggest the earlier it can be done the better; before a child's framework of ideas becomes inflexible. The activities booklets...suggests how this might be done with children as young as 11 years old. However, it cannot be done in isolation from ideas about friction and gravity.' (Osborne, Schollum and Hill, 1981, p.21)

  Our only disagreement is that we would not wait until children are eleven years of age; there is much that can be achieved in the early years of schooling.

- ***Supporting metacognitive strategies***

  We assume throughout the more specific remarks in the sections which follow that children will be encouraged not just to think, but to think about their thinking. This means being aware that they have ideas, that their peers have ideas and that scientists have ideas. It means engaging in the intellectual struggle to articulate unambiguously and consistently their own representations as well as considering seriously the ideas of others.

- ***Teachers taking children's ideas seriously***

  We assume that teachers will be interested in children's ideas and will take these ideas seriously. Recognising pupils' starting points is essential to supporting learning with understanding. This 'taking seriously' means accepting them as provisional, accepting the limits on children's understanding, while at the same time helping them to develop their ideas as far as they are able. Often, this will imply less, (often far less) than conventional scientific understanding; it means accepting the principle of 'intermediate understanding' as an educationally valid construct rather than a threat to standards of scientific accuracy.

- ***Accepting the refexivity of constructivism***

  Constructivism as a theory applies just as much to university researchers and teachers as to pupils. Teachers must scrutinise their own understanding of the concepts which they are addressing with their pupils.

- ***Seeking evidence for beliefs***

  Science frequently uses empirical enquiry to seek evidence and test hypotheses. It is also an imaginative activity, but one in which beliefs are required to be supported by evidence. We assume that pupils will be encouraged to test their beliefs against primary and secondary sources of evidence derived from and motivated by, whenever possible, their own active enquiries.

7.2 The notation of forces

Members of a culture share meanings. They extend their spoken communication by using external symbol systems. Some of the notation systems that are relevant to the communication of scientific ideas about forces are arrow notations, drawings, language and quantification. Each of these external symbols systems will be reviewed in the light of the data emerging from the reported research.

7.2.1 The use of the arrow notation to represent forces

Arrows are pervasive in modern society, though in their abstract rather than their physical manifestations. They may serve to remind us of the span of hominid cognition from making, testing and using flint artefacts through to defining the properties and uses of arrows as abstract symbols to represent forces. Arrows as symbols are what concern us here.

Figure 7.1 Some demands of the arrow notation to represent forces.

Drawing demand (Single arrow)	Conceptual demand (Single arrow)
Direction of arrow	Force has direction
Straightness of arrow	Forces act in straight lines
Length of arrow	Magnitude of force
Location of arrow's tail	Objects as point masses
(Two arrows)	**(Two arrows)**
Arrows drawn 'head-to-head'	Opposing forces
- equal lengths -	- Balanced forces (zero net force, body being stationary or moving at constant velocity)
- unequal lengths -	- unbalanced forces
Arrows drawn in same direction	Forces are additive in same direction
Arrows drawn in different directions	Both forces influence resultant movement
(Multiple arrows)	**(Multiple arrows)**
Arrows drawn in various directions to represent all the forces acting on a body	Directions of individual arrows combined to determine total force; equal and opposite forces cancel one another out. With unequal opposite forces, the net force is the smaller subtracted from the larger.

The research reported above described how pupils showed very little evidence of having been exposed to teaching and learning about the convention of using arrows to represent forces. This understanding was probed with both KS2 and KS3 pupils, pre-intervention, but in view of the results obtained, was not pursued with the younger group in the post-intervention interviews. The KS3 post-intervention results showed a dramatic increase in pupils' appreciation of the arrow convention to represent *direction*, with gains in understanding of the representation of *magnitude* substantial, but not quite of the same order. The interpretation of net direction of movement was not pursued. The evidence suggests that the use of arrow drawing in association with work on forces is under-exploited. Extrapolating downwards from the KS3 results, it seems likely that the greater use of the convention could result in positive gains amongst KS2 pupils also, though this remains to be confirmed. It would seem to be profitable to consider more precisely what the notation *demands* of the learner, and what it offers in the sense of *supporting* understanding. Such a review requires, first of all, some thought about external symbols and notation systems in general. To begin the analysis, the aspects of the drawn symbol and its meaning presented in Table 7.1 seem to be relevant to the age group and the KS1-3 curricular demands, though it is not suggested that all need to be understood at once.

Lee and Karmiloff-Smith (1996) report a lack of consensus in the literature over the technical vocabulary used to discuss notation systems but suggest three major principles: they are independent of i) their creator, ii) location and iii) time. Notation systems operate across generations and facilitate the communication and accumulation of knowledge. It is clear that children are capable of understanding and manipulating a number of notation systems from an early age: drawing, written language, maps, scales, number and musical notation. From the age of two, some understanding of the 'stand for' relationship between notations and what they represent is in evidence, and at three, they can use notations to solve problems in the real world. It is accepted that the pace of development may vary from the use of one system to another, (Lee and Karmiloff-Smith, *op cit*.). In the case of arrow notation, the precise relationship between internal representations and external notation remains to be described in detail. How much of the burden of accurate notation resides in the symbol system itself and how much in conceptual understanding? The answer is that we do not know, but it is possible to offer, even at this stage, a logical analysis of the demands, informed by limited empirical data from our study.

The demands indicated in Table 7.1 are only a beginning of the analysis. For example, even commonplace everyday instances of motion are likely to involve multiple interacting forces. It is also critically important to know, if we are to predict movement outcomes, how such forces are acting in relation to the centre of mass of the objects under consideration. (A javelin will travel in a 'straight' line only if the force is applied though its centre of mass; anywhere else and it will spin, albeit still around its centre of mass.) While acknowledging that we are on the threshold of great complexity, we should not become faint-hearted; the objective is one of helping pupils through a constructive series of intermediate understandings. The way forward is to determine what is accessible to pupils at what age and stage of their thinking and plan teaching accordingly.

If they do nothing else, arrows signal direction, so this would seem to be the appropriate starting point. As indicated in Chapter Six, there is a tendency to use arrows to label *location*, a quite legitimate function in other areas of the curriculum, but not when dealing with forces. Location can be labelled accurately by arrows coming from and pointing towards no matter where, (though there is a more general convention in labelling science diagrams to use horizontal or vertical arrows). Conventional understanding is that which is *agreed*. There seems to be minimal conceptual demand in *agreeing* to use arrows to label the *direction* of forces. Such a resolve is likely to encourage children to think more carefully about forces having direction, and the direction of the particular forces they are representing.

More problematic is likely to be the agreement that *forces act in straight lines*. Children did not see the necessity of drawing straight lines, though a fundamental concept in Newtonian descriptions of force and motion is that forces act in *straight* lines. This is an example of a critical interface between conceptual understanding and conventional representation: children will more likely draw straight arrows if they have it in mind that forces act in straight lines. Is it perhaps legitimate to argue the converse: children will more likely think of forces acting in straight lines if they have been encouraged to draw straight line arrows to represent forces? (We must know our enemy: everyday experience shows us that thrown objects follow parabolic paths through the air; even worse, footballs are intentionally 'bent' around defences and cricket balls 'swing'. Such trajectories have to be understood, in time, as the result of complex interactions of forces.)

Turning to the length of an arrow as a representation of the magnitude of a force, agreement to use the convention seems to be all that is required. (Agreement has both a social and *affective* dimension; in this context, intrinsic interest might suffice.) Our data suggest that young children readily arranged pushes and pulls ordinally, so relative magnitude is not a difficult idea. Of course, more precise quantification and the use of measurement scales will come later.

The idea that the position of the arrow's tail is important can probably be introduced in a macroscopic manner at Key Stage 2, since centre of mass is likely to be a difficult idea in this age group, especially if it involves irregular objects and notions of density.

To represent arrows 'head-to-head' in order to represent forces acting in opposition to one another, or as reaction forces, does not seem to imply any great conceptual burden. The arrow notation might actually help children to make better sense of reaction forces, offering more accessible support than words alone to the formation of the concept that rigid bodies can 'push back'.

7.2.2 Drawing

It is a familiar strategy to most teachers to approach a difficult topic from several angles, different perspectives, using analogies, models and whatever comes to mind to find the representation which 'works', the 'key to unlock the door'. In the theoretical rationale underpinning our approach, we adopt a similar but more formalised view, that of Karmiloff-Smith's Representational Redescription. The research presented in this and previous reports in the series has used children's drawings to illustrate children's beliefs very extensively. These drawings are useful in communicating something of the quality of classroom activities in which children engaged, but they are far more than that, and far more than cosmetic decorations. The extensive use of drawings reflects our view that this form of notation is one which is easily accessible to children as a modality through which their internal representations of how the world works may be externalised. This report, particularly Chapter Five, also reproduces extensively examples of children's drawings. These illustrations usually have comments attached to them, sometimes in the child's hand, at other times annotated by their teacher or the verbatim comments drawn from the individual interview. Many teachers have adopted the technique of annotated drawings as an elicitation strategy. As well as being useful diagnostically, the drawings can be retained for reference as a record of children's thinking at a given time.

We have long recognised that engaging children in elicitation activities cannot be a cognitively neutral activity, any more than it can be affectively neutral. Being asked to articulate one's ideas clearly, consistently and unambiguously, being questioned about details of meaning, however supportively and congenially this is conducted, must be expected to have an impact on thinking. Ideas which might have existed only in the most inchoate intuitive form are required to be explicitly articulated. This is not a problem, other than being an issue which must be honestly addressed in reporting research which might claim to be collecting 'baseline' data. In the context of drawing, the principle of explication can be viewed positively and deliberately as part of the process through which children construct their meanings. There was one striking example which can be interpreteted in terms of the impact of the use of drawing on thinking, that of children's drawings of the ball hitting the playground and bouncing away.

In the pre-intervention activity, children were asked to draw the ball in sequence, in the three frames provided. (Previous experience confirmed that children tend to be familiar with comic-strip conventions and are perfectly happy to represent sequential points in time in this manner.) When compared with their post-intervention reponses, it was apparent that there were far fewer references to the deformation of the ball on hitting the ground when the response was elicited independent of the drawn representation. It is inferred that the drawing focused children's attention on the shape of the ball and helped them to frame a more accurate response. Since reaction force seems to present particular problems, this example of the support which drawing can offer is potentially valuable. Of course, drawings could be further annotated with words and arrows.

7.2.3 The language of forces

Language is another example of a symbol system used by a culture to communicate meanings which are independent of particular individuals, time or place. Language is the repository of a culture's knowledge, and the science sub-culture has its own specialist vocabulary which children have to assimilate if they are to share precise understanding of conventional science ideas. A frequent difficulty is encountered when vernacular and scientific vocabulary overlap; Solomon discusses the inherent tensions between the 'life world' and the science domain, (Solomon, 1993). As primary educators, we are perhaps more optimistic that children can be successfully inducted into a more precise use of technical vocabulary. Put more emphatically, accurate consensual language labelling of phenomena of scientific importance must be integral to the acquisition of a scientific mode of thinking. It cannot be regarded as an add-on bonus.

The introduction of the word, 'force' is a good starting point to begin the discussion about vocabulary. Children's examples of forces showed an age-related shift, from concrete, overt actions predominating at KS1 to inferred, abstract instances (for example, of forces acting at a distance) at KS3. Children were asked, 'What name do we use in science for all kinds of pushes and pulls?' in order to ascertain the incidence and extent of the generalised and abstract concept label, 'force'. Only about one fifth of the KS1 pupils generated the word 'force' in response to this question. At KS2, the frequency was about half the sample while at KS3 it rose to around 90 per cent. The research confirmed that the word 'force' is a fairly high level abstraction, one that is not easily accessible to the younger children in the sample. It seems entirely appropriate to guide children towards describing specific events using the terms 'push' and 'pull' at KS1 , as *precursors* to the more generalised term, 'force', rather than as *instances* of the term 'force', bearing in mind that a minority of children may confuse even these simple actions.

Children's understanding and use of some specific terms – 'air resistance', 'gravity' and 'weight', for example, provide further emphatic support for requiring the use of the accurate meanings of words to describe unambiguously agreed phenomena. This is not an argument for teaching vocabulary *independently* of concepts; it is an argument for demanding the correct words to label achieved understandings, so that understanding is maintained and reinforced by correct usage. Some of the vocabulary relevant to forces which would benefit from clear usage is briefly reviewed.

Air resistance. The sensation of a moving body of air on a person – i.e. what is referred to as 'the wind' in everyday expression – is invoked by many children to explain the effect of 'air resistance' as perceived when a vehicle moves at speed through the air. This phenomenon tends not to be understood as a force which opposes the movement of an object which is moving through air. Rather, the 'wind' or 'wind resistance' force seems to be thought of as coming into operation when certain critical thresholds are passed. For example:

- slow moving objects are commonly not regarded as encountering (or generating, as some children would have it) 'wind', 'wind resistance' or more accurately 'air resistance';
- the mass of an object is regarded as critical by many children, so that this force opposing movement is not thought to apply to objects having a large mass;
- the size of an object may, like its mass, be regarded as a threshold property rather than a variable property.

The 'wind' is certainly capable of exerting a force as masses of air shift between high and low pressure areas. Equally, 'air resistance' is a tangible force which opposes the movement of objects through a mass of air. The term 'wind resistance' is one to be discussed if and when it arises, to be subsequently discouraged. It is the result of a conceptual short-circuit between two conceptually discrete areas. There is consequently a danger of a conceptual confusion being cemented by an inaccurate linguistic labelling.

Rather than being thought of as acting within a system of forces, these attributes of moving objects which are deemed relevant to a consideration of air resistance are thought of as *causal* rather than *interactive*. Thus pupils refer to 'wind' or 'wind resistance' – the movement of a body of air opposing the direction of movement of an object – rather than an interaction between the surfaces of that object and a body of air.

Gravity. To the scientist, 'gravity' is not a word that carries meaning. In vernacular usage, it probably means something like 'that which holds us to the Earth' – a property of the Earth rather than a force which applies *between* masses, anywhere and everywhere. The everyday definition is actually at odds with the scientific view and probably tends to reinforce an erroneous idea.

Weight. Scientists also use a precise definition of weight, one that is underpinned by assumptions about how gravity acts. Thus, to the scientist, the force on an object due to the gravitational pull of the Earth is what physicists call that object's 'weight'. It was clear in our study that many children were operating a definition of 'weight' which did not take into account a causal relationship between an object and the force of gravity on that object. At the extreme, pupils treated weight and gravity as quite separate. Indeed, some suggested that weighty boots could compensate for the (assumed) absence of gravity on the Moon.

There are wider issues about understanding of forces which are associated with language. For example, the transitive and intransitive use of the verb, 'to move' is discussed in earlier sections. The counter-intuitive sense of 'the wall pushes back' is a difficult enough idea perceptually and conceptually, but one which actually seems to be confounded by the particular language used to describe how reaction forces operate. It might be helpful to substitute another, more acceptable phraseology.The vocabulary has to accommodate (or recognise) the difficulty of sentence construction with respect to the misleading introduction of the notion of *sequence*. 'The wall pushes back' or 'The stool pushes back' is such an unusual use of language that it seems to contradict common sense. 'The wall exerts a force in the opposite direction', might be more acceptable.

The 'narratives' of how force and motion are undertood from different perpectives and belief systems (Appendix III) are offered as a reminder that the 'stories of forces' should not be ignored. Narrative description is a highly accessible modality to children, through which they might be encouraged to relate causal sequences to one another, for articulating and cross-checking of one another's interpretations of events.

7.2.4 Quantification of forces.

Quantification is a technique which is fundamental to scientific thinking and enquiry; it is what allows comparisons to be made and results to be accurately recorded and communicated. While in mathematics, the introduction of any physical quantity tends to be carefully graded, there was little precedent of which the research group was aware of a parallel analysis of the introduction of the measurement of *forces*. Following some exploration of pupils' classification of forces, their thinking was later directed towards comparisons of magnitude. This was approached by asking them to name three pushes (and then, three pulls) in order of magnitude. The youngest children were encouraged to draw their responses while the older pupils were invited to make written responses.

At first inspection, the results were surprising in that the performance of KS1 and Lower

KS2 children showed the expected trend of increasing capability with age, while the Upper KS2 and KS3 performance was lower. A scrutiny of responses revealed that the KS3 pupils tended to name formal forces but failed to differentiate these unambiguously in terms of relative magnitude.

It was assumed that a helpful precursor to the introduction of standard units of measurement of force would be for pupils to explore, initially, the quantification of forces using their own non-standard measures. (This is standard good practice preceding the introduction of formal units of measuring length, etc.) In the event, few teachers actually managed to implement the idea of children constructing their own, non-standard force measurers. Successful identification of the commercial force-meter was fairly widespread and showed some increase following the intervention activities. Nonetheless, awareness of its force-measuring function was known to only around half the pupils at KS2 and about three quarters at KS3.

Intervention activities seemed to have been successful in getting pupils to become aware of the units which force-meters measure: 'force' or 'newtons' was offered by about one quarter of Lower KS2 pupils, one third at Upper KS2 and about three quarters at KS3. As regards awareness of the horizontal and vertical possibilities of measuring forces, an appreciation of vertical uses was more widespread though many of these referred to measuring *'weight';* horizontal uses were mentioned much less frequently, the highest rate in the groups questioned being about one third of Upper KS2 pupils.

In summary, the force-meter's use is neither well established nor well understood at KS2 and KS3 and the widespread implementation of this aspect of the curriculum remains to be achieved. It is not suggested that measurement of forces *per se* is of paramount educational value, rather that quantified values offers another way of thinking about, manipulating and 'redescribing' aspects of forces. Such opportunities need to be exploited as they arise. For example, the simple exercise of ordering everyday events, initially as an ordinal series, perhaps moving to estimating the absolute values of the forces involved in newtons, and finally to measured comparisons, would be the sort of sequence likely to prove useful. Current practice seems to miss out the stage of offering pupils opportunities to quantify intuitive experiences.

7.3 Evidence of progression in ideas

7.3.1 Progression in ideas about agency

There was some evidence in the examples children cited when asked to give an example of a push by a non-human agent of the following transition:

1. The youngest children (KS1) think of themselves and other people as capable of pushing and this capability is generalised to other living things. They tended to think of movement as subjective and active, 'to move' in its intransitive usage. This subjective, active and egocentric view does not necessitate a view of forces as acting between two (or more) objects.
2. Lower KS2 children revealed more awareness of pushes (and to a lesser extent,

pulls) as being events happening in the natural world. The pushing of the wind was frequently mentioned, and other geo-physical events to a lesser extent. Appreciation of the range of non-living instances of phenomena which are capable of exerting a force might be important in helping children to shift from a subjective to more objective conceptualisation of agents, though some carry over of animistic attributions is well-established in the literature.

3. The responses of pupils at Upper KS2 contained more examples of human artefacts in the form of machines and wheeled vehicles than of any other response category. Such examples may be useful in bridging between the intransitive and transitive use and understanding of the verb 'to move'. Vehicles move themselves, but they are also frequently associated with moving other objects.
4. The main category of response in evidence from KS3 pupils were those labelled by technical terms such as 'air resistance', 'friction', 'gravity' and 'upthrust'. These examples mark a shift towards awareness of technical vocabulary naming forces in more abstract terms. The kinds of examples cited enhance the possibility of forces being recognised as invariably involving pairs of objects.

This sequence is more than a description of a developmental trend. It is an interpretation of the development of pupils' outlook in terms of the factors which impinge and are likely influences on their thinking. The factors which have been selected as salient in this analysis are those which support development in the direction of conventional scientific understanding which holds that forces have to be understood as working in pairs, between objects. The value of mapping such a progression is not just for its intrinsic developmental interest in descriptive and interpretative terms. In an educational context, we seek such developmental predispositions for prescriptive and didactic purposes. If this is the way children's understanding is disposed to grow, we need to ask questions as to how such 'growing conditions' may be optimised in the classroom. In other words, effective intervention should seek to exploit developmental predispositions.

7.3.2 Ideas about the gravitational force of the Earth

While it is established in the literature that pupils may think of gravitational force as either a push or a pull, it was a surprise to find that a significant proportion at all ages (though declining with increasing age) could think of gravity as *both* a push *and* a pull towards the Earth. 'Pull' was the more commonly held view, being expressed by about one third of Lower KS2 pupils, about half at Upper KS2 and four fifths at KS3. It is tempting to infer from these cross-sectional data that the understanding emerges fairly steadily over the seven years between the ages of seven and fourteen and furthermore, that this understanding might be expected to be capable of being accelerated, given focused intervention. About one fifth of KS2 pupils described the gravitational force of the Earth as a 'push'. The proportion of pupils describing the effect of the earth's gravity as '*both a push and a pull*' actually increased, following intervention, to 45 per cent at lower KS2, 17 per cent at Upper KS2 and 11 per cent at KS3.

Very few pupils described gravitational force as an attraction between masses (one Upper KS2 and one KS3) or between the Earth and other objects (one Lower KS2 and two KS3). (See confirmatory evidence from Bar *et al.*, 1997). This understanding was achieved by only a small minority, but might exemplify what many others might be capable of understanding rather than being symptomatic of precocious insight on the part of the pupils involved. Newton's insight is a description rather than an explanation. (The inclusion of variables such as mass and distance and the inverse square law add complexity, but these ideas are not essential to an initial, basic understanding of gravitational force.) Those pupils who offered this most sophisticated level of response are unlikely to have generated such insight through their own individual activity. It is far more probable that the information was socially transmitted. If so, they must have been in a state of 'readiness' for such knowledge. To decide whether it is appropriate for such transmission to be more widely promulgated, we need to know the nature of such readiness. (In Vygotski's terminology, the defining characteristics of the 'zone of proximal development' which makes the learner receptive to the scaffolding of knowledge about attractive force between masses). Logical analysis suggest that an appreciation of the Earth as a separate spherical body capable of attracting objects towards its centre from any point around it is essential antecedent knowledge. Perhaps knowledge that other bodies can have an effect on the Earth – the Moon's effect on the oceans being an example – might also be prerequisite. Hypotheses for intervention such as these, arising from empirical enquiry, need to be fed back into an iterative process of curriculum research; we have to check the circumstances in which teachers can support (or even accelerate) progression. The fact that some pupils have achieved understanding alerts us to the possibilities of others following the same sequence. (We must value pupils' individuality and special talents, but most education is a process of learning the well-beaten pathways.)

Reviewing pupils' understanding of gravitational force, it is possible to suggest four levels of understanding revealing increasingly generalised understanding.

1. Gravity is not associated with any clear direction. Gravity is understood as something which causes objects to fall 'downwards' or towards the ground.
2. Gravity is thought of as a force acting between the Earth and other bodies near the Earth.
3. Gravity is linked to the mass of the Earth and the mass of objects attracted to the Earth.
4. Gravity is conceived as a force between masses which might happen anywhere in the universe.

As we (and various researchers before us) discovered, there are many conditions which pupils see as *variables* impinging directly on gravitational forces which scientists or educators might prefer to describe as *context* effects. To pupils, these conditions are perceived as being causal rather than incidental. Educational research has a complex task to unravel these pupils' perceived effects from their entanglement with the actual effects defined by scientists. The following examples illustrate some of the situational effects which were encountered.

- The Earth's gravitational force is caused by spin or air; gravity might be a pull or push, or both
- Gravity is *not considered to be acting at all* by a significant proportion of pupils when a ball has been thrown and is moving vertically upwards. A minority suggested that gravity would be operating, but to a *reduced extent* during upward movement. When that ball is at the apex of its trajectory, most children suggested that gravity would be operating.
- When a can was thrown from a moving car, forces other than gravity appeared to dominate children's thinking.

- Many children explained the outcome of Neil Armstrong's hammer and feather experiment on the Moon (both objects hitting the ground simultaneously) in terms of an absence of gravity.
- Weight and gravity were treated by many pupils as separate phenomena, leading them to suggest that heavy boots were needed on the Moon to compensate for the lack of gravity. A similar idea was expressed to explain a helium balloon floating in air; paper clips were said to be contributing 'weight' (rather than attributing the downward force to gravity) which was counteracting the tendency of the helium balloon to rise.
- The relationship between mass, weight and gravity was poorly understood in the situation in which pupils were asked to explain the difference between units of measurement of mass and force.

7.3.3 Ideas about frictional forces

Familiarity with the word 'friction' and the idea which it describes were surprisingly extensive. Large shifts were recorded in the direction of an increasing frequency of correct responses, post-intervention, suggesting that this is an area in which gains in understanding may be expected from targeted intervention. A common idea is that friction is acting only when there is *movement* between surfaces, a belief which falls short of the scientific definition in which friction can cause a system to remain static by opposing a tendency to movement.

7.3.4 Balanced forces

A helium filled balloon provided a situation in which pupils might offer confirmation of the perception of the idea of balanced forces. Children added paper clips to the balloon's string until it moved neither upwards not downwards. They were then asked to comment on the forces acting on the balloon. A large proportion of pupils referred to two balanced forces acting with a steady increase in the incidence of correctly identified balanced forces up to about one third of the KS3 sample. (Rather more KS3 pupils referred to balanced forces but did not identify correctly the forces involved; the KS2 sample were more likely to omit any mention of balance or to nominate only one force.

The helium-filled balloon seems to be a particularly useful stimulus to the consideration of balanced forces in a static situation. It also invites analogies with floating and sinking of objects in water.

7.3.5 Reaction forces

A concept probe using a top-pan balance was selected on the basis that this would make the concept of reaction force most perceptible and tangible to pupils. Nonetheless, the conceptualisation of a force pushing back was not obvious or accessible to a majority of KS2 pupils. About 40 per cent of KS2 pupils demonstrated an understanding of reaction force being equal, this proportion rising to about 70 per cent at KS3.

The idea of reaction force was also examined in the context of children's experience of sitting on a chair. About one quarter made reference to 'reaction force' post-intervention, the idea having been scarcely in evidence at all in the same context prior to intervention. A very small number of pupils framed their responses in terms of balanced forces, more nominating incorrect than correct forces. The KS2 pupils performed at least as well as those at KS3. It seems that children may be exposed to several (in this instance, perhaps up to nine) years of teaching about forces without establishing the fundamental idea that forces always act in pairs. Balanced forces in static situations perhaps need to be discussed earlier than is the case in current practices.

Although the situation of a rubber ball dropped onto a playground was anticipated to maximise the possibility of those who had some awareness of reaction force mentioning it – because of the observable compression of the elastic ball – this, in the event, did not occur. Only a very small minority of pupils referred to 'reaction force' either in formal language or via some equivalent circumlocution. Younger pupils tended to centre their attention on the factor of the *hardness* of the playground (one third KS1, one quarter Lower KS2). The appropriate language, by means of which younger children might be enabled to discuss reaction forces in a more meaningful way, is in need of attention.

The pre-intervention elicitation technique was to ask children to draw the ball just before hitting the playground, at point of impact, and in the air bouncing away again. The drawings revealed an appreciation that the ball deformed and then reformed on the part of one fifth of KS2 pupils and two thirds at KS3. In contrast, post-intervention, which invited verbal responses without recourse to drawing elicited a markedly reduced attention to deformation of the ball: less than ten per cent at KS2 and 28 per cent at KS3. The use of drawings would appear to encourage Representational Redescription and the focus on two-dimensional visual representation succeeds in drawing attention to a salient feature in a manner that a verbally articulated response did not.

A large proportion of attempts to explain the bounce of the ball were framed in terms of intrinsic qualities of the ball - its roundness, bounciness, the fact that it was made of rubber – rather than using expressions to describe force and motion. The obvious question for a teacher is how children might be moved from the specific to a consideration of the more general and abstract. One obvious response is that the teacher must encourage children to focus on more general properties. Children might be asked to check other properties of bouncing objects. Do wooden balls, square or solid objects bounce? Maybe posing such questions is sufficient to spur many children to shift to a level of abstraction on the spot, while for others, a longer journey might be expected.

7.3.6 Momentum

It is instructive to look back to, 'Toward Changing Children's Ideas' about forces emanating from one of the earliest systematic enquiries in science education which was based on a constructivist rationale: Roger Osborne's 'Learning in Science Project', at the University of Waikato, New Zealand. (See Osborne, Schollum and Hill, 1981; Schollum, Hill and Osborne, 1981.) It is reasonable to ask to what extent teaching approaches towards forces have changed in the almost two decades since the Waikato group's publications. Osborne et al. took the view that children's frequently asserted intuitive view that force is something in a projected object is similar to the physicists' concepts of momentum. (Ogborn and Bliss, 1993, demonstrate the extent to which children's 'common-sense' theories of motion, including the idea of '*effort of the motion of an object*', can cohere; see Appendix IV.) Physicists do not consider momentum to be a force; it is the product of *mass* times *velocity* of the body, a measurable quantity which can be changed by the application of forces. While, in the physicists' terminology, children would be quite wrong to suggest that a ball thrown through the air falls to the ground because it has used up the force it carried within it, they would be much closer to the conventional view if they used the language of the ball's 'momentum decreasing'.

Pupils' ideas about moving bodies have much in common with the scientific concept of *momentum*, the quantity of motion in a body given by the product of mass and velocity. The points of correspondence are often dismissed by the conventional scientific viewpoint which sometimes refers to them as evidence of a 'naïve impetus theory'. Others suggest a more radical approach, but one which is firmly located in the constructivist rationale of starting teaching from pupils' existing ideas. Since many pupils think of a force as something in a moving object by virtue of its motion, Osborne *et al.*, suggest offering them the correct scientific label for the attribute which they have identified, namely '*momentum*'. Examples are then discussed of objects gaining or losing momentum, while the distinction between force and momentum continues to be identified.

Although validating pupil's notions of momentum does not appear to be a strategy which has gained either widespread approbation or implementation, others who have seen the merit of the approach have taken the idea further. It is possible to conceptualise force as a substance-like quantity having extensive properties, or even as currents of momentum, the mathematical formulation being redescribed as a fluid metaphor. The curricular implementation of such an approach might start with the human understanding of bearing a load, feeling the force required in the opposite direction as an analogy of how the pillar holding the beam bears a load. In static bodies, the tension can be described as the flow of momentum. In dynamic situations, the analogy can be drawn of two buckets linked by a pipe, fluid flowing into one flows into the other. Such ideas are neither fanciful nor lacking in rigour, as the publications of Hermann *et al.* (see for example, Herrmann and Schmid, 1984) testify. The model, it has been suggested, can be adopted with mathematical rigour and consistency to advanced theoretical and applied levels of physics. One of the great attractions of the approach is the link which it encourages between the laws of motion and thermodynamics.

7.4 Some initial thoughts on the sequencing of the teaching of forces

7.4.1 General Understanding of the concept of 'Force.'

It is generally accepted that the learning is more effective if the scientific label for a concept is not given until after some understanding of the concept has been achieved. The evidence from this research suggests that 'force' is no exception to this view point. Nevertheless, a sequence of development towards the correct use of the term force is more likely to be effective if it reflects the cognitive development of the learner. Such a sequence would appear to be:

- whole-body experiences of pushing and pulling (personal to the learner but also recognising the need for an object to be pushed or pulled);
- description of these experiences using appropriate language ('push' and 'pull' extended to include such terms as kick, throw, jerk); such language necessarily implies appreciation of direction;
- extension of 'push' and 'pull' experiences to a recognition of similar actions by non-human animals;
- consideration of the effects of pushing and pulling on the movement and/or shape of the pushed or pulled object;
- using the awareness of these effects as an introduction to pushes and pulls exerted by inanimate objects (cars, magnets, water, wind), with a reiteration of the need for there to be other objects which experience the effects;
- introduction of the scientific use of the term 'force' to cover all forces of push and pull. (One object exerts a force on another).

In terms of any proposed changes to the National Curriculum for England and Wales this sequence would postpone the use of the term 'force' until KS2.

7.4.2 Quantification of forces

Quantification is an essential element of science in that is often contributes significantly to the quality of the evidence being obtained.

The following sequence for the quantification of forces would need to be run in parallel with that suggested above for the development of the general concept of force.

- Description of the size of pushes and pulls in broad terms, (big, small, medium, linked with differing sizes of effects);
- sequencing of given pushes and pulls in order of magnitude;
- meaning of forces in non-standard units (requires the construction by the learner of a suitably accurate force-meter which is capable of measuring both pushes and pulls);
- introduction of the standard unit - the newton (awareness of the magnitude of the newton to be gained from standardisation of the force-meters, estimation exercises and direct measurements).

In terms of the National Curriculum the first two steps in the above sequence would appear to be appropriate for KS1 and the latter two for the second half of KS2.

7.4.3 Conventional representation of forces with arrows

Considerations of the precise meaning of the terms 'push' and 'pull' lead inevitably to the recognition that forces have direction. Children's drawings of situations involving forces often, therefore, include arrows. However, in other areas of the curriculum arrows are used to indicate location. Teachers wanting to use 'force' arrows on drawings in order to help children work through their thinking and hence to assist in formative assessment of understanding, need first to ensure that the children recognise the dual function of arrows, namely to represent direction or location. The conventional use of the shaft length to communicate the relative sizes of forces can be introduced at a later stage, subsequent to the introduction of measurement by force-meter.

The use of arrows on drawings to represent both size and direction can be particularly useful at the stage when the children are considering several forces acting simultaneously. (See 7.4.5 Balanced and unbalanced force).

The evidence from some of the schools involved in this research is that, particularly at KS2, children represent 'pushes' with arrows where the head touches the object being pushed and 'pulls' with arrows where the tail touches the object being pulled. It may well, therefore, be advantageous for teachers to use this same modification of the convention in order to communicate ideas to children or to assess their understanding of them.

7.4.4 Specific forces - gravity, friction, air resistance, reaction

Although the implications for the teaching of these specific forces are considered separately below it is assumed that they will, at least to some extent, be taught concurrently.

7.4.4.1 Gravity

Gravity is such a commonly used 'term' that children have it within their vocabulary from a relatively early age. Their appreciation of the meaning of the term develops as more evidence becomes available to them. For teachers helping to provide this evidence and encouraging the discussion of it the following sequence of development is suggested.

- Gravity keeps things on the ground, stops them floating away.
- Gravity is a property of the Earth, so is a pull from beneath.
- The pull of gravity is directed towards the centre of the Earth.
- The size of the force of gravity depends on the mass of the object being pulled by the Earth.
- The size of this force is the weight of the object.
- Gravity on the Moon is less than that on Earth.
- The size of the gravitational force is determined by the mass of the object and that mass of the Earth/Moon/planet.
- There is a gravitational force between any two objects.
- The size of this gravitational force depends on the distance between the objects.

An understanding of the effects of gravity on falling objects does not appear to be directly linked to the developments outlined above. By the end of KS2 most children are willing to accept that the rate of fall is independent of mass but an understanding of why this should be so appears to be beyond most, even at the end of KS3 (See 7.4.3).

7.4.4.2 Friction

The suggested sequence for the concept of friction is that the children are moved from the understanding of 'grip' as a property of an uneven surface to an appreciation of friction as a force acting to prevent relative movement of two surfaces in contact.

- A rough surface impedes the movement of an object across it.
- Different surfaces impede this movement to different extents.
- Introduction of 'friction' as the scientific term for this force which changes movement. (Needs to follow recognition that all changes in movement require the action of a force).
- The direction of the frictional force is opposite to that of the movement.
- Both of the surfaces in contact contribute to the magnitude of the frictional force.
- Friction can occur even in the absence of movement.

7.4.4.3 Air resistance

If air resistance is to be presented as one example of a frictional force, one in which one of the surfaces is fluid, then its introduction would need to follow the sequence outlined in 7.4.4.2 Friction above.

A helpful comparison would be with the frictional force between two surfaces one of which is static.

It is unreasonable to expect children, who do not understand that the rate of fall of objects is independent of their mass, to interpret correctly the effects of air resistance on falling objects.

7.4.4.4 Reaction forces

The conceptual difficulty presented by the concept of reaction force would suggest that it be left until quite late in the overall sequence of the teaching of forces. However, it is again suggested that the teaching begins with whole-body, personal experiences and moves towards the abstract and inanimate.

- Whole-body experiences to consolidate idea of no movement resulting from equal and opposite forces.
- Whole-body actions against flexible objects (springs) to experience 'opposite' nature of reaction force.
- Whole-body action on top-pan balance to introduce equivalence size.
- Inanimate objects on top-pan balance to consolidate equivalence of size.
- Consideration of inanimate object on rigid surface (no movement, therefore balance of forces).
- Consideration of reaction forces in non-static situations.

The arrow representation of forces can be of considerable assistance during discussions of reaction forces. The use of language which does not invoke personal, animate experiences is also to be recommended.

7.4.5 Balanced and unbalanced forces

The consideration of forces in isolation is a useful introduction but eventually it will be necessary to consider real situations in which several forces have to be considered together. The essential pre-requisite is the appreciation that forces have both size and direction.

- Whole-body experiences to recognise that two forces can either oppose or reinforce each other.
- Introduction of the terms balanced (net force zero) and unbalanced for forces in combination.
- Investigations of the effects of forces acting together.
- Continuous application of a force results in continuous change (acceleration).
- Consideration of situations in which there is no change in movement - static and constant speed (balanced forces).

LIST OF APPENDICIES

Forces Research

APPENDIX I

SPACE SCHOOL PERSONNEL

(for research carried out into children's understanding of Forces in 1996/1997)

School	Head Teacher	Teachers
Bradshaw CP School	Mr John Kenyon	Mrs Jenny Boyle Mrs Kate Dean
Chesterfield High School	Dr Alan Irving	Mrs Joanne Walker
Cole Street Primary School	Mrs Gail Webb *	Mrs Jo Hall
Farnborough Road Infant School	Mrs J Hartsham	Mrs Jayne Haines
Formby High School	P G Baldock	Miss Lilly Eaves
Kew Woods School	Mr DWT Hughes	Mrs Claire Hardy
Park View Primary School	Mr Adams	Mr David Nieman
Scarisbrick CP School	Mrs Sue Harrison *	Mrs Susie Haden Mrs Audrey Stocks
St Andrew's RC Primary School	Mrs E A Jones	Mrs Jean Fitzsimmons
St Lawrence JMI	Mr K Allen	Mr Mark Thomas
St Margarets C of E High School	Dr Dennison	Ms Gillian Shilton
St Oswald's School	Mrs Margaret F Ellams	Mrs Vivian Ward
Windlehurst CP School	Mr Ashcroft	Mrs Gillian Green
Wolveram CP School	Mrs Beryl Clarke *	
Woodend Primary School	Mr Alex Blythin	Mrs Wendy Grime

* Headteachers who contributed to project teaching.

APPENDIX II

EXAMPLES OF CONCEPT PROBES

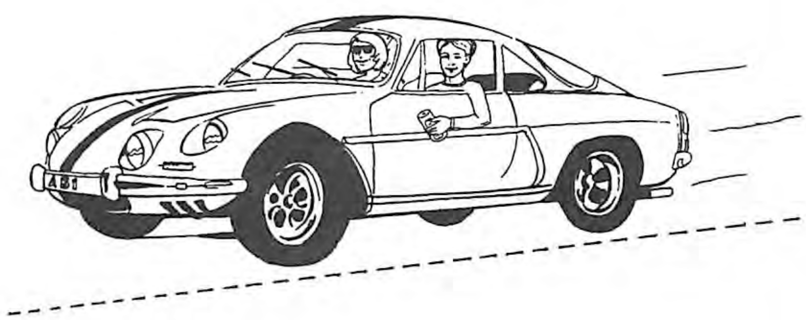
The following concept probes are those for which data are presented in the main body of the report. They were originally presented in association with practical activities, where possible. They were also bound into Key Stage specific booklets. To avoid repetition, each concept probe is reproduced only once in this appendix. The key on the right indicates by shading the Key Stage to which each probe was exposed.

1. What do you have to do to make your bicycle start moving?

KS1	KS2	KS3

2. In the drawing the child is just letting go of the can. The car is being driven forwards quite fast.

KS1	KS2	KS3



a) On the drawing put a letter C where you think the can **will first** hit the road.

b) Why do you think the can **first hit** the road at the place where you put the letter C?

3. Think about what you do when you push.
Draw or write **FOUR** things that you do which are pushes.

KS1	KS2	KS3

4. Think about what you do when you pull.
Draw or write **FOUR** things that you do which are pulls.

KS1	KS2	KS3

5. Write how you decide whether you are pushing something or pulling it.

KS1	KS2	KS3

A push is when I ....

A pull is when I ....

6. (a) Can you think of a push that is **NOT** done by a person?

KS1	KS2	KS3

(b) Can you think of a pull that is **NOT** done by a person?

KS1	KS2	KS3

KS1	KS2	KS3

7. Can you think of a **very small push**?
Draw or write your idea in the box.

Can you think of a **very big push**?
Draw or write your idea in the box.

Can you think of a **medium-sized push**?
Draw or write your idea in the box in the middle.

a very small push	a medium-sized push	a very big push

KS1	KS2	KS3

8. Can you think of a **very small pull**?
Draw or write your idea in the box.

Can you think of a **very big pull**?
Draw or write your idea in the box.

Can you think of a **medium-sized pull**?
Draw or write your idea in the box in the middle.

a very small pull	a medium-sized pull	a very big pull

9. What words do we use in science for all kinds of pushes and pulls?

KS1	KS2	KS3

....

10. (i) What it this measurer called? ....

KS1	KS2	KS3

(ii) What does it measure? ....

(iii) Give **TWO** different ways that it can be used to measure.

a) ....

b) ....

(iv) Rulers measure in centimetres.

This measurer measures in ....

11. (i) Is the effect of gravity on objects a PUSH, a PULL or BOTH.

KS1	KS2	KS3

Tick **ONE** box to say what gravity is.

a push ☐

a pull ☐

push and pull ☐

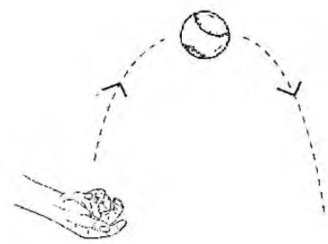
(iii) Explain how gravity works.

....

....

....

12. A ball is thrown up in the air.



KS1	KS2	KS3

Is gravity acting on the ball:

(i) when it is moving upwards? ....

(ii) just when it reaches its highest point? ....

13. Why do astronauts wear big boots when they walk around on the Moon?

KS1	KS2	KS3

....

14. Mary has a 500 gram packet of butter.
When she hangs it on a newton-meter it reads 5.

KS1	KS2	KS3

Why does it read 5, and not 500?

....

15. Jim rides his bicycle across the school playground.
When he rides across the school field he has to pedal harder.

KS1	KS2	KS3

Why is it harder to ride across grass?

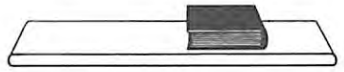
....

....

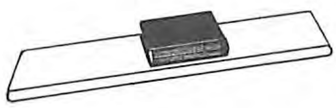
16. Under each drawing write if you think that the force of friction is acting on the book.

KS1	KS2	KS3

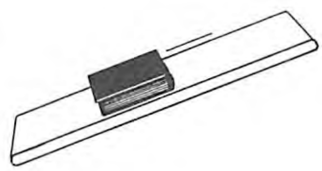
Plank level
book still



Plank raised a little
book still



Plank raised higher
book sliding



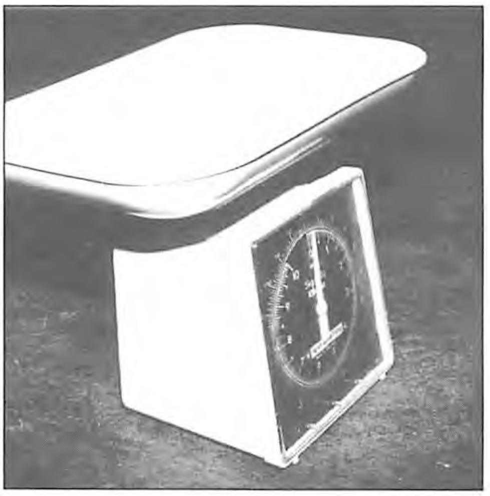
17. In the video you saw the astronaut on the Moon drop a hammer and a feather. They both hit the surface of the Moon at the same time.

KS1	KS2	KS3

Why does this happen on the Moon but not on Earth?

18. John pushes down on the scale pan with his hand.

KS1	KS2	KS3



The reading on the scale pan is 10 newtons.

What will be the force on his hand?

Tick **ONE** box.

Reading on force-meter	
less than 10 newtons	
10 newtons	
more than 10 newtons	

19. What forces are acting on you when you sit on a stool?

KS1	KS2	KS3

....

....

20. If you drop a tennis ball onto the playground it will bounce.

KS1	KS2	KS3

What makes it bounce?

....

....

21. If astronauts want to bring their spaceship to a stop way out in space, what do they do?

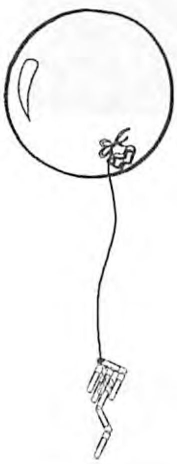
KS1	KS2	KS3

....

....

22. The children have put some paperclips onto the string of their helium balloon.
Their balloon stays still. It does not move up or down.

KS1	KS2	KS3



What can you say about the forces acting on their balloon when it is like this?

....

....

23. Look carefully at the drawing

KS1	KS2	KS3

What exactly do the arrows on the drawing tell you about the forces acting?

....

....

....

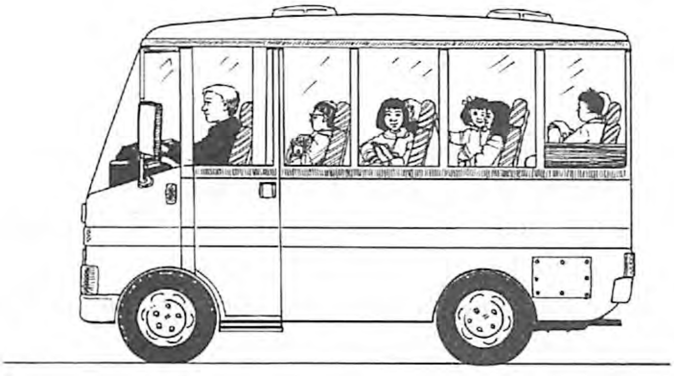
....

....

....

23. The school minibus is moving along the road.

KS1	KS2	KS3



(i) Draw arrows on the picture to show the forces acting on the bus.

(ii) Put labels on the arrows to show what the forces are.

KS1	KS2	KS3

(iii) What can you say about the forces on the bus while it is increasing its speed?

....

....

KS1	KS2	KS3

(iv) What can you say about the forces on the bus when it is moving at a steady 30 miles per hour?

....

....

APPENDIX III

THEORIES OF MOTION

Aristotle's cosmology

'Aristotle's treatment of how bodies move was one of the characteristic determining features of his world picture or cosmology. Heavy bodies move downwards in a straight line towards the centre of the universe, which is the centre of the Earth; light ones, that is, bodies which have positive lightness, move away from the centre, again in a straight line. This is the key to the doctrine of the elements. Earth goes straight down; fire goes straight up; air goes up because it is light, but not as light as fire; and water goes down, because it is heavy, but not as heavy as earth. So we have earth, surrounded by water, then air and finally fire: these four spheres make up the elementary world of below the Moon. The only bodies that are neither heavy or light are by the same token non-elementary: they are heavenly bodies with their own appropriate motion, which is circular round the centre of the universe. Circular motion is appropriate to heavenly bodies since no change has ever been observed in the heavens. All we see is endless repetitions of the same patterns of movement, but there is no trace of the generation and decay which is the mark of our elementary world. The heavens must be made of a fifth element (quintessence), an imperishable, incorruptible substance. Since the quintessential heavens are completely different from the Earth and its surrounding elements, there could be no thought of treating all motions in the universe as subject to the same laws. As far as local motion on or near the Earth was concerned, Aristotle was content with principles that were more or less satisfying to commonsense, at least until subjected to a serious examination.'

'There was no need to explain why a body was at rest in its natural place: that was where it was supposed to be, so it could not be expected to move from there unless forced to. Physics was the study of nature: central to it was the study of natural motions, the study of how bodies return to their proper places. It was motion, not rest, that needed an explanation. There were, or course, also motions that were not natural: these were forced or violent motions. Things like chairs or carts or spears did not move of their own accord: to move them took effort, which was to be expected because they were being moved from their natural rest; violent motions merited incidental attention. But even with natural motions like the free fall of heavy objects, the resistance of the medium had to be considered, since a stone, for instance, obviously falls more quickly through air than through water. In fact, Aristotle took heavy bodies to fall with speeds proportional to their weights in a given medium. He also took the speed of fall to be inversely proportional to the resistance of the medium, though what Aristotle had in mind is more faithfully captured by Galileo's terminology: the more subtle the medium, the faster the body falls; the crasser, the slower.'

From: Michael Sharratt's (1994) 'Galileo. Decisive innovator. Blackwell, Oxford UK and Cambridge USA. pp.30-31.

Newton's laws of motion

- Every object stays at rest or in a state of uniform motion in a straight line unless a force acts upon it.
- If a force acts on an object, that object accelerates at a rate given by dividing the force by the mass of the object.
- If one body exerts a force on another body, then the second body exerts an equal and opposite force on the first.

Sketch for a common-sense theory of motion

From: Bliss, J and Ogborn, J, (1993) A common-sense theory of motion. Chapter 7, pp. 120-133. In Black P. J. and Lucas, A. Children's informal ideas in science. Routledge. London and New York.

Two basic and related terms of the theory are 'support' and 'falling'. If an object is supported, it does not fall; if it is not supported, it falls, until it is once more supported. Falling has an initial cause, namely a loss of support, but is a natural motion in that one need not look for a cause (a force or agency) for it to continue, only for a continued lack of support.

Everything needs support, except only the ground, which gives support but is not itself supported. Thus the ground never falls but often stops a fall. Examples of kinds of support include resting on something, being fixed to something or hanging from something. Water and air can also support things (floating), this support often being partial.

To support something needs 'strength' or 'effort' (or both). Thus a shelf supports books by being strong; alternatively an aeroplane or a bird can support itself by its own effort, by flying. People support things (e.g. carry loads) using both strength and effort.

If the strength of a support is not enough, it may break. If the strength is enough the support takes (that is, absorbs) the weight of things it supports. We do not have to think of a well supported object having weight, unless the support is liable to break. As a support, the ground is infinitely strong and cannot break.

There can also be partial support. A swimmer may be partially supported by the water, and may make up the rest of the support by the effort of by swimming. A partial support means a partial fall, such as sinking. A dropped piece of tissue 'floats' down, partially supported by air.

A law of falling is that, having started to fall, things fall more rapidly the higher up they start and the heavier they are.

For these reasons, movement is conceptualised as taking place either on the ground (or on something supported by the ground), or as taking place in the air, above the ground. Motions which go up or down are distinguished from those which merely 'go along'. In this sense, the 'space' of motions has a preferred direction.

To describe motion further we need two more basic concepts, 'place' and 'path'. An object sitting still is at a certain place relative to other objects – on, under, beside, etc. One kind of motion consists of changing the place of something, as in passing a plate or pushing something aside. Another kind of motion is that in which the object is moving by itself – going on its way. The path it is following, and where it is along that path, is what locates it, not the place it happens to be in any moment. Motions are judged relative to the ground.

Motions of both kinds require effort, unless achieved by falling. Effort is used to change the place of something; to change the path, including starting and stopping; and to keep going along the path. Any lifting or raising involved requires additional effort. There are three possible sources of effort: effort of another agent on the object; effort generated by the object; effort of the present movement of the object.

Thus if you hand me a book or pass the salt you supply effort *on* the object to change its position. If you kick a ball along the ground you supply effort *on* the ball to start it going, after which it rolls using the effort *of* its motion. An athlete running or a car being driven use effort generated by themselves, in order to keep moving and, if they need to swerve or stop, to change path.

The effort needed is larger the heavier the object. The effort to start or keep moving is larger the larger the speed. If place is being changed, the effort is larger the larger the change of position; if path, the larger the effect on speed and direction of path.

The character of each kind of motion depends on the kind of support present. An object such as a bird or aeroplane uses effort both to support itself and to keep itself going. A ball thrown upwards in the air has effort *on* it from the thrower, but uses the effort *of* its motion to rise. When this is used up, since it has no effort to support itself and is not supported, it falls.

The effort of the motion has the special characteristic that it cannot be used to change the path of the same object (otherwise a motion would control itself). An object has no effort *of* motion when it is at rest relative to the ground.

The effort *of* motion is handed on dynamically moment by moment. The present motion makes the coming motion. When the speed changes little, as with a tennis ball or a dart, motion along the path is easy, with little or no effort being taken away from the effort of the motion. A motion like this uses up little effort, but still employs effort to keep going.

APPENDIX IV

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Primary SPACE Project

Science Processes and Concept Exploration

Research Reports

This Research Report is one of a series produced by the Primary SPACE Project, which was based jointly at the Department of Education, University of Liverpool and the Centre for Educational Studies, King's College London, under the direction of Professor Wynne Harlen and Professor Paul Black. The reports describe collaborative research conducted with teachers aimed at understanding the development of young children's scientific ideas. The original research was funded by the Nuffield Foundation. Titles in the Research Report Series include:

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In the curriculum strand of its work, the SPACE project worked with the Nuffield-Chelsea Curriculum Trust and the publishers Collins*Educational*. The research results have been developed into materials for teachers and pupils. The publications cover the provisions of the National Curriculum for Science in Key Stages 1 and 2, and include:

11 Teachers' Guides for Key Stage 2
11 Teachers' Guides for Key Stage 1
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