DOCUMENT RESUME

ED 362 504 SP 034 771

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TITLE Long Term Impact of a New Approach to Teacher Education for Primary Science.
PUB DATE Sep 93
NOTE 42p.; Paper presented at the Annual Meeting of the British Educational Research Association (Liverpool, England, United Kingdom, September 1993).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Constructivism (Learning); Elementary Education; Elementary School Science; *Elementary School Teachers; Faculty Development; Foreign Countries; *Inservice Teacher Education; Knowledge Level; Longitudinal Studies; Long Term Memory; *Scientific Attitudes; *Scientific Concepts; Short Term Memory; *Teacher Improvement
IDENTIFIERS *Analogical Reasoning; National Curriculum; United Kingdom

ABSTRACT

This paper reports the results of a 2-year longitudinal study of the development of primary teachers' understanding of science concepts (specifically, "force" and "energy") following inservice education, and the extent to which movement towards the scientific view was achieved and maintained. The approach to inservice education made extensive use of constructivist strategies and analogical reasoning to promote the qualitative learning of science concepts. The long term development in conceptual understanding of a sample of 53 primary school teachers was monitored in depth over the 2-year research period. Some of the principal research findings were: (1) nearly all teachers did improve their understanding of force and energy considerably, and this improvement was still evident 6 to 12 months following inservice training; (2) following training, all teachers had moved substantially towards the scientific view; (3) some concepts were more easily acquired than others; (4) there was evidence of "slipping back," i.e., marked short-term gains which were no longer so evident in the longer term; (5) teachers may retain misconceptions even when these are addressed intensively, and teachers may develop new misconceptions as a result of training; (6) in the long term, teachers were able to recall a wide range of bothe general and concept-specific aspects of the training, which they perceived as helpful in developing their understanding. Implications of these findings and 10 statistical tables complete the document. (Contains 35 references.) (LL)

Long term impact of a new approach to teacher education for primary science

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Paper presented at the British Educational Research Association Annual Conference
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September 1993

Abstract

This paper reports the results of a two year longitudinal study of the development of primary teachers' understanding of *force* and *energy* following inservice education, and in particular the extent to which movement towards the scientific view was achieved *and maintained*. The approach to inservice education made extensive use of constructivist strategies and analogical reasoning to promote the qualitative learning of science concepts. In all, the long term development in conceptual understanding of a sample of 53 primary school teachers was monitored in depth over the two year research period.

Some of the principal research findings were that (i) at the outset of the research nearly all the teachers had little scientific knowledge and understanding of the concepts force and energy; (ii) following training all teachers had moved substantially towards the scientific view; (iii) in many cases this movement was quite remarkable, but in others the change was relatively modest; (iv) some concepts were more easily acquired than others (it was possible to rank more than 30, all to do with aspects of force or energy, in order of difficulty); (v) there was evidence of 'slipping back' i.e. marked short term gains which were no longer so evident in the longer term; (vi) teachers' may retain misconceptions even when these are addressed intensively during inservice training; (vii) teachers may develop new misconceptions as a result of such training; (viii) in the long term teachers were able to recall a wide range of both general and concept-specific aspects of the training which they perceived as helpful in developing their understanding.

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Background

In recent years a number of studies have investigated primary school teachers' understanding of science concepts. The conceptual areas covered by this research include *forces and their effects* (Kruger et al 1990a, 1990b and 1990c; Summers 1992a), *energy* (Kruger 1990; Summers and Kruger 1992), *changes in materials* (Kruger and Summers 1989), *astronomy* (Mant and Summers 1993; Summers and Mant 1994; Cohen 1982; Targan 1987; Noce et al 1988), certain *biological concepts* (Lenton and McNeil 1991a, 1991b), *electric current* (Webb 1992), and *gravity and air resistance* (Smith and Peacock 1992). These studies have shown that (a) many primary teachers lack knowledge of the key concepts of science, and (b) that where there is some acquaintance with such concepts, a majority of the teachers hold views of them that are not in accord with those accepted by scientists.

The problem of primary teachers' lack of understanding of science has become particularly acute in the UK following the introduction of a National Curriculum for science (DES 1991). Whereas science in the primary school had previously tended to focus on the processes of science, the new curriculum spells out in considerable detail, and for the first time, the knowledge and understanding of science concepts expected of children from ages 5 to 16. This is an immense challenge for primary science education.

In the UK several reports over the years have identified improvement of subject knowledge as a key requirement for better primary science teaching (e.g. DES 1978 and 1989, Alexander et al 1992). But how easily can this be achieved? In particular, to what extent can short bursts of inservice training (the current UK model) help ordinary primary school teachers develop a non-trivial and lasting understanding of the concepts they are now expected to teach? The research described in this paper addressed these questions.

The approach to teacher education which underpinned the study was new in that (i) it focused on the understanding of science concepts rather than processes, and (ii) it used constructivist strategies (described later) to develop this understanding.

Aim

The principal aim of the study was to find out how primary school teachers' understanding in the two conceptual areas *force* and *energy* develops following inservice training utilising constructivist strategies and making extensive use of analogy. A full account of this extensive two-year research programme and its findings (both quantitative and qualitative) can be found in Summers et al (1993). In the restricted space available for this article the focus will be on just two aspects of the research. First, the main quantitative findings concerning the progression of teachers' understanding will be described. Second, brief accounts will be given of teachers' perceptions of general aspects of the training, of the development of their conceptual insights, and of the impact of new knowledge on their teaching.

The main research question posed at the outset of the research was:

> can a constructivist approach to learning effect long term conceptual understanding in primary school teachers?

The strategy used to answer this question involved documenting teachers' understanding in three stages: (i) before exposure to a planned programme of inservice experiences covering the conceptual areas force and energy; (ii) as soon after exposure as was feasible (typically between one and three weeks); and (iii) in the longer term (between 6 and 12 months later).

The choice of six months to one year as long term was dictated by pragmatic considerations, in particular the funding available to support the work.

Scientific understanding of force and energy

The research sought to identify teachers' knowledge in terms of the views currently accepted by the scientific community. It was therefore necessary from the outset to establish clearly what constituted an appropriate understanding of force and energy for primary teachers, in scientific terms.

An understanding of force was broadly conceptualised by the research team in terms of:

a. recognising/identifying forces.
b. adding forces.
c. forces and motion.

Within these three areas, 16 more detailed components of an understanding of force were identified (see the left hand column of Table 1 at the end of this article) based mainly upon (i) a scientific analysis of the area, (ii) earlier research into primary school teachers' difficulties with the concept, (iii) expert science educators' views of the level of knowledge and understanding necessary *to teach* the UK primary science National Curriculum. These 16 aspects, known as 'profile components' or PCs, were the units used to build up an overall profile of a teacher's understanding of force at the various stages of the research. Analysis of much of the data from the forces research instruments (described later) was carried out in terms of these 16 profile components.

An understanding of energy was conceptualised in terms of:

a. possession/storage of energy.
b. transfer of energy.
c. conservation of energy.
d. the nature of energy.

Within these areas 14 profile components were identified using the same considerations as for force, and were used in the same way. The energy PCs are listed down the left hand side of Table 2.

The learning strategies

The materials

A pack of inservice primary teacher education materials dealing with force and one dealing with energy had been developed in a previous research and development project conducted by the research team. These were used for the training courses. The materials are available publicly (Kruger et al 1991a, 1991b) and have been described in the science education literature (Summers 1992a, 1992b; 1993a).

A key feature of these materials is that they are based on a constructivist approach to the learning of science concepts. Particular aspects of the materials reflecting this approach are that:

1. they are based on research into primary school teachers' existing knowledge and understanding of force and energy (see Kruger et al 1992 for a summary).

2. they include activities requiring teachers to explore children's views and become aware of their own views (preconceptions).

3. metacognition is encouraged by introducing explicitly a constructivist model early on as an approach to both children's and the participants' own learning.

4. extensive use is made of of analogy, and in particular the theoretical notions of anchoring and bridging analogies proposed by Clement (1987), to develop qualitative conceptual understanding (see below).

5. at appropriate times, teachers are presented with the scientific view (called the 'expert view' in the materials) of the targeted concepts.

6. they involve active, collaborative learning in which views are expressed, exchanged and developed through discussion and social interaction.

In addition, the materials incorporate the following features:

7. the approach is qualitative (no mathematics required).

8. all the PCs for force and energy (see the previous section) are covered.

9. they involve practical activities using everyday materials rather than specialised science equipment.

10. self assessment questions are included throughout the materials, and are followed up in group discussions (where expert answers are available for consultation).

The constructivist model

The initial stages of the constructivist model used during the inservice courses involved teachers eliciting children's views of phenomena involving forces and energy and, at the same time, making explicit their own views of these same ideas. Teachers subsequently shared their own views, and the views of their pupils, with each other. Making teachers realise that their views, like those of children, often differ from those of science, and reassuring teachers that they are like most other people in this respect, were the starting points for the inservice training.

The succeeding stage, the promotion in the teachers of dissatisfaction with their existing views, followed readily from the teachers' awareness, as intelligent adults, of the anomalies and shortcomings in their understanding as they tried to give coherent explanations for the phenomena presented. Course leaders remarked on the quite heated discussions occurring at certain stages of the training as this dissatisfaction manifested itself. In later stages of the model generation of qualitative understanding and movement towards the scientific view was promoted through practical activities and extensive use of analogy.

Anchoring and bridging analogies

The forces training materials made extensive use of the four-stage approach to learning described by Clement (1987). In this approach a 'target problem' is first described, i.e. the nature of the difficulty people encounter with the targeted scientific idea. An 'anchoring example' is then cited, i.e. an instance involving the scientific idea which is in agreement with most people's intuitive beliefs and also corresponds to the scientific view. This is followed by a 'bridging analogy' which attempts to bridge the gap between disbelief (of the target problem) and acceptance (in the case of the anchoring example) by showing that they are both analogous. Finally a conceptual model, a representation which is scientifically acceptable, is presented. The energy materials used a similar sequence to move teachers from limited scientific or everyday ideas towards an expanded formulation of the scientific view.

The role of these strategies within teaching that acknowledges constructivism has been described in an authoritative review article by Scott et al (1991).

The training

Thirty one teachers followed an inservice course using the forces materials, and 22 teachers a course using the energy materials. Each course was organised as four 2-hour (approximately) class sessions, but with supporting out-of-class activities such as reading the 'expert view' and completion of 'spot the expert view' questionnaires as preparation for a subsequent session. Although it might seem that these are short periods of time in which to develop conceptual understanding, it must be stressed that they are realistic (possibly even ambitious) in terms of the time likely to be available in teacher education courses for most primary teachers in the UK (particularly inservice courses).

Research instruments

These are listed in Figure 1. The extracts below illustrate the nature of the main instruments and the ways in which they were they were used at each stage of the research.

Pre-exposure questionnaires (FQ1 and EQ1)

At the outset of the research, a questionnaire (FQ1 for forces or EQ1 for energy) involving statements about everyday situations was presented to the teachers. Its purpose was to begin the elicitation of teachers' views about force or energy before exposure to learning experiences. The questionnaire contained pictures of various situations with statements about them which included both 'correct' scientific statements and scientifically 'incorrect' or intuitive ones of the kind that had been made by teachers during earlier research (e.g. Kruger et al 1990a, Summers and Kruger 1992). Teachers were asked to give their views about the statements by responding 'true', 'false', 'don't understand' or 'not sure'. An example is given in Figure 2a.

These questionnaires were versions of those developed during the earlier research, modified to include any PCs found to be scarce or absent so that testing of teachers' understanding across the entire range of profile components for force or energy was ensured. There were 39 such statements about 8 drawings in the forces questionnaire, and 42 about 8 in the corresponding energy instrument.

Clarifying questionnaire responses

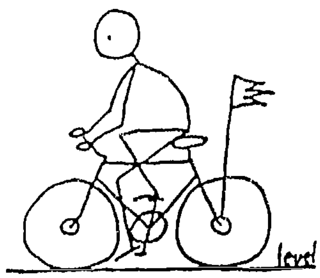
In follow-up interviews FI1 or EI1, conducted typically a week or so later, views implied by teachers' responses to statements in the questionnaires FQ1 or EQ1 were probed. This was to clarify any aspects of teachers' responses about which the interviewer was in doubt, such as 'don't understand' or 'not sure' responses, or inconsistent ones, and to confirm that inferences the research team had made from the responses did in fact represent the teachers' views. If a teacher altered a response made at the outset of the research as a result of discussion during this interview, that altered response was regarded as the teacher's initial viewpoint for the purposes of the research.

In the post-exposure interviews FI2 or EI2 teachers were asked to comment on the responses they had made before exposure to learning strategies and give reasons for any they now wished to alter.

Figure 1 Overview of instruments used in the research

	FORCES INSTRUMENTS	ENERGY INSTRUMENTS
STAGE I	**Pre-exposure forces questionnaire (FQ1)** **Schedule for pre-exposure forces interview (FI1)** *Component parts* • *Introductory questions* about teachers' (1) feelings about teaching forces, (2) perceptions of own understanding, (3) meanings for 'force'. • *Speedo task* • *IAI cards* • *Clarifying responses to FQ1* • *Arrows task* • *Post-interview conversation*	**Pre-exposure energy questionnaire (EQ1)** **Schedule for pre-exposure energy interview (EI1)** *Component parts* • *Introductory questions* about teachers' (1) feelings about teaching energy (2) perceptions of own understanding (3) origins of any knowledge of energy possessed • *IAI and IAE examples* • *Clarifying responses to EQ1* • *Questions about* (1) the nature of energy (2) measuring energy (3) conservation of energy • *Post-interview conversation*
STAGE II	**Schedule for post-exposure forces interview (FI2)** *Component parts* • *Introductory questions* about teachers' (1) meanings for force, (2) ideas about force and energy. • *Reviewing/revising pre-exposure questionnaire (FQ1) responses* • *Explanation task* for each FQ1 instance • *Repeat of one IAI card from FI1* (bcwl on green) • *Repeat of arrows task* • *New IAI cards* parallel (analogous) to those used in FI1 • *Post-interview conversation*	**Schedule for post-exposure energy interview (EI2)** *Component parts* • *Reviewing/revising pre-exposure questionnaire (EQ1) responses* • *Explanation task* for each EQ1 instance • *Questions about* (1) the nature of energy (2) measuring energy (3) useful INSET activities (4) conservation of E • *Repeat of three pre-exposure IAI/IAE examples* • *New IAI/IAE examples* parallel or analogous to those used pre-exposure • *Post-interview conversation*
STAGE III	**Schedule for long-term forces interview (FI3)** *Component parts* • *Introductory questions* about the impact the training has had on the teachers' classroom performance - content, method, planning etc. • *Tick sheet* for teachers' perceptions of changes in their understanding of some aspects of forces • *New IAI instances* (new contexts): *arrows task* for each instance • *New IAI instances: responses to questions* on each instance (TRUE, FALSE, DON'T UNDERSTAND, NOT SURE) • *New IAI instances:explanation task* about each instance • *Post-interview conversation*	**Schedule for long-term energy interview (EI3)** *Component parts* • *Introductory questions* about the impact the training has had on the teachers' classroom performance - content, method, planning etc. • *Tick sheet* for teachers' perceptions of changes in their understanding of various aspects of energy • *New IAI instances* (new contexts): *free response* to each instance • *New IAI instances: responses to questions* on each instance (TRUE, FALSE, DON'T UNDERSTAND, NOT SURE) • *New IAI instances: explanation task* about each instance • *Post-interview conversation*

a. Extract from pre-exposure forces questionnaire (FQ1)



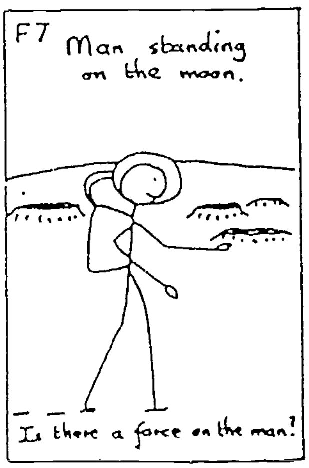
The slowing bike

(This cyclist is slowing down. he's not pedalling or using his brakes.)

24. The force from when he was pedalling is gradually petering out.
true( ) false( ) don't understand( ) not sure( )

25. The ground pushes up against the bike.
true( ) false( ) don't understand( ) not sure( )

b. Example of an IAI card



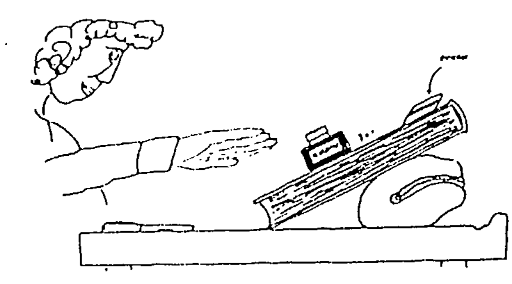
Man on the moon (MM)

Interviewer describes situation:
The astronaut is standing still on the surface of the moon.

Focus question asked of teacher:
What forces are acting on the astronaut?

c. Example of an IAI situation used for a combined task

IAI card



Description of situation by interviewer
A child leaned her book against her pencil case and *placed* her ink bottle and eraser on it. The eraser is lying there *not moving* but the bottle is sliding *faster and faster* towards the desk.

Focus question asked of teacher
Show the forces acting on (1) the eraser, (2) the ink bottle by drawing arrows. Talk to me about each 'force arrow' as you draw it.

Figure 2 Extracts from the research instruments (see text)

Explanation tasks

Interviews FI2 and EI2 also probed teachers' understanding more deeply by means of explanation tasks about each questionnaire instance. These tasks were given after discussion of the set of statements about the instance. For example, in the case of an instance depicting a stationary box on a slope (I = interviewer, T = teacher):

> I: (Explanation task:) Why isn't the box sliding?
> T: Because the forces on it cancel each other out. The first one, the reaction; the weight coming down this way - that is transferred to that way because of the angle of the slope. But the friction of the slope is equal to that.
> (Teacher 11, 'Box on the slope' explanation task)

Explanation tasks were also used in Stage III of the research (see below under 'combined tasks').

IAI cards

The interview-about-instances or IAI technique (Osborne and Gilbert 1980) was used at each stage of the research to probe teachers' predictions and interpretations of situations depicted as line drawings on cards. An example is shown in Figure 2b.

The IAI instances used initially in the FI1 and EI1 interviews were tried and tested instances from previous studies described in the research literature (e.g. Learning in Science Project 1980).

Interviews FI2 and EI2 probed teachers' ability to transfer ideas across contexts by replacing some situations (e.g. 'tossed-up tennis ball') with analogous ones ('bouncing on a trampoline') devised by the research team. A range of nine 'parallel IAI' instances of this type explored the influence of context on teachers' views as an optional extra part of interview FI2 (in practice many teachers completed all of these cards while only 6 omitted them altogether).

New IAI cards were devised for Stage III of the research. These are described below under 'combined tasks'.

Drawing tasks

Two drawing tasks formed part of the FI1 interview. First, a 'car speedometer task' was designed to elicit teachers' understanding of uniform and changing motion. Second, an 'arrows task' required teachers to draw arrows representing the forces acting in six of the IAI instances used earlier in the interview. This gave an alternative means of expressing views about forces in the same situations and enabled teachers to show *directions* of forces. The arrows task was repeated in the post-exposure interview.

Combined tasks

The elicitation of teachers' long-term understanding of forces was achieved largely by means of a combined 'interview/questionnaire/arrows task/explanation task' instrument in which teachers considered six new IAI situations similar to those used in earlier interviews and drew the forces acting in the situation, talking about them as they did so. This combined approach gave a better opportunity in the time available for teachers to show their understanding. An example is given in Figure 2c.

The following is an extract from the dialogue (with a fairly expert teacher) while the arrows were being drawn:

> T: There's the reaction of the book, the gravity on the eraser, and friction up the slope preventing it sliding down. (I: Is there a net force on the eraser?) No because it's not moving because they're all working equally ... (I: What about the ink bottle?) Gravity down, reaction that way, friction - same as before, but they're unbalanced so it's moving and there's a net force down the slope ... the glass is a slippery surface so the frictional force is greater on the eraser ... (Teacher 14, Ink bottle and eraser)

After this, teachers were asked to tick one of the four possible responses to various statements and then give reasons for their choice. For example, for the ink bottle and eraser:

> I: Statement 18. It's just a single force on the eraser which makes it stay where it is.
> **true( ) false(√) don't understand( ) not sure( )**
> T: False (I: Why not?) Because there is more than one force. (I: So it's staying where it is because of more than one force?) Yes.
> (Teacher 14, Ink bottle and eraser)

Teachers were then given an explanation task relating to the situation, which might include explaining an idea about forces (e.g. friction) embodied in the situation to a colleague. Explanation tasks were devised to cover all profile components.

The long term energy instrument EI3 was of broadly the same structure except that the arrows task was replaced by an initial invitation to respond freely to each of six IAI energy instances by talking about the role of energy in the situation depicted. Teachers were then asked to respond 'true', 'false', 'don't understand' or 'not sure' to statements about each of these IAI instances (with reasons), and to undertake explanation tasks of the form 'how would you explain this to a colleague?'.

Sample and administration of the instruments

Sample

An opportunity sample of 53 primary or middle school teachers (45 female) from three Local Education Authorities took part in the research. They included head teachers, deputies, science coordinators and main professional grade teachers with no particular responsibility for science. The length of teaching experience ranged from 1 to 30 years. Very few of these teachers had substantial science backgrounds. Only 10 had studied a physical science to the age of 16, and only three to age 18. Subject backgrounds in biology were better represented with 32 having followed a course to age 16 and 6 to age 18. Only 9 of the teachers had followed a main science course in college, although half of the sample had received some form of science inservice training during their careers.

The sample was divided into four groups: 'in-house' forces, 'in-house' energy, 'remote' forces and 'remote' energy. Each of these groups worked through the teacher education materials described earlier. The two in-house groups were following inservice science courses at a college of higher education. These groups were taught by science education experts (the research team). The two remote groups consisted of clusters of primary school staff following the course materials in their own schools. These were led in each case by a volunteer group member who acted as 'course leader'. The latter had no particular expertise in science and no training was provided for them. Their role was essentially that of coordination and organisation.

Administration

The pre-exposure questionnaires were administered personally by a member of the research team to ensure a full response. These questionnaires were completed, in silence, in 15 to 30 minutes. Pre-exposure interviews took place as soon as possible after completion of the questionnaires (typically between one and three weeks later).

The post-exposure interviews took place in the participant's schools as soon as practicable after the training courses had finished. This interview was designed to last 50 minutes but many teachers seemed to enjoy exercising their new-found knowledge on all of the (optional) parallel IAI instances and reflected on the whole interview experience in a 'post-interview conversation', so that in some cases interviews lasted up to 90 minutes.

The long term interview schedule was administered between six and ten months later, again in the participants' schools. The interview typically took 50 minutes, but many teachers were willing to stay and contribute to a post-interview conversation until nearly 90 minutes after the start.

At each stage of the research audio recordings were made of the interviews. These were subsequently transcribed and analysed.

Analysing and recording results

Analytical framework

When establishing the nature of teachers' conceptual understanding for the purposes of this research, two aspects of their views were considered:

1. the extent to which teachers' views corresponded to the scientific view as defined by the profile components described earlier.

2. the precise nature of the misconceptions teachers possessed.

The research explored how each of these aspects was affected by the learning experiences provided during training. A learning experience could convince the teacher that the scientific view is superior, perhaps because of its greater plausibility, consistency, applicability or powers of explanation. Alternatively, or in addition, it might demonstrate that a teacher's intuitive views or misconceptions are unsatisfactory because, for example, they contain logical inconsistencies. 'Coding sheets' were devised as a means of recording changes during the three stages of the research both in teachers' scientific view of the domain and in any intuitive views they held.

The coding sheets

A major problem faced by the research team was how to analyse and record large amounts of questionnaire and interview data for 53 teachers at each of the three stages of the research. The schematic framework shown in Figure 3 was derived to solve this problem and is a central feature of the analytical methodology.

An A3 sized record card of the kind outlined in Figure 3 was completed for each of the 53 participant at each of the three stages of the research. The PCs for force or energy (depending on course materials followed) were listed down the top half of the left hand side of the sheet. Intuitive views revealed by the research were listed below the PCs. The centre part of the sheet

PROFILE COMPONENTS	QUESTIONNAIRE RESPONSES					IAI CARDS			ARROWS TASK			Frequency of correspondence with scientific view: Never/ hardly ever	Sometimes	Always/ nearly always
1. Weight recognised as a force	GB14 x	CNM5 √		*CM8* √		BS n	CM x		BS x	CM x		3/18		
. . .														
4. Friction recognised as a force	BS36 √	BS38 √	CM10 √			BS √	CM n		BS √	CM √				14/14
. .														
14. Affirm that forces on a stationary object are balanced	CNM3 x	BS35 √		*CNM1* √		BS √	CM		BS n	CM			5/10	
. .														
INTUITIVE VIEWS														
.														
Fi... Belief that a force from a hit, push etc is put into a moving object and keeps it going	SB24 √	SB26 n	GB12 √	GB15 √		BS	CM √		BS	CM x				14/15
. . . . .														

Key: GB = golf ball
BS = box on slope
CM = car moving
CNM = car not moving
SB = slowing bike

Figure 3 Schematic example (partial) of a teacher's pre-exposure coding sheet. Only a small fraction of the total number of cells which were on the actual sheet are shown.

was divided into vertical columns corresponding to each of the instruments used in the interview schedule for this stage of the research. So, for the example shown in Figure 3 (forces pre-exposure stage), these columns are headed 'questionnaire responses', 'IAI cards' and 'arrows task'. Under these headings are rows of cells headed by the name of a particular questionnaire statement (e.g. GB14 standing for 'golf ball, question 14') or IAI instance (e.g. BS standing for 'box on slope'). Each row of cells is aligned with one of the profile components or intuitive views listed down the left hand side of the sheet.

So, each cell in the grid corresponds to a particular PC or intuitive view, and to a particular questionnaire statement or IAI instance. In the case of the questionnaires, there were too many statements to fit everyone alongside every PC. So, in general, only those statements which were designed to give information about a particular PC were represented by cells in that PCs row. However, during discussion, it was sometimes found that a particular statement unexpectedly gave information about a PC or intuitive view which it was not initially designed to explore. To cover this eventuality, some unlabelled cells were left in each row to enable this information to be recorded (an example is shown in italics in Figure 3 as CM8 in the PC1 row).

The coding sheets used for the other two stages of the research and for energy were similar to that described above, but with some variation in column headings when different instruments were used e.g. a column headed 'explanation tasks' was needed for the post-exposure and long term sheets, for both force and energy.

Analysing transcripts

The transcripts were analysed in terms of the PCs and intuitive views listed on the coding sheet. PCs which were affirmed correctly by the interviewee were noted by means of their number (e.g. 5, 9 etc) in the left-hand margin of the transcript. Names of forces or aspects of energy omitted or misunderstood by a teacher (e.g. friction, kinetic energy etc) were jotted in the right-hand margin and the corresponding PC, followed by a cross, entered in the left margin (e.g. 4x, 1x etc).

Any intuitive views that became evident were noted in the form of the intuitive view coding (e.g. Fi), either alone if affirmed, or followed by a cross if denied.

Equivocal responses were indicated by the PC number followed by 'nip' ('no inference possible').

Using the coding sheets

Information from the analysed transcripts was then transferred to the coding sheet. Recognition or correct use of a particular aspect of force (e.g. friction) by a teacher during discussion of a situation (e.g. BS: 'box on the slope') was shown by a tick in the appropriate cell representing that situation, entered opposite the corresponding profile component (PC4: 'friction recognised as a force'). If the teacher was in error, for example, by saying that the forces on a stationary car are not balanced, a cross was entered opposite the appropriate profile component (PC14: 'affirm that forces on a stationary object are balanced'). These examples are illustrated in Figure 3.

A further category of response, 'n', meaning 'no inference possible' was also used. If, for example, a teacher made a response in which friction was referred to in such a way that it was impossible to decide whether it was regarded as a force or not, 'n' was inserted rather than a tick or cross (e.g. the CM card in Figure 3).

The same procedures were used for recording teachers' intuitive views as for PCs described above. Affirmation of an intuitive view, such as 'belief that a force from a hit, push etc is put into a moving object and keeps it going' during discussion of one of the situations (e.g. driven golf ball) was shown by a tick in the cell for that situation opposite the corresponding coding for that view (Fi on the coding sheet). A denial of this intuitive view was indicated by a cross in the cell, and 'n' was entered where no inference was possible.

PCs and intuitive views evident from arrows tasks were transferred directly to the coding sheet following inspection of the arrows drawn and of the name or description given to them by the teacher.

This description makes the analysis seem straight forward. In practice a quite elaborate set of criteria had to be developed for awarding ticks and crosses e.g. 'denying a statement which is itself a denial of the scientific view' was one of 9 criteria for recording a tick, while 'denial of, or uncertainty about, a statement which affirms the scientific view' was one of 9 criteria for awarding a cross. Full details of the criteria used for awarding ticks and crosses to teachers for the various profile components are given in the full project report (Summers et al 1993).

Correspondence with the scientific view

The ticks and crosses were summed for each profile component horizontally across the coding sheet and their numbers expressed in the form of a fraction. The *numerator* signified the number of affirmations or correct use of a PC made by the teacher in all the instruments used (i.e. ticks on the coding sheet).The *denominator* was the total number of responses relating to a PC about which an inference could be made (i.e. ticks plus crosses - 'n' responses were **not** included).

The fraction 'numerator divided by denominator' was entered in one of the 3 columns on the right of the coding sheet headed 'frequency of correspondence with the scientific view', depending on its value:

never/hardly ever	(fractions equivalent to 0-24%)
sometimes	(fractions equivalent to 25-75%)
always/nearly always	(fractions equivalent to 76-100%)

For example, if at the pre-exposure stage, the (imaginary) teacher in Figure 3 failed on 15 occasions to affirm PC 1 ('weight recognised as a force') but did affirm it 3 times, her score would be 3 out of 18 (3/18). This means she is coded as 'hardly ever' possessing the scientific view of weight. However, if on all 14 occasions that she mentioned friction she affirmed it as a force, she would be coded as 'always' having the scientific view of PC 4.

An identical procedure was followed for intuitive views, but this time the fraction represented the frequency of correspondence of the teacher's views with those of science **in the reverse sense** to PCs. Here the smaller the numerator compared with the denominator, the *greater* the degree of correspondence with the scientific view.

There was no set number of affirmations or denials (the denominator) for a given profile component or intuitive view. The number differed from teacher to teacher depending on how the teacher interpreted particular situations. Also, note that some of the cells in Figure 3 are empty. This is means that the PC in question simply did not arise for this particular teacher when the instance was discussed.

Results

Data concerning changes in teachers' views during the research were looked at in three ways:

- by comparing, for *each profile component*, the numbers of teachers whose views corresponded to the currently held scientific view at each stage of the research.
- by looking at the correspondence of individual teachers' views with those of science, with respect to *groups of profile components* (e.g. recognising forces, adding forces etc).
- by examining the numbers of teachers who expressed *intuitive views* at each stage of the research.

The principal findings are described in the sections which follow. All tables are to be found *at the end* of the article.

1. Progression of teachers' scientific understanding

Table 1 shows the number of teachers in each of the three categories representing frequency of affirmation of the scientific view (*never/hardly ever, sometimes, always/nearly always*) at each of the three stages of the research for each of the force profile components. Table 2 shows the equivalent findings for energy. Hence these tables show how the understanding of the sample as a whole developed with time for each separate profile component.

The data were obtained from the coding sheets for each teacher. Each sheet places the teacher concerned in one of the three categories *never/hardly ever, sometimes, always/nearly always* for each profile component at each stage of the research i.e. pre-exposure, post-exposure and long term. All the coding sheets were inspected and the number of teachers in each category for each PC at each stage was counted.

High numbers in the *never/hardly* pre-exposure columns indicate that many aspects of force and energy were initially little known or understood by the teachers. On the whole, aspects of force to do with motion were least understood, although affirmation of PCs involving recognition of some fundamental forces was also infrequent in some cases (particularly weight, the relationship between weight and gravity, reaction and, to a lesser extent, friction). Clearly, following training, the understanding of most profile components was dramatically improved, with massive shifts to the *always/nearly always* column at the post-exposure stage and in the longer term. Teachers' ability to correctly identify forces improved dramatically, while many teachers' ideas about force and motion were changed profoundly during the research (consider, for example, the turn around in PC11). However, on the whole, progress for PCs to do with force and motion was more limited than in other areas.

The results for energy show low initial knowledge and understanding of a number of PCs, notably those do do with gravitational potential energy and internal energy, efficiency and power, and most aspects of conservation of energy. Affirmation of energy as an idea rather than a substance was rare at the pre-exposure stage. Following training there were again dramatic changes. This was particularly true in the case of aspects of conservation of energy. The PCs where progress was poorest were those concerned with internal energy, work, power (where the training had no impact on teachers' understanding) and energy measurement.

Relative difficulty of profile components

Since Tables 1 and 2 show how the understanding of each individual profile component by the sample as a whole progressed, they can be thought of as providing an indication of the difficulty or 'ease of acquisition' of each profile component. This idea was quantified by attributing an 'index of understanding' for each PC at each stage of the research. The index was calculated by giving a weighting of 0, 1, and 2 respectively to each of the three categories representing frequency of affirmation of the scientific view (*never/hardly ever*, *sometimes*, *always/nearly always*) and applying this weighting to the numbers of teachers in Tables 1 and 2 (see Appendix 1 for further details). The index represents levels of understanding within the group as a whole ranging from zero (every teacher never/hardly ever affirms the PC when the opportunity arises) to 2 (all teachers who have the opportunity to affirm the PC always/nearly always do so). The results are shown in Table 3 for force and Table 4 for energy.

Classifying the understanding of the PCs in terms of index values (little: 0 - 0.3; some: 0.4 - 1.2; good: 1.3 - 1.5; very good: 1.6 - 1.7; expert status: 1.8 - 2.0), the changes in the sample's understanding of the PCs from before training to the long term stage were described. For example, understanding of force profile component 1 ('weight recognised as a force') moved from 'some' at the pre-exposure stage to 'good' in the long term; PC 1a ('knowing the direction of weight') moved from 'good' to 'expert' in the same interval, and so on.

According to the degree of change shown in teacher's understanding of each PC calculated in this way, the PCs were classified in terms of their difficulty. A small change of understanding (or none) following training indicated a difficult PC, and a large change showed an easy one. This classification is shown in Tables 5 and 6.

2. Progress of individual teachers

The above analysis is concerned with the sample as a whole and does not provide information on the progress of individual teachers. However, since frequencies of affirmation of the scientific view had been recorded for each PC for each teacher at each stage of the research on the coding sheets, the progress of each individual in the sample could be charted. The results of this analysis are summarised in Tables 7 and 8.

The data in these two tables were obtained from the fractions illustrating the frequency of affirmation/correct use of the scientific view for each PC which are shown in the shaded cells on each teacher's coding sheet (see Figure 3). Within each group of PCs (e.g. *Recognising forces*) all the numerators were summed and the same was done for all denominators. The resulting fraction was expressed as the percentage shown in Tables 7 and 8. These tables therefore indicate how the overall frequency of PCs concerned with the three principal aspects of force and the four for energy changed in the sample during the research. This analysis allowed identification of teachers who had progressed to different extents, and was used as the basis for constructing illustrative case studies for the main research report. Here we restrict ourselves to a few summative comments.

Force

Scores of more than 80% were referred to by the research team as representing 'almost expert' status, since teachers who achieved them were nearly always affirming and using the scientific view correctly in the contexts presented by the research instruments. In terms of overall understanding of force, Table 7 shows that eight teachers achieved 'almost expert' understanding in all the 3 categories and six others achieved long term scores of around 70%+ in each category. On this basis, about half of the sample can be regarded as having made good or very good progress towards the scientific view. Only four teachers had two long term scores under 70%. In nearly all cases, long term performance was worst for *forces and motion*. Clearly, the impact of the training was most successful for 'recognising forces' with 23 of the 31 teachers achieving a long term of score 81%+ compared with only three before exposure. For 'adding forces' the movement was less dramatic, but even so 17 teachers achieved a long term performance of 'almost expert' status compared with just two before exposure.

The phenomenon of 'slipping back' (long term scores lower than those obtained post-exposure) is evident from the data in Table 7 for many teachers, especially (and as mentioned earlier) in the case of *forces and motion*. However, for a small number of teachers this trend is reversed, with higher long term scores indicating an apparent consolidation of knowledge.

Energy

In the case of energy (Table 8), at the beginning of the research no teacher obtained high scores in all four groups of PCs. One, with three scores of more than 70% seemed closest to 'expert' understanding, followed by another with three scores of 60%+. The rest had some understanding of a single group of PCs (usually transfer of energy) or had little understanding of any of them.

At the post-exposure stage, about half the teachers obtained scores of 70%+ for all four groups of energy PCs. Scores of the other teachers were in the 50-80% range. With only 3 scores of under 50% in any group of PCs within the entire sample, it could be claimed that all of the teachers had made substantial progress towards the scientific view.

In the long term, a quarter of the teachers maintained a status of 'expert' (four scores of 80%+) or approaching 'expert' (four of 70%+). About half the teachers had one or two of their post-exposure high scores slip back (five to less than 50%). Only one showed an overall return to something approaching her pre-exposure state. With the rest, any lowered scores indicated a slipping back in understanding of just one or two of the four aspects of energy investigated.

Clearly, the training was most successful for 'conservation of energy' and 'the nature of energy', although in each case less than half the sample achieved long term scores of 81%+. Although there was definite and substantial movement towards the scientific view in the cases of 'possession of energy' and 'transfer of energy', hardly any of the teachers reached the 'almost expert' category of 81%+.

3. Intuitive views

During the course of the research teachers expressed large numbers of non-scientific, intuitive views about force and energy. The full project report describes 15 such views for force and 18 for energy. Tables 9 and 10 summarise the frequency of occurrence of the more prevalent views i.e. views that were expressed by at least half of the sample at some stage of the research.

The categorisation of the data shown in these tables must be viewed with a degree of caution since the allocation of a particular teacher to one of the groups *never/hardly ever*, *sometimes*, or *always/nearly always* was often based on low frequencies of an intuitive view. This is particularly true at the long term stage, where the research instruments concentrated on exploring profile components and gave relatively few opportunities for teachers to affirm or reject intuitive views. This was necessary since time was needed to explore new aspects of the research at this stage e.g. teachers' perceptions of the impact of new knowledge on their teaching. On the other hand, at the pre-exposure and post-exposure stages the instruments were deliberately designed to explore certain misconceptions e.g. by expressing these in statements requiring answers of the form 'true', 'false', 'don't understand' or 'not sure', and through subsequent discussion with teachers of their responses. Even so, the 'raw' frequencies for individual teachers were often still low. Hence, Tables 9 and 10 should be regarded as giving only a rough indication of trends in the data. Some of these trends are outlined below, first for force and then for energy.

Force

The most striking feature of the data in Table 9 is the existence of the impetus misconception Fi (belief that a force from a hit push etc is put into a moving object and keeps it going) in 30 of the teachers at the start of the research and its absence in 22 teachers, and partially for a further 8, at the post-exposure stage. It is also striking that the non-appearance of this belief persisted completely in 20 teachers and partially in three of them in the long term, with 8 reverting to their originally held intuitive view. This trend is mirrored in the figures for the misconception Fa ('Fading away') in which the motive force is thought to gradually dwindle or fade, and which is thus intimately bound up with Fi (and other similar impetus-like ideas).

The impetus notions Fw (weight acts horizontally or other wrong direction as a motive force), Fm (Momentum as a persistent motive force), and Fmt (movement is a motive force) were also seen to be prevalent at the start of the research but largely did not appear at the post-exposure and long term stages. Interestingly, Fnf (a net force acts in the direction of motion) seemed to be a more difficult idea to remove. Nearly all of the teachers displayed the notion initially and although about a half of them moved towards the scientific view post-exposure, this proportion slipped back to just over a third in the long term. This finding tallies with the difficulties teachers experienced with PC 15 (affirm that the forces on an object are balanced during uniform motion) evident from Table 1.

Fs (Force as a sticker - i.e. it keeps things where they are) was seen initially in about a third of the teachers but there was a sustained decrease in its occurrence during the research which seems to fit with the increased number of teachers affirming PC 14 (affirm that the forces on a stationary object are balanced) shown in Table 1.

Energy

Table 10 shows that several intuitive ideas about energy commonly expressed at the start of the research were more rare after training. The ideas that energy is present only during movement (Em) or activity (Ea) were present to varying extents in about three quarters of the teachers initially but this decreased to under a quarter post-exposure and long term. The idea that energy was only present in appliances when electricity flowed (Ee), held by more than half of the teachers before training, was seen in one teacher post-exposure and three in the long term. Nearly three quarters of the teachers believed that energy eventually disappeared (Eg - failure to recognise conservation) before training but only one or two teachers held to this belief thereafter.

These trends can be correlated with the broadening of teachers' ideas about energy to include the energy of stationary or non-operative objects (see PC 4 in Table 2) and the greatly increased understanding of ideas about conservation (see PCs 9-11 in Table 2).

Reductions in the numbers of teachers showing other intuitive views were less marked, while views such as Epot (a potential, or ability, to have energy in the future - not now) were displayed consistently by substantial numbers of teachers throughout the research. The usage of the everyday meanings of 'power' as electricity (Ep/e) or strength (Ep/s), rather than in the scientific sense, was seen to persist in teachers throughout the research. This is to be expected in view of the failure of the training to convey the scientific meaning of the term to any of them (see data for PC 8 in Table 2).

Some other findings of the research

An interesting but difficult question is the extent to which the growth in teachers' understanding of particular ideas (or, indeed, the lack of such growth) can be attributed to the particular learning strategies used during the inservice training. The only evidence available in connection with this question comes from *teachers' perceptions* elicited during the long term interview. In this interview teachers recalled many aspects of the training which they thought had enhanced their understanding. Some examples of teachers' perceptions in relation to the constructivist nature of the training are described below.

Many teachers mentioned *key concepts* which gave them particular insights into particular areas. Some of these are also described, along with a brief account of teachers' perceptions of the effect of new knowledge on their teaching.

Interested readers can find more detailed accounts of these essentially *qualitative* findings of the research in the full project report.

Elicitation of preconceptions

Interestingly, few teachers mentioned the elicitation of their own views at the start of the training as being useful. However, there was clear evidence that elicitation of *children's* views (also part of the training) had since been adopted as a teaching strategy. This became apparent in the long term interview when teachers were asked about the affect of newly acquired knowledge on their teaching. This was done with those teachers in the sample (about half) who had taught aspects of force or energy between the post-exposure and long-term stages. More than half of these teachers said they now start with the learner's existing ideas and teach in a more investigative, open-ended way.

Metacognition

There was considerable evidence of metacognitive development, with teachers understanding their own learning processes. This was especially so as they became aware of conflict in their views, or of the partial nature of their understanding. Many described in detail the nature of the changes in their own ideas during training sessions, and over the longer period, and often identified the key ideas which had helped them. They also recognised the nature of the difficulties they experienced as they wrestled with new ideas:

> T: I always associated gravity with magnetism and ... atmospheres .. I thought it was connected with the Earth spinning ... now I know any two bodies can cause an attraction ... it was the experiment with different sized balls that really brought it home.
> (Teacher 10, Q2, FI3)

The training had given the teachers a heightened awareness of their intuitive views and those of children. The stubbornness of these was often overtly acknowledged during conversation:

> T: When you get to this age (*i.e. adult*) you get set in thinking in certain ways and certain words mean certain things and it becomes difficult for them to take on a different meaning ... I think children will take them on board much more easily.
> (Teacher 25, Sky-diver explanation task, FI3)

> T: They are like bad driving habits - hard to change ...
> (Teacher 53, Two toboggans explanation task, EI2)

Teachers could now recognise an intuitive feeling as scientifically wrong, both in themselves and in their colleagues, and acknowledge that a scientific explanation did exist, even if they couldn't supply it or perhaps still felt more attracted to their original view. One teacher referred rather ruefully to the 'quaint mediaeval view' she formerly held of the forces acting on a projectile. Others felt the approach taken by the training did enable them to realise the incompleteness of their knowledge and understanding and the nature of any inadequacies which would be confronted when they came to use it in teaching.

Use of analogy

Taught analogies were frequently invoked. This teacher is recalling a 'bridging analogy' from an inservice activity where the roughness of two surfaces was represented by the interlocking bristles of two brushes. This had convinced her that friction was a force because it demonstrated friction stopping things moving:

> T: The bristles were making obstacles ... I used to think something going down a slope stopped because it had run out of momentum. I never thought it was stopping or slowing down because of friction (I: A complete change of perspective?) Yes.
> (Teacher 3, Q2, FI3)

The key friction experience for Teacher 17 was holding an eraser in one hand and bending it with the fingers of her other hand - this was an 'anchoring example' designed to illustrate how a force arises from the distortion of an object. The eraser was analogous to the tiny projections on any surface whose distortion gives rise to a frictional force.

> T: When you first asked I didn't think friction was a force ... now I know it's a force that opposes any kind of movement ... The activity that had the most impact was bending the rubber with your finger. (Teacher 17, Q2, FI3)

A 'force of reaction' activity in which an apparently rigid table is shown to 'bend' minutely, by means of the deflection of a beam of light from a torch resting on it, had a profound affect on the teacher below. She recalled the 'bridging analogy' activity that so affected her view. However, she could not articulate the analogy, that surfaces bend and act like springs, nor the conceptual model, that all surfaces bend minutely in a spring-like way when an object rests on them.

> T: The light one ... where we went into the dark room ...I stayed there a long time ... that convinced me of what was going on ... I can't remember what my thoughts were at the time ... suddenly the veil dropped from my eyes and I could accept what people were talking about when they talked about reaction from objects (I: You were converted in a dark room?) Yes!
> (Teacher 12, Q2, FI3)

Other teachers also recalled 'anchoring example' activities as being responsible for their new scientific understanding, but were unable to specify the associated analogical aspects of it or the conceptual model provided. Some teachers with more advanced understanding did cite the conceptual models provided during training as being responsible for improving their understanding further, e.g. Teacher 24 (a secondary science specialist teaching upper juniors part-time at one of the 'remote' schools):

> T: Reaction? I'm pretty certain of that ... some of the examples have improved my understanding, because of ... the model ...

> the molecules and thinking of it in terms of particles and bonds... when you put a book on the table it does infinitesimally bend.
> (Teacher 24, Q2, FI3)

Taught analogies were often used spontaneously during interviews, such as 'the millionaire benefactor' analogy which showed the greater effectiveness of money (and so energy) when concentrated than when dispersed. The failure of money analogies to make an impression on a number of the teachers in the remote groups could be due to the use of a domain perceived as unfriendly - one teacher described how for her money has mathematical connotations and she, 'being an arts person', switches off from mathematics and science.

Meeting the scientific view

Accounts of the 'expert view' (i.e. the scientist's view) of the various aspects of force and energy were seen by teachers as a key part of the training. So, for example, 'homework' questionnaires were given to teachers in which they assessed the truth of statements about the role of forces or energy in real-life situations. The scientist's 'expert view' of these situations was given out and discussed when the 'homework' was brought to the next training session. Teacher 25 explained the value, for her, of this approach:

> T: It was saying, 'Make a decision' ... you had to think about it ... if you got it wrong, it made you want to know what was the right answer and why that was wrong. (I: ... it's important that you have the answers?) Definitely. (I: You wouldn't want it open-ended?) No ... the fact that we got the answers afterwards on a piece of paper (*i.e. the 'expert' view*) was vital for the ones we were confused on. (Teacher 25, Q2, FI3)

Although the scientific view was provided in the training materials at appropriate points, teachers in the remote groups missed the presence of an expert in person during the practical activities:

> T: I feel there was a need to discuss some of these topics with the 'experts' ... it does turn staff off when there isn't anyone there who can clarify things for them.
> (Teacher 27, Q2, FI3)

A number of teachers referred to a problem of the lack of further validation of their new knowledge. The scientific understanding of members of the science community is constantly being reinforced and validated by the system within which they are trained and work. These teachers' were aware of a need for similar reinforcement of the ideas which they had acquired from the training once it had been completed.

Active learning and discussion

Some training techniques seemed to be particularly successful in stimulating learning as a social activity involving group discussion:

> T: The best session was the second ... when everyone opened up ... in the first they were very worried and anxious ... it was the very lively discussion brought about by having to fill in those Sankey diagrams ... (Teacher 41, Q2, EI2)

Teachers often attributed certain insights about profile components to discussion of particular topics, e.g. weightlessness:

> T: I thought weightlessness was just a term people use for floating about because there is no gravity ... I didn't connect gravity and weight. (Teacher 1, Q2, FI3)

However, social learning was not without its problems. Teacher 26 illustrated the difficulties of communication between people with different background knowledge, and also showed the stubbornness of her prior ideas:

> T: I felt as if a lot of us (the remote group) were groping around in the dark and somebody there with a scientific background would come in and try and explain but I don't think that was successful because ... they didn't know how to put it across to us because they were being scientific ... I don't think they could quite see why we didn't understand it.
>
> *(later)*
>
> I know what I'm supposed to believe (*i.e. deny impetus*) ... I don't think anything will ever say to me what I've just done to that tennis ball is no longer having an effect on it, now it's on the other side of the net - I can never come to terms with that.
> (Teacher 26, Q2, FI3)

Many felt that the practical 'hands-on' aspect of the training was indispensable and that merely to assert that something was the case was not convincing enough:

> T: The written things - I didn't believe them. I thought, 'I don't understand, can't quite see how that works.' (I: You have to have some kind of experience?) Yes, I could be convinced by an argument but an object pushing something up (*force of reaction*) is hard to think of. (I: But the hand on the brick experiment really did get the point across?) Yes because you did realise your hand was pushing up on it. (Teacher 22, Q2, FI3)

However, a few felt that they had learned more from the illustrations, diagrams and discussions than from practical activities:

> T: Those diagrams where we had to put where the forces were going (*i.e. pre-course work*)were good, we thought those out. I can't remember any of the experiments or practical work. It purely was having it talked through. (I: You'd think that the things you do would affect you.) With children that's absolutely vital but we're adults and more used to reading information ... I spent too long on the practical activities... didn't get enough adult information from them. (Teacher 10, Q2, FI3)

Overall, practical 'hands on' experience and discussion were among the most valued of the training strategies used in the training.

Key concepts and insights

A number of teachers identified *key concepts* as as being responsible for *insights* which led to greatly improved understanding of certain areas. For example, the notion of a frame of reference helped teachers' understanding of gravitational potential energy. For some, the idea of friction as a 'variable' force, one that increases until it reaches a limit, was essential for understanding why a pushed car suddenly starts to move. For others, the key to understanding friction was the association of force not only with movement:

> T: I've thought about friction before but I'd never really thought about forces acting on things when they're stationary ... I realise now how ridiculous that was.
> (Teacher 16, post-interview conversation, FI2)

Teacher 9 explained how the Newtonian concept of inertia or 'unchangeability of motion' was, for him, the key to an understanding of net force:

> T: It's keeping hold of the central concept that you'll only have a net force when the state of a body changes. Once I understood that - that something carries on unless something reacts or acts against it to stop it or change it ... that was the nub of the whole thing... as long as I had that concept to hang on to, then everything else fell together. (Teacher 9, Q3, FI3)

However, some teachers felt that the improvement in their understanding did not come from particular experiences or concepts causing a sudden insight or Gestalt-type 'flip' into a new way of seeing. Instead their learning was a more holistic phenomenon ('it was the whole thing'). They described a gradual dawning of a new awareness due to the constant repetition of the ideas throughout the training.

> T: It was the questions ... getting the answers wrong ... looking up the answer ... having long conversations with people ... then gradually coming to terms with it .. to an acceptance that 'push' in this context means something different to the way I'd usually understand it ... it isn't producing a movement, it's just sort of static. (Teacher 25, Q2, FI3)

Often the effect of an insight was to give an already familiar term from the teacher's experience a broader meaning:

> T: I hadn't thought of friction before as holding things where they were ... (I: what was your view of friction before?) It was just things rubbing together and getting hot.
> (Teacher 5, Q3, FI3)

There were examples of learning from the training materials providing insights into an example or problem from their own life experience:

> T: I thought the hockey ball I hit goes as far as I intend it to go. I never thought of other things acting on it to stop it ... I thought it ran out of momentum. (Teacher 3, Q2, FI3)

Some teachers confessed to having their world view and reflections about everyday experiences changed by the training. One teacher described how she had thrown a pebble from a cliff top into the sea while on holiday and instead of admiring the patterns of the ripples, as she would have done before, found herself pondering about the forces acting on the pebble!

Impact of new knowledge on teaching

The research investigated teachers' *perceptions* of the affect of newly acquired knowledge on their teaching. As mentioned earlier, this was done with those teachers in the sample (about half) who had taught aspects of force or energy between the post-exposure and long-term stages.

These teachers felt they had improved in confidence and had greater understanding of the concepts they had to teach, although they still recognised their own persisting conceptual difficulties. There was more awareness of the learning outcomes they desired and some felt better able to make judgments about the appropriateness of ideas for teaching to different age-groups (almost all the teachers felt that ideas about forces or energy could be taught to primary school children). There was also greater sensitivity among teachers to their use of language when teaching and more awareness of learners' problems. A finding of note was that more than half of the teachers said they now start with the learner's existing ideas and teach in a more investigative, open-ended way.

About half of the teachers had *not* used their new knowledge. The reason given for not having taught aspects of energy or forces since the training was usually that these had not yet come up on the school's curriculum timetable. Many of the schools operated a two-year cycle of planned and integrated topics and it was a matter of chance whether one of these involved work on forces or energy in the interval between the second and third stages of the research.

Here it is noticeable that 'force' and 'energy' are regarded as discrete compartments of knowledge to be taught when prescribed by the school plan rather than as wider, generally applicable ideas of relevance to all areas of the curriculum. As a result of the revolution in primary mathematics teaching in the last twenty years, the good primary teacher sees opportunities for teaching mathematics in music, physical education, craft, history and so on, as well as in 'mathematics lessons'. An important step forward would be to encourage this same development in science.

Summary

The main question posed by this research was whether a constructivist approach to learning can produce long-term understanding in primary school teachers. The findings indicate that nearly all teachers did improve their understanding of force and energy considerably, and that this improvement was still evident 6 to 12 months following inservice training.

In summary, the principal research findings reported in this paper were that:

(i) at the outset of the research nearly all the teachers had little scientific knowledge and understanding of the concepts force and energy.
(ii) following training all teachers had moved substantially towards the scientific view.
(iii) in many cases this movement was quite remarkable, but in others the change was relatively modest.
(iv) some concepts were more easily acquired than others (it was possible to rank more than 30 concepts, all concerned with aspects of force or energy, in order of difficulty).
(v) there was evidence of 'slipping back' i.e. marked short term gains which were no longer so evident in the longer term.
(vi) teachers' may retain misconceptions even when these are addressed intensively during inservice training.

Further findings (not reported here in any detail but described in the main research report) were that:

(vii) in the long term teachers were able to recall a wide range of both general and concept-specific aspects of the training which they perceived as helpful in developing their understanding.
(viii) courses led by experts are better received by teachers and produce better long term gains in understanding.
(ix) there was evidence of a gap between teachers' perceptions of the change in their understanding and an objective assessment of this change (operating both ways i.e. over-estimation for some concepts and underestimation for others).
(x) teachers may develop new misconceptions as a result of such training.
(xi) many teachers reported that they are now more confident, more sensitive to language and learning difficulties in science, and that they now start from children's existing ideas.
(xii) there is a need to find ways of supporting teachers following training so that their knowledge and understanding can be reinforced and validated.

Teachers' knowledge in the long term, although greatly improved, was often characterised by the coexistence of scientific and intuitive views; partial understanding of scientific ideas; real-life interference (difficulty in idealising situations in order to analyse them scientifically); partly recalled school knowledge (usually poorly understood); inconsistency (vacillation between scientific and intuitive ideas); and ephemeral understanding ('I thought I'd got this, but now it's gone'). The full report of this project presents many examples of these characteristics. It also includes extensive accounts of teachers' explanations for phenomena, their perceptions of effective strategies for learning specific concepts, comparisons between perceived and actual understanding, and further details of teachers' perceptions of the influence of new knowledge on their classroom teaching. Case studies of the development of understanding also form part of the report.

Commentary

A key feature of the results is that inservice training, if well designed and based upon a current consensus of what constitutes good practice, can substantially improve primary teachers' understanding of science concepts. However, although greatly improved, the evidence supports the view that in many cases the scientific understanding achieved is likely to be partial and 'messy' with, for example, misconceptions coexisting alongside scientific views and teachers unsure of their new knowledge. Some teachers will progress at a greater rate than others, and some concepts will be more easily acquired than others.

What are the implications of these findings for the National Curriculum in England and Wales? Here we wish to make three points.

1. In the past the science curriculum at primary level has not taken account of the extent to which the teachers have knowledge and understanding of the concepts specified, nor of the ease with which these concepts can be acquired. And, of course, for a very good reason - there was no formal evidence available. The research reported here begins to chart these unknown waters. The findings that some ideas are more difficult for teachers to acquire than others (also reported by Smith and Peacock, 1992) would seem to be an important consideration in any future development of the curriculum. It is also relevant here to note that this observation applies equally to children as it does to teachers. In specifying the National Curriculum little evidence was available concerning primary aged children's abilities to cope with the concepts included. But here, as with teachers, there is now research evidence to take into consideration. For example, in the U.K. the Science Process and Concept Exploration project (SPACE 1986-90) has carried out a considerable amount

of research to identify the scientific ideas that *can* be learnt by many primary school children. This research base is admittedly still limited in scope but, at the very least, the findings do draw attention to factors that have hitherto been largely ignored in primary science curriculum development.

2. The present study, and research in the USA (e.g Neale et al 1990), has shown that primary teachers can develop their understanding of science but that, for many, this is a difficult and lengthy process. At the moment training courses are arguably too ambitious in scope, perhaps due to a lack of awareness of how difficult it is for adults to develop a good and robust understanding of scientific ideas. The current model of a 20-day course covering numerous content areas will undoubtedly yield some benefits. But if lasting, non-trivial understanding is the goal a more focused approach should be considered. A sophisticated concept such as force (or energy), for example, merits extended inservice provision on just this one theme.

   An important issue is how teachers are to be supported following training as they attempt to use their newly acquired knowledge in teaching. With the demise of local education authority advisory teachers there is surely, in principle, a role here for the specialist science teacher in primary schools. But such specialists are few and far between, and in any case the small size of many primary schools would seem to indicate the necessity for a continuing reliance on strong generalist teaching.

3. And one further comment on training. A number of science educators now believe that development of content knowledge by itself is not sufficient to guarantee any substantial improvement in the quality of classroom teaching (see Summers, 1993b for a review of relevant literature). It is also necessary to identify appropriate pedagogical content knowledge (Shulman 1986, 1987) in relation to the particular ideas and concepts to be taught. Here, at primary level, there appears to be relatively little research evidence to inform practice. So the key questions arise of how pedagogical content knowledge is to be generated and disseminated. There is here, surely, a rich area for development.

   Clearly, teachers need both conceptual understanding and pedagogical knowledge and skills, and it is important that both are considered when planning inservice provision. In addition, there is evidence to suggest that teachers' beliefs about science and the teaching and learning of science may be important influences on classroom teaching (see, for example, Brophy 1991). This is an area which merits explicit attention in inservice courses, but there is little research evidence to inform practice.

Final thoughts

In spite of the evidence from this study that primary teachers can acquire a better understanding of certain aspects of force or energy, the question remains of whether this means they are able to teach these scientific concepts more effectively to children. There is now a need to follow teachers into the classroom and observe the impact of their new knowledge on teaching and children's learning. This would enable identification of any further help needed by teachers, and inform the future development of inservice training.

Acknowledgement

We would like to thank David Palacio for his many helpful comments on the research reported in this article.

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TABLES

Table 1 Progression of entire forces sample in relation to each PC for forces

The number of teachers in each of the three categories representing frequency of affirmation of the scientific view is shown for each of the three stages of the research. No. of teachers N=31.

	Pre-exposure			Post-exposure			Long-term		
PROFILE COMPONENTS	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always
Recognising forces									
1. weight recognised as a force.	9	17	5	2	10	19	3	9	19
1a. knowing the direction of weight.	5	9	14*	1	3	23	0	3	27
2. gravity identified with weight (strictly mass).	15	5	10	1	5	25	3	6	22
2a. knowing the direction of gravity.	1	4	26	0	1	30	0	0	31
3. affirm that gravity depends on size.	21	0	9	8	0	22	0	0	16
4. friction recognised as a force.	10	6	15	0	4	27	0	3	28
4a. knowing the direction of friction.	7	3	12	0	4	27	1	7	23
5. recognise reaction (surface's upward push) as a force.	21	4	6	1	2	28	0	2	29
5a. knowing the direction of the force of reaction.	1	1	12	0	0	30	0	7	24
6. recognise a simple push or pull as a force.	0	1	30	1	0	30	0	2	29
6a. know the direction of the push/pull.	0	3	23	0	0	30	0	0	31
7. air resistance recognised as a force.	8	9	14	1	10	20	4	10	17
7a. know the direction of air resistance.	1	4	19	0	12	19	2	8	21
Adding forces									
8. acceptance of the notion of 'net force'.	0	5	26	0	1	30	0	0	31
9. identify whether a net force is acting or not.	2	19	10	0	6	25	1	11	19
9a. give the net force a correct direction (or value, if zero).	4	26	1	0	22	9	2	19	10
Forces and motion									
10. distinguish uniform from changing motion.	0	0	31	0	0	29	0	0	11
11. denial of impetus.	29	1	1	3	7	21	6	8	17
12. affirm that motion and force need not be in the same direction.	22	8	1	9	12	10	5	12	13
13. affirm that the only forces acting on a projectile are its weight and air resistance.	28	1	2	7	6	18	9	7	15
14. affirm that the forces on a stationary object are balanced.	5	13	13	0	4	27	2	6	23
15. affirm that forces on an object are balanced during uniform motion.	26	4	1	19	5	7	22	3	6
16. affirm that momentum is *not* a force.	27	4	0	8	8	15	6	4	21

* Note: where the no.s add up to less than 31, teachers either did not express a view about that PC or did so but no inference was possible from their response.

Table 2 Progression of energy sample as a whole in relation to each energy PC

The number of teachers in each of the three categories representing frequency of affirmation of the scientific view is shown for each of the three stages of the research. No. of teachers N=22.

PROFILE COMPONENTS	Pre-exposure			Post-exposure			Long-term		
	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always
Possession of energy 1. recognise that a moving body has/stores energy.	0	13	9	0	0	22	0	7	15
2. affirm that a stretched/strained body has/stores energy.	1	3	18	0	2	20	0	10	12
3. recognise that fuels store energy.	0	7	15	0	1	21	0	0	22
4. recognise gravitational potential energy.	21	1	0	5	7	10	7	9	6
5. recognise internal energy.	19	1	2	6	13	3	15	7	0
Transfer of energy 6. identify an energy-transfer.	0	8	14	0	1	21	0	2	20
6j. know that jobs get done during energy-transfer.	9	3	10	1	2	18*	0	10	12
6w. affirm that energy is transferred by work.	15	0	0	17	3	2	17	5	0
6s. affirm that energy is transferred as sound.	10	1	11	2	1	19	4	0	16
6h. affirm that energy is transferred by heating.	0	4	17	0	2	20	1	9	12
6l. affirm that energy is transferred as light.	3	7	12	0	3	19	2	1	11
6c. affirm that energy is transferred during change of state.	8	9	4	3	9	10	4	11	7
6e. affirm that energy is transferred by electric current.	0	2	19	1	0	21	0	3	17
7. know that efficiency is 'how well' energy is transferred.	19	1	2	5	8	9	8	7	7
8. know that power is the rate of energy-transfer.	22	0	0	22	0	0	22	0	0
Conservation of energy 9. recognise that energy 'spreads out' (dissipation).	17	2	3	1	0	21	0	3	19
10. recognise that energy becomes less useful (degradation).	16	2	0	0	7	15	5	4	13
11. know that the amount of energy stays constant before and after an event (conservation).	17	4	1	0	6	16	0	4	17
12a. affirm that energy is a quantity of something.	2	3	16	2	1	19	0	4	18
12b. use or explain units of energy measurement.	10	1	2	5	4	5	8	10	3
The nature of energy 13a. recognise 'forms' of energy heat, sound, light, electricity.	0	1	21	0	0	19	0	3	18
13b. recognise the 'job-doing capability' aspect of energy.	4	8	9	1	6	15	0	2	20
14. recognise that energy is an idea, not a substance.	18	2	2	6	4	12	4	8	10

* Note: Where the numbers add up to less than 22, teachers either did not express a view about the PC or did so but no inference was possible from their response.

Table 3 Table showing changes in the 'index of understanding ' for the forces profile components

0 = all teachers never/hardly ever affirm the PC when the opportunity arises.
2 = all teachers who have the opportunity to affirm the PC always/nearly always do so.

profile component	index of understanding		
	pre-exposure	post-exposure	long term
Recognising forces			
1. weight recognised as a force.	0.87	1.55	1.52
1a. knowing the direction of weight.	1.32	1.81	1.90
2. gravity identified with weight.	0.83	1.77	1.61
2a. knowing the direction of gravity.	1.81	1.97	2.00
3. affirm that gravity depends on size.	0.60	1.47	2.00
4. friction recognised as a force.	1.16	1.87	1.90
4a. knowing the direction of friction.	1.23	1.87	1.71
5. recognise reaction (surface's upward push) as a force.	0.52	1.87	1.94
5a. knowing the direction of the force of reaction.	1.79	2.00	1.77
6. recognise a simple push or pull as a force.	1.97	1.94	1.94
6a. know the direction of the push/pull.	1.88	2.00	2.00
7. air resistance recognised as a force.	1.19	1.61	1.42
7a. know the direction of air resistance.	1.75	1.61	1.61
Adding forces			
8. acceptance of the notion of 'net force'.	1.84	1.97	2.00
9. identify whether a net force is acting or not.	1.26	1.81	1.58
9a. give the net force a correct direction (or value, if zero).	0.90	1.29	1.26
Forces and motion			
10. distinguish uniform from changing motion.	2.00	2.00	2.00
11. denial of impetus.	0.10	1.58	1.35
12. affirm that motion and force need not be in the same direction.	0.32	1.03	1.27
13. affirm that the only forces acting on a projectile are its weight and air resistance.	0.16	1.35	1.19
14. affirm that the forces on a stationary object are balanced.	1.26	1.87	1.68
15. affirm that forces on an object are balanced during uniform motion.	0.19	0.61	0.48
16. affirm that momentum is *not* a force.	0.13	1.23	1.48

Table 4 Table showing the 'index of understanding ' for the energy profile components at each stage of the research
0 = all teachers never/hardly ever affirm the PC when the opportunity arises.
2 = all teachers who have the opportunity to affirm the PC always/nearly always do so.

profile component	index of understanding		
	pre-exposure	post-exposure	long term
Possession of energy 1. recognise that a moving body has/stores energy.	1.41	2.00	1.68
2. affirm that a stretched/strained body has/stores energy.	1.77	1.91	1.55
3. recognise that fuels store energy.	1.68	1.95	2.00
4. recognise gravitational potential energy.	0.05	1.23	0.95
5. recognise internal energy.	0.23	0.86	0.32
Transfer of energy 6. identify an energy-transfer.	1.64	1.95	1.91
6j. know that jobs get done during energy-transfer.	1.05	1.81	1.55
6w. affirm that energy is transferred by work.	0.00	0.32	0.23
6s. affirm that energy is transferred as sound.	1.05	1.77	1.45
6h. affirm that energy is transferred by heating.	1.81	1.91	1.50
6l. affirm that energy is transferred as light.	1.41	1.86	1.64
6c. affirm that energy is transferred during change of state.	0.81	1.32	1.14
6e. affirm that energy is transferred by electric current.	1.90	1.91	1.85
7. know that efficiency is 'how well' energy is transferred.	0.23	1.18	0.95
8. know that power is the rate of energy-transfer.	0.00	0.00	0.00
Conservation of energy 9. recognise that energy 'spreads out' (dissipation).	0.36	1.91	1.86
10. recognise that energy becomes less useful (degradation).	0.11	1.68	1.36
11. know that the amount of energy stays constant before and after an event (conservation).	0.27	1.73	1.73
12a. affirm that energy is a quantity of something.	1.36	1.77	1.82
12b. use or explain units of energy measurement.	0.38	1.00	0.76
The nature of energy 13a. recognise 'forms' of energy - heat, sound, light, electricity.	1.95	2.00	1.86
13b. recognise the 'job-doing capability' aspect of energy.	1.24	1.64	1.91
14. recognise that energy is an idea, not a substance.	0.27	1.27	1.27

Table 5 Classification of forces PCs according to their ease of acquisition by the teachers

This table is based on the changes in teachers' understanding seen between pre-exposure and long term stages

Ease of acquisition of PC	*Profile component*
very easy	1a. knowing the direction of weight. 2a. knowing the direction of gravity. 3. affirm that gravity depends on size. 4. friction recognised as a force. 5. recognise reaction as a force. 6. recognise a simple push or pull as a force. 6a. know the direction of the push/pull. 8. acceptance of the notion of 'net force'. 10. distinguish uniform from changing motion.
easy	2. gravity identified with weight. 4a. knowing the direction of friction. 5a. know the direction of the force of reaction. 7a. know the direction of air resistance. 14. forces on a stationary object are balanced.
quite difficult	1. weight recognised as a force. 7. air resistance recognised as a force. 9. identify whether a net force is acting or not. 11. denial of impetus. 16. affirm that momentum is *not* a force.
very difficult	9a. give the net force a correct direction (or value, if zero). 12. motion and force need not be in the same direction. 13. the only forces on a projectile are its weight and air resistance. 15. forces on an object are balanced during uniform motion.

Table 6 Classification of energy PCs according to their ease of acquisition by the teachers

This table is based on the changes in teachers' understanding seen between pre-exposure and long term stages

Ease of acquisition of PC	*Profile component*
very easy	3. recognise that fuels store energy. 6. identify an energy-transfer. 6e. affirm that energy is transferred by electric current. 9. recognise that energy 'spreads out' (dissipation). 12a. affirm that energy is a quantity of something. 13a. recognise 'forms' of energy - heat, sound, light, electricity. 13b. recognise the 'job-doing capability' aspect of energy.
easy	1. recognise that a moving body has/stores energy. 6l. affirm that energy is transferred as light. 11. know that the amount of energy stays constant before and after an event (conservation).
quite d.:ficult	2. affirm that a stretched/strained body has/stores energy. * 6j. know that jobs get done during energy-transfer. 6s. affirm that energy is transferred as sound. 6h. affirm that energy is transferred by heating. ** 10. recognise that energy becomes less useful (degradation).
very difficult	4. recognise gravitational potential energy. 5. recognise internal energy. 6w. affirm that energy is transferred by work. 6c. affirm that energy is transferred during change of state. 7. know that efficiency is 'how well' energy is transferred. 8. know that power is the rate of energy-transfer. 12b. use or explain units of energy measurement. 14. recognise that energy is an idea, not a substance.

Notes:

*Understanding of PC 2 *regressed* from very good to good and so is classified as quite difficult.

**Understanding of PC 6h *regressed* from expert status to good and so is classified as quite difficult

Table 7 ... **Progression of each teacher in the two forces groups in relation to the 3 groups of PC** (*recognising forces:* PCs 1-7; *adding forces:* PCs 8 and 9; and *forces and motion:* PCs 10-16)

This table shows, for each of the three groups of PCs at each stage of the research, the number of times a teacher affirmed, correctly used or recognised the scientific view *expressed as a percentage* of the number of times the scientific view *could* have been affirmed or used correctly.

Teacher No.	Pre-exposure			Post-exposure			Long term		
	Recognising forces	Adding forces	Forces and motion	Recognising forces	Adding forces	Forces and motion	Recognising forces	Adding forces	Forces and motion
(in-house) 1.	39	55	32	92	78	35	90	82	82
2.	41	55	19	95	86	81	97	76	55
3.	49	46	11	86	70	79	82	65	29
4.	39	60	19	83	75	63	70	80	48
5.	76	73	36	97	95	100	97	99	98
6.	61	75	26	89	85	78	81	93	71
7.	14	51	38	82	51	59	53	77	41
8.	61	61	31	76	77	27	75	79	24
9.	78	78	33	86	88	76	92	100	100
10.	77	73	38	84	79	84	78	80	70
11.	79	76	32	95	98	100	96	91	85
12.	51	60	19	94	92	63	84	50	84
13.	68	73	31	82	79	49	88	88	86
14.	81	68	31	82	99	92	80	100	69
15.	66	69	16	76	83	87	76	81	78
16.	54	77	31	92	86	82	90	83	59
17.	34	26	23	83	81	90	94	65	53
18.	68	73	30	93	74	65	94	82	68
19.	83	78	33	94	80	21	94	81	60
20.	63	71	20	96	89	78	93	84	80
(remote) 21.	64	81	36	99	92	84	82	83	51
22.	48	72	21	93	97	88	91	97	51
23.	52	78	24	87	73	28	81	65	38
24.	85	97	95	95	99	98	96	98	100
25.	34	70	29	81	72	74	76	82	57
26.	64	75	23	79	78	55	88	80	42
27.	68	71	15	88	81	69	77	76	72
28.	43	62	17	76	83	56	82	70	16
29.	61	63	18	91	80	56	86	72	19
30.	54	63	21	91	85	58	87	78	31
31.	61	62	25	90	84	81	83	94	90

Table 8 **Progression of each teacher in the energy sample in relation to the 4 groups of PC:** *possession of energy* (PCs 1-5), *transfer of energy* (PCs 6 to 8), *conservation of energy* (PCs 9 to 12) and *the nature of energy* (PCs 13-14).

This table shows, for each of the three groups of PCs at each stage of the research, the number of times a teacher expressed (affirmed, recognised or used correctly) the scientific view expressed as a percentage of the number of times the scientific view could have been affirmed or used correctly.

Teacher No.	Pre-exposure				Post-exposure				Long term			
	possession of E	transfer of E	conserv-ation of E	nature of E	possession of E	transfer of E	conserv-ation of E	nature of E	possession of E	transfer of E	conserv-ation of E	nature of E
(in-house) 32.	37	46	17	40	71	83	91	80	71	73	82	89
33.	31	51	14	20	75	82	98	40	69	80	92	100
34.	76	78	84	29	92	94	95	100	78	90	89	100
35.	22	65	0	60	78	95	93	75	59	78	83	100
36.	29	71	12	43	70	72	89	100	63	67	90	80
37.	33	65	15	25	80	78	93	83	59	55	74	75
38.	28	71	29	38	64	86	88	83	66	63	92	92
39.	20	56	24	75	48	77	87	33	35	45	67	67
40.	26	61	7	75	77	86	88	100	64	72	100	88
(remote) 41.	73	73	62	25	75	81	89	82	75	67	94	100
42.	35	65	12	43	76	91	92	93	70	81	85	95
43.	17	38	21	40	56	85	95	96	47	63	78	70
44.	24	68	35	50	59	81	85	78	43	52	38	62
45.	35	77	27	50	59	77	83	100	46	62	72	100
46.	32	70	5	0	74	71	30	56	80	73	44	90
47.	41	87	69	67	96	84	92	100	83	87	91	85
48.	25	78	19	50	65	77	86	83	24	50	48	83
49.	21	46	73	43	56	51	79	67	52	37	86	75
50.	25	67	5	17	33	82	89	67	41	42	69	86
51.	43	84	25	50	95	95	90	100	73	80	84	90
52.	25	56	10	0	43	88	83	78	27	68	95	36
53.	44	84	10	0	83	74	82	71	60	68	69	90

Table 9 Progression of forces sample as a whole in relation to intuitive views about force

The number of teachers in each of the three categories representing frequency of expression of the intuitive view is shown for each of the three stages of the research. No. of teachers N=31. Where the numbers add up to less than 31, some teachers made no reference at all to the intuitive view during interview. Numbers in the Never/Hardly ever column represent teachers who *denied* the intuitive view.

	Pre-exposure			Post-exposure			Long-term		
INTUITIVE VIEWS [* impetus notions]	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always
*Fi ..... *Belief that a force from a hit, push etc is put into a moving object and keeps it going*	1	0	30	22	8	1	20	3	8
*Fw.... *Weight acts horizontally or other wrong direction as a motive force*	0	0	18	1	2	8	13	3	4
*Fm .... *Momentum (as a persistent motive force)*	1	2	27	16	7	7	21	5	4
*Fnf .... *A net force acts in the direction of motion*	1	3	26	7	10	14	5	8	17
*Fmt.... *Movement is a motive force*	11	1	14	27	1	2	1	0	0
*Fa .... *'Fading away' p-prim (diSessa)*	1	3	27	20	7	4	19	4	8
Fs .... *Force as a sticker (i.e. it keeps things where they are)*	9	12	9	22	7	2	24	3	1
Fe .... *Confusion of force with energy*	3	0	12	8	1	8	2	0	1
Fga.... *Gravity depends on air/atmosphere*	18	0	4	26	0	2	1	0	0
Fgm.... *Gravity depends on magnetic centre*	14	0	5	18	0	4	6	0	1
Fhb .... *Weight acts independent of gravity ('heavy boots')*	16	1	5	22	0	5	0	0	1

***Note:** Where the numbers add up to less than 31, this indicates teachers who made no reference to the intuitive view at all during interview ('nil occurrence' means none of the teachers did so). Numbers in the Never/Hardly ever column represent teachers who *denied* the intuitive view.

Table 10 Progression of energy sample as a whole in relation to intuitive views about energy

The number of teachers in each of the three categories representing frequency of expression of the intuitive view is shown for each of the three stages of the research. No. of teachers N=22.

	Pre-exposure			Post-exposure			Long-term		
INTUITIVE VIEWS	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always	Never/ Hardly ever	Some-times	Always/ Nearly always
Em .... *Energy is only present if there is movement.*	6	9	7	20	2	0	20	2	0
Ea .... *is needed to be active/ operating/doing something*	4	2	13 *	16	2	3	9	5	1
Ef - *Energy is confused with force (e.g. 'it's not energy but a force or momentum').*	1	0	21	5	8	9	0	2	11
Eg - *Energy has gone or vanished, so no E is present.*	6	5	11	21	1	0	20	1	1
Et - *Energy is tangible; it exists in a physical sense.*	2	5	13	13	2	5	11	7	4
Ee - *Energy only present when electricity flows.*	7	5	8	20	0	1	17	0	3
Ew - *Wattage is merely equivalent to 'brightness'.*	1	1	15	0	0	4	9	1	6
Ep/e - *Power means electricity'*	0	0	20	1	0	11	1	2	8
Ep/s - *Power = 'strength', 'force' or 'operating agency'*	0	0	19	1	0	15	0	1	19
Eh - *Energy is human liveliness.*	11	4	3	16	1	5	6	1	8
Elo - *E found in living things only, not in inanimate objects.*	13	2	5	19	2	1	19	1	2
El - *E of living things, because they're alive ('life-force')*	0	1	21	8	2	12	0	1	6
EI - *Identical things must have equal energy, regardless of circumstances.*	4	3	11	8	5	6	5	0	5
Epot - *A potential (ability) to have E in the future (not now)*	0	0	12	0	0	11	0	0	7
Epers .... *'Personal' energy within the human body*	0	0	9	0	0	11	0	0	14

***Note:** Where the numbers add up to less than 22, this indicates teachers who made no reference to the intuitive view at all during interview ('nil occurrence' means none of the teachers did so). Numbers in the Never/Hardly ever column represent teachers who *denied* the intuitive view.