Overcoming misconceptions: using bridging analogies to cue scientific ideas

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OVERCOMING MISCONCEPTIONS: USING BRIDGING ANALOGIES TO CUE SCIENTIFIC IDEAS

BY

ANNE NELMES

A Thesis Submission for a Doctor of Philosophy Degree

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University

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Overcoming Misconceptions: Using Bridging Analogies to Cue Scientific Ideas

Pupils come to physics lessons with some scientifically wrong ideas, sometimes referred to as misconceptions but often just misplaced conceptions; correct in some contexts but not in others. It is often difficult to change these misconceptions.

Analogy has long been used to aid understanding of scientific concepts. However, the jump between analogue and target is sometimes too great, possibly because the similarity of the features compared is not significant enough. To improve mapping of similarities, bridges can be used which are part way between the analogue (anchor) and target. The anchor usually involves concrete phenomena where the pupils' intuitive ideas agree with the scientific view. This research looks at the use of bridging analogies in overcoming misconceptions in several topics. The conclusion is that, short-term, 'traditional' teaching gives better results whereas the bridging analogy approach may give better long-term retention of concepts.

Rather than trying to overtly use analogy, it may be more effective and less time consuming to cue the right idea using analogy on a very low key level, without the pupils realising that an analogy has been used. The idea of cueing correct ideas comes from work done by diSessa and others on phenomenological primitives (p-prims). These are small knowledge units which are cued to an active state to explain phenomena. It is hoped the correct p-prim will be cued by use of the analogy and, if cued repeatedly, will strengthen. Again, research is carried out in several topics.

The results are interesting. Generally, during the bridging analogy approaches, there is an increase in the sense of the scientific explanation for the experimental group even though they do not know why they have become surer of that explanation. However, the control group has sometimes shown a decrease in the sense of the scientific explanation.

Although cueing p-prims is quick and easy to do using low-key analogies, it only works in the short-term and pupils need to understand concepts for long-term success which may be done more effectively using bridging analogies taught in a more overt manner.
ACKNOWLEDGMENTS

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“And I cherish more than anything else the Analogies, my most trustworthy masters”

Johannes Kepler
INTRODUCTION

Misconceptions

Consider the idea that objects ‘require an unbalanced or net force to keep them moving at a constant velocity’. This is a common student misconception and many such misconceptions are extremely difficult to change (see, for example, Driver et al, 1985).

The term ‘misconception’ is not always the best one to use when discussing students’ conceptions. It implies that they are always wrong and always need replacing. This is not necessarily the case. There has been a recent trend (Duit, 1993) to accept that students’ intuitive ideas are important and ‘work’ for the student in everyday life. They can be extremely difficult to change and teachers should perhaps aim to teach children when it is appropriate to use which type of conception. It may be more acceptable to use the following terms instead: alternative frameworks, preconceptions, everyday conceptions, pre-instructional conceptions, or intuitive ideas.

In this research, the word ‘misconception’ is used to mean a conception which is not scientifically correct and which interferes with progress in understanding science.

Misconceptions are rife in physics, as pupils have had multiple experiences with the subject matter before ever having had a single physics lesson. They have had 11 or more years in which to build up a myriad of conceptions that work, more or less, be they right or wrong, based on everyday experiences, especially kinaesthetic ones.
Misconceptions can also occur due to the fact that everyday language often differs from the precise use of words in scientific language. For example, the word ‘work’ in science is only used when a force produces motion whereas there is a much more general meaning when the word is used in everyday language.

There exists an argument as to whether misconceptions are produced against a background of somewhat stable naïve theories (see, for example, Vosniadou, 1994) or whether students construct answers based on much smaller, elemental pieces of knowledge (see, for example, diSessa, 1993, 1996; Minstrell, 1992). What answer is produced will depend on which knowledge element is cued which, in turn, will depend to a large extent on the exact context of the question. Many methods have been used to try to bring about conceptual change (see Section 1.2) and one of these is the use of bridging analogies (analogies used as stepping-stones to bridge students’ and scientists’ conceptions). With respect to the above, it seems timely to review the use of bridging analogies and investigate to what extent they succeed in different topics and how they work especially when used in a low-key manner. The results may go some way to resolving this argument.
Specific research problems and questions

- To investigate whether scientific misconceptions can be overcome by the use of bridging analogies.

It is easier to understand a close analogy than a distant one. Pupils may not be willing to accept straightaway that A is analogous to C but, by introducing B, they may agree that A and B are analogous as are B and C. Thus, they may become more confident in the analogous relationship between A and C. The anchor-bridge-target model aims to start where the student is and finish where the scientist is, having crossed the chasm using conceptual bridges usually going from the very concrete to the rather abstract.

- To analyse the bridging analogy process using phenomenological primitives (p-prims).

P-prims are the very basic notions that pupils hold which have arisen from their interaction with the world. When faced with having to explain a phenomenon, p-prims are ‘cued to an active state’ depending on the context. Whether they remain active depends on the subsequent chain of mental events. An example of a p-prim is Ohm’s p-prim. This is where effect, resistance and effort are linked:

- Increased effort (same resistance) $\rightarrow$ increased effect
- Decreased effort (same resistance) $\rightarrow$ decreased effect
- Increased resistance (same effort) $\rightarrow$ decreased effect

This can apply to many situations, e.g. pushing harder against a weight to increase motion and increasing current through a resistor by increasing the potential difference. If a pupil is asked to explain a phenomenon, something in the question may cue this p-prim, which they will consider as an explanation in its own right.
not needing any further justification. (See Section 1.4 for a more detailed discussion of p-prims).

If the anchor in the analogy process cues a scientifically correct p-prim which is then kept in an active state by the bridges until the target is reached, this could be why bridging analogies are successful? Alternatively, the introduction of analogy could cause the pupils to consciously use the analogy to solve the target problem. Therefore, one question is:

➢ Do p-prims account for any success in this bridging analogy method or does the introduction of analogy cause more conscious thought processes?
CHAPTER ONE

Literature review

Introduction

Section 1.1 of the literature review deals with constructivism and constructivists since this provides the theoretical perspective to this research. The general ideas of constructivism are considered together with those of certain constructivists who are felt to be most relevant to this work. These constructivists include von Glasersfeld, Piaget, Kelly, Dewey, Vygotsky and Bruner. Some constructivist theories which have stemmed from them are also reviewed.

Section 1.2 concerns teaching strategies. These have a constructivist flavour and are generally split into two types: discontinuous and continuous. Discontinuous strategies usually involve some sort of cognitive conflict whereas continuous strategies tend to start with a student's correct conception, even if it is rather unrefined and not particularly 'scientific', and go from there. Various strategies are discussed together with their advantages and disadvantages. In addition, metacognitive approaches are reviewed. This section is included as it helps to clarify and fix the teaching strategy to be used in this study.

Section 1.3 deals with student conceptions, primarily those that have been termed misconceptions. A general introduction is given followed by a detailed look at the misconceptions considered in this research.
In section 1.4 criticisms of misconception research are discussed, particularly its seeming disparity with constructivism. Alternatives to misconceptions research are reviewed in detail, primarily fine-structure theories such as facets and phenomenological primitives (p-prims). Possible links between misconceptions and p-prims are made.

Section 1.5 discusses analogies. It starts by giving some examples of where analogies have famously been used in the history of science. It then goes on to explain more generally about what analogies are, listing their advantages together with the attributes that go to make a good analogy. Disadvantages of analogies are included. Theories of analogies of the type A:B::C:D are given followed by a discussion on models of teaching analogy. A discussion of analogy and unconscious contextual clues follows and it is this which promotes the suggestion of using analogy in a low-key manner to cue p-prims. The part on textbook analogies gives information on how the analogies used in this research will be analysed. The section concludes with a discussion on analogies as advance organisers and the links between analogies and models.

Section 1.6 reviews how analogies fit in with the ideas of constructivism.

Section 1.7 introduces the work done on bridging analogies as this is the specific teaching strategy chosen.
1.1 Constructivism and constructivists

This research is approached from a constructivist perspective, one which views constructivism in its broadest sense, incorporating the ideas of von Glasersfeld, Piaget, Kelly, Dewey, Vygotsky, Bruner and others. In this section, constructivism and its meanings are briefly reviewed and the work of various constructivists is examined. It deals with the theories of how children learn in order to provide some ideas about what a ‘deep or meaningful learning’ approach might involve.

‘Traditional’ methods of teaching made two suppositions. One of these was ‘decomposability’. This means that knowledge and skills can be broken into component pieces. The second supposition was ‘decontextualisation’ which means that these component pieces can be used in any context (Resnick, 1989). These ideas were based on behaviourist psychological theories formed in the early part of the twentieth century. The simple skills could be taught and assessed separately with the idea that the separate parts could be combined later to develop into complex skills (Gipps, 1994). This is known as the ‘building block’ model where learning is seen as sequential. Although the idea of decomposability may work for some learning, it is of little use for problem-solving since the parts do not add up to the whole. It is the interaction between the component pieces and knowing which to use that is important for this type of complex skill. For example, an unstructured mathematical problem needs more than basic arithmetic skills. Although a pupil may be expert at addition, multiplication etc. he or she needs to know where and when to use these basic skills and how they fit together. It is now becoming accepted that basic skills are strengthened when carrying out higher-ordered skills.

The second assumption of decontextualisation follows on from the first of decomposability. If complex skills could be decomposed into discrete simple skills then these should have applicability in all contexts (Resnick and Resnick, 1992). However, it is now being more acknowledged that skills and knowledge
are intertwined with the contexts in which they are learnt and practised and there is limited transferability (Gipps, 1994; Resnick and Resnick, 1992). One study which Gipps (1994) mentions is that of Wolf et al (1992). Trainees in the Youth Training Scheme were given tuition on problem-solving tasks either within their own discipline or of different sorts and a control group was given no preparation at all. Although both experimental groups fared better than the control group when carrying out problem-solving tasks outside their discipline, the group which had had an assortment of training out-performed the group which had had training only within their own discipline. The conclusion reached was that varied practice improved generalised learning.

Current learning theory has its origins in relatively recent work in cognitive psychology and constructivism which involves networks and connections. Learning does not involve merely recording information and data but interpreting them. Learning is regarded as adaptive where schemata are continually restructured in the light of new experience and ideas presented (Driver, 1989).

Constructivism - an introduction

It is difficult to define constructivism since it is a rather vague term encompassing many views. It can be said to originate from Ausubel’s often quoted statement – “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.” (Ausubel, 1968 p 406) However, this in itself is not a definition and is open to many interpretations. Strike (1987) proposed two principles to sum up constructivism:

1. ‘The mind’ is actively involved in constructing knowledge.
2. Concepts are invented rather than discovered.

The first principle, taken with Ausubel’s statement, seems to constitute the essence of constructivism: that learning is the active application of ‘the mind’ dependent on incoming information interacting with existing conceptions.
Radical constructivism often uses von Glasersfeld as a reference position. His views have been summarised in the following two principles (Glasersfeld 1989, p.162).

Principle A: The ‘trivial constructivist principle’: “knowledge is not passively received but actively built up by the cognizing subject.”

Principle B: The ‘radical constructivist principle’: “the function of the brain is adaptive and serves the organisation of the experiential world, not the discovery of ontological reality.”

Duit (1993) adds the third principle of ‘viability’: it is only the successful conceptions that remain.

From these principles, it may seem that the ‘mind’ and scientists are at odds. The mind wishes to build up ideas so that it has control over the world (whether or not these ideas are absolutely correct does not matter so long as they work in the context in which they are used). However, from a positivist perspective, scientists wish to build up a picture of what is ontologically correct, i.e. to find out the true nature of reality and how it works. They believe that there is a universal truth, unchanging over time and independent of the observer. If science itself is viewed from a constructivist perspective, then the ‘mind’ and scientists seem more compatible. From this viewpoint, according to Driver et al (1994), “the objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature” (p 5). Science does not aim to give truth but to provide a path for interpreting phenomena and coping with the world (Kearney, 2002).
A major criticism of this flavour of constructivism is the lack of social context (Matthews, 1993). It seems to be the individual making sense of the world with no input from others and this has led to the criticism that the pupil, in the radical constructivist view, is actually cut off from the rest of the world. (e.g. Marton and Neuman, 1989). However, von Glasersfeld (Duit, 1993) does realise the importance of the social context although he does not enlarge on it in his writing.

Others have said that it even leads to the denial of the existence of a real world outside the individual (e.g. Matthews, 1993). Earnest (1993), however, believes that it is consistent with there being a real world but that an individual can have no certain knowledge of the reality.

O’Loughlin (1992) states that constructivism rejects the essentially mutual and social character of meaning making and that it is unsound because of its failure to deal with the crucial matters of culture, power and discourse in the classroom. Others, e.g. Vygotsky, who would still call themselves constructivists, have tried to address these issues.

Interactionism (genetic structuralism) – Piaget

Introduction
Piaget was interested in genetic epistemology - the development of knowledge. He was one of the first researchers to theorise that children construct their own knowledge which is different from that of their parents - knowledge that has to evolve and change to become adult knowledge (Bliss, 1993). He also introduced the so-called clinical method. A clinical interview (Posner and Gertzog, 1982; White, 1985) usually contains a task where the pupil has to work with some physical objects. The optimal task is simple and concept-orientated. After the task has been completed, the researcher can then ask questions of the pupil concerning what they have said or done. This is to explore understanding and should be carried out steering clear of leading questions. Later in the interview, alternatives
can be suggested to the interviewee to see how secure their original concept is. A transcript of the interview is usually informative about what prior knowledge and misconceptions a pupil has. Although Piaget is not universally as highly regarded now as he once was, there are significant ideas to be gained from his work.

Piaget’s interest lay not in the individual subject but in the epistemic subject – “that cognitive nucleus which is common to all subjects at the same level” (Piaget, 1971, p 139). He wished to study what was universal between children and not their individual differences in order to learn about the structure development of knowledge rather than psychological issues with individuals (Bliss, 1995). This has led to criticisms of his theories as not being entirely applicable to individuals and, of course, pupils are individuals (Bliss, *ibid*).

**Piaget’s stage theory**

Piaget proposed that mental structures exist which change as the child develops. These he puts into his theory of qualitatively different stages describing the mental development from birth to adolescence. The stages are:

- **Sensorimotor** 0-2 years  Simple reflexive behaviour precedes the capacity to form schemata (beginnings of symbolic thought).

- **Preoperational** 2-7 years  Symbolic thought usage develops together with growth of imagination.

- **Concrete Operational** 7-11 years  Logical thought about physical processes develops together with the capacity to perform operations such as conservation.

- **Formal Operational** 11+ years  Ability to think hypothetically and abstractly develops.
All the stages are experienced but at different ages according to the individual child. There was also included the idea of stage mixture. Children might understand conservation of length before conservation of quantity but they both need the same type of logical operation. This was referred to as ‘horizontal décalage’.

Two critics of Piaget were Brown and Desforges (1977, 1979) who felt that the theory was inadequate where it could be tested but that it was mostly untestable. They saw the idea of ‘stage’ as being merely definitional and ‘horizontal décalage’ as a way of dealing with awkward anomalies.

Limitations on Piaget’s theory include the fact that domain-specific descriptions are few, certainly in the stage of formal operational thinking and this makes it difficult when dealing with secondary education. Learning has been claimed by several researchers to be domain-specific rather than the more general operational schemes that Piaget identified in the formal reasoning stage (Carey, 1985). It was once thought that problems are context free (Resnick and Resnick, 1992) whereas it is now felt that there is a close connection between skills and contexts. Research by Simon et al (1994), for example, found little consistency in children’s responses between similar problems set in different contexts.

Students tend to differentiate their knowledge into domains and teachers should aim to help them to integrate these domains (Linn and Songer, 1993). Too much differentiation leads to isolating tiny areas of understanding and not being able to deal with problems in different contexts. This is easy to do when work is not fully understood. If the cognitive goals are not easily reached using constructive processes then pupils may resort to memorisation techniques.

Yet another stumbling block is that formal operational thought may not be attained by up to 80% of 16 year olds (end of compulsory education in England).
(Shayer et al, 1976). Even well educated adults find tests much easier when they are based on concrete examples (Johnson-Laird et al, 1972).

More recent evidence (Donaldson, 1987) has shown that children are not as egocentric as Piaget supposed. Often, the experiments that he set up had little meaning for the child who did not always understand what was required. When they were made less abstract, the findings showed less egocentricism. One example of this is a situation set up by Hughes (1975). It consisted of two walls which made a cross and two dolls, one of which was a policeman and the other a small boy. The object of the experiment was to see whether a child could place the boy doll so that the policeman doll could not see him. This required the child to consider the viewpoint of the policeman and thus not be egocentric. The children (three-and-a-half to five years) tested using this were 90% successful in their answers. Thus, when the task makes sense to a child and he or she fully understands what to do, there is evidence that the child can show an ability to not be egocentric. It was felt that Piaget’s tasks were often complicated and confusing for the children interviewed.

Children are also better able to reason than Piaget gathered from the results to his experiments. Again, failure of the experimental set-up, including the exact wording of the questions, may be to blame for lack of convincing results (Donaldson, 1987).

One of the greatest criticisms of Piaget’s underestimation of childhood reasoning powers comes from learning language (Donaldson, 1987). Piaget thought that children under seven were extremely limited in their reasoning powers. However, they use grammar rules before that age. This is not just mere copying but building up and using grammar rules. A child might say, “I goed to the seaside”. This shows that they have constructed the usual rule for the past perfect tense by adding ‘ed’ to the verb. Chomsky provided an explanation of this by introducing the ‘language acquisition device’ (LAD) that is supposed to be highly specific towards
language development. However, it does seem unlikely that language develops on its own without other complementary skills. Macnamara (1972) proposed the concurrent acquisition of being able to make sense of or interpret situations that involve direct human interaction.

Piaget as a structuralist
Piaget saw the fundamental ideas of structuralism as being useful in finding similarities between different types of knowledge.

Piaget notes three main ideas concerning structure. These were wholeness, transformation and self-regulation. Wholeness meant that the structure was more than a sum of the parts. Transformation meant that the laws of structure are both structuring and being restructured. Self-regulation meant that there was self-maintenance and closure.

Structuralism sees phenomena as interlinked rather than isolated and the shift in focus is to examine the relationship between the phenomena. For example, in the social sciences, structuralism downplays the role of the individual subject whilst stressing the structured nature of the human condition with its inherent restrictions and organization (Piaget, 1971), hence Piaget’s concentration on the epistemic subject.

Piaget as a constructivist
In general, criticisms have been about Piaget’s stage theory rather than his constructivist approach.

Not only did Piaget want to know about the structures of knowledge, he wished also to know how they developed. This developmental or genetic structuralism is what Piaget called ‘interactionism’ which he later interpreted as a kind of constructivism. Constructivism for Piaget entailed the child constructing his or her own logical ideas through interaction with the environment (Bliss, 1993).
Piaget identified various processes that he regarded as being innate, universal and age-independent. These are assimilation, accommodation and equilibration. Assimilation refers to the process of incorporating new information into existing schemata. However, new data do not always fit into existing schemata and there must be an adjustment of thinking in order to deal with this; this is the process of accommodation. The processes of assimilation and accommodation are intertwined and both are always present to some degree in each interaction of external data and schemata. The whole process of dealing with new information is known as equilibration. This can be summarised as in Figure 1.
EXISTING SCHEMATA + NEW DATA / EXPERIENCES

DOES NEW DATA / EXPERIENCE FIT INTO EXISTING SCHEMATA?

yes

EXISTING SCHEMATA CONTINUED - ASSIMILATION

no

SCHEMATA MODIFIED - ACCOMMODATION

EQUILIBRATION

Figure 1 Piaget’s processes of assimilation, accommodation and equilibration
This model has been criticised by several authors. Brainerd (1978) said that it was merely descriptive without being explanatory. Olsen (1978) argues, however, that Brainerd is approaching the problem from an empirical-positivist viewpoint rather than from a structuralist view of Piaget. The two can be valid but not compatible.

Piaget influenced much of what still takes place in science laboratories. His idea that mental activity is internally focused led to the hypothesis-testing approach where the pupil is meant to discover concepts by applying logical thought to the results of their own experiments. ‘Hands-on’ science became important and teachers came to assume a supportive role (Trumbell, 1990). A specific example of Piaget’s influence was in the Cognitive Acceleration through Science Education (CASE) project (see pages 53-54) which was designed to speed up the cognitive development of children - in Piagetian terms, to accelerate their progress from concrete to formal operational thinking. It was based partly on Piaget’s ‘cognitive conflict’. The concept that the stages of cognitive development are the same for all children led to curricula that depended heavily on the developmental level of the students rather than their previous experience, individuality, or the social arena.

In summary, Piaget established a tradition by developing the clinical method. He also held the idea that children’s ideas are fundamentally different to those of adults. His ideas of assimilation, accommodation and equilibration put the child at the centre of the teaching-learning interaction.

Individual constructivism – Kelly’s theory of personal constructs

Kelly also had a constructivist approach although he focused more on the individual than the epistemic subject of Piaget.
He used the model of ‘man-the-scientist’ (Kelly, 1955) since each person needs to be able to predict and possibly control everyday events in much the same way as scientists predict and control events. In order to do this, a person views the world through “transparent patterns” or constructs, which we use to “fit over the realities of which the world is composed” (ibid, pp 8-9). The fit is sometimes poor but necessary if one is to make any sense of the world at all. The constructs are revised as they are tested against the outcome of events.

Each person makes their own constructs that are unique to that person although they may share common ground with others.

He also took the opposite view from Piaget about self-regulation. Piaget thought that the child was not aware of the processes of the construction of cognitive structures whereas Kelly held the view of conscious self-regulation of the child.

**Kelly versus Piaget in science instruction**

Translation of Piaget’s ideas into teaching seems somewhat easier than those of Kelly. Since Kelly concentrates on the different construct system of individuals, teachers would have to be aware of all these in order to prepare individual teaching/learning plans and strategies. Piaget’s ideas provide us with a more general, average view although this has its own problems. One of these is that, if pupils of the same age are being taught, Piaget would lead us to believe that they are not all at the same stage. In any case, will the same strategy work with all pupils even if they are at the same stage?

**Learning in interactive environments - Dewey (Roschelle, 1995)**

Whereas Piaget focused on the growth of structure, Dewey concentrated on experience – reflecting on experience is an active transaction and depends on prior knowledge. When we are confused or uncertain about an experience, we make use
of ‘inquiry’. This uses, according to Dewey (1938), reflection on experience and experiment to transform schemata and perception in order to bring coherence, coordination and meaning to our transactions.

Dewey believed that time, tools and talk were effective ways to allow inquiry to succeed. Challenging experiences are necessary to transform prior knowledge but Dewey did not see placing explicit conflict between prior knowledge and scientific concepts in children’s minds as being an appropriate way of proceeding. He believed that inquiry happens, not in the head, but in interaction with the environment and with others. He was very much a social constructivist.

Sociocultural constructivism - Vygotsky (Roschelle, 1995)

Piaget could be said to have minimised the importance of social interaction whereas Vygotsky felt it to be of utmost importance.

His main attitudinal difference from Piaget is that, whereas Piaget saw the driving force for development as being internal, Vygotsky felt it to be external, being provided in the main by the teacher. Learning was, for him, a two-way social interaction between teacher and child (and between children). This interaction largely depended on language as a tool. Language takes a central role in his theory of the development of thought processes, in both their formation and reorganisation (Howe, 1996). Because of this two-way interaction involving verbal communication, Vygotsky has cast the teacher in a far more important role than Piaget ever did.

Vygotsky saw children as having spontaneous concepts which are not in conflict. These grow upwards in generality and, in doing so, allow the possibility of more systematic reasoning. While this is occurring, scientific concepts from the scientific community, e.g. teachers, feed downwards in order to deal with the spontaneous concepts. The intertwining which occurs does so against a
background of social interaction in which one of the main tools is language. Vygotsky introduced the term of ‘zone of proximal development’ (ZPD). This is the area between what the child can do without help and with help in the form of social interaction. The child is forever being drawn upwards with his or her prior knowledge being restructured during social discourse against a cultural background. This is shown in Figure 2.
Figure 2 Vygotsky’s zones of proximal development
One way to help the pupil in this upward journey is to provide ‘scaffolding’. An example would be to allow the child to concentrate on just one aspect of a task. Teachers provide the scaffolding which can link a child’s present level with his potential level. This support is gradually removed as the child reaches the new level (Gipps, 1994). This can be extended to scaffolded assessment. This needs to be interactive where the teacher can question and probe the pupil to try to allow him to reach the next level. The degree of help required would be a good predictive indicator of potential within a domain (Brown et al, 1993). Of course, the major problem with interactive assessment is that it needs to be on an individual basis and, to be economically viable, it is unlikely that assessment, for accountability purposes at least, will ever be like this (Gipps 1994). Another way to assist would be for the teacher to reason aloud about a problem so the pupil can learn by imitation. A third way is to use ‘mediational means’ to increase the pupil’s ability to compare their understanding with that of others and perhaps then begin to act on it. An example of mediational means is giving the correct terminology about a topic so that when a pupil uses a scientific word or term it is being used to mean the same thing as when other pupils or the teacher use it. An example is the word ‘force’. It is important that both the pupils and the teacher use the word with the same scientific meaning otherwise many misunderstandings and misconceptions can occur.

Bruner

Bruner was a psychologist and in the 1960s he developed a theory of cognitive growth, approaching the subject from a different angle to Piaget. He was concerned more with environmental and experiential factors influencing an individual’s intellectual growth. He suggested that development is in gradual alterations in how the mind is used.

In his landmark book, *The process of education* (Bruner, 1960), he viewed children as active problem solvers who were always ready to learn a topic, even a
difficult one, albeit on a simplified level. This led to the idea of the spiral curriculum. “A curriculum as it develops should revisit these basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them” (ibid p 13). Pupils may not fully appreciate all the steps of an argument but may intuitively grasp the conclusion at an early age. The necessary gaps can be plugged when the topic is revisited.

For Bruner, a major aspect of teaching and learning was that of structure rather than facts.

The teaching and learning of structure, rather than simply the mastery of facts and techniques, is at the center of the classic problem of transfer... If earlier learning is to render later learning easier, it must do so by providing a general picture in terms of which the relations between things encountered earlier and later are made as clear as possible. (Ibid, p 12).

He also felt that motivation for learning should be in the topic itself rather than in passing examinations or gaining a good mark.

As Bruner developed his theories he became more influenced by Vygotsky’s ideas and placed learning within a social and cultural context.

Information Processing Psychology (Roschelle, 1995)

In the second part of the 20th century Information Processing models were suggested, using the analogy of the mind as a computer of symbolic data. The more successful models were based on Piaget’s ideas of accommodation where schemata are modified and assimilation where data are made to fit existing schemata. Unfortunately, these models have not worked well where there are many misconceptions, as the brain cannot be completely reprogrammed as can a computer. Nor are computers competent at social interaction. However, Information Processing is useful in allowing prior knowledge to be described
precisely and it can also provide the learner with tools such as ‘semantic networks’ and ‘tree diagrams’ to reflect on prior knowledge and understand associations and hierarchies.

Situated Learning (Brown, Collins and Duguid, 1989; Lave, 1988)

Roschelle (1995) explains that Situated Learning has been only recently introduced as a theory (towards the latter part of the 1980s), partly in response to Information Processing’s apparent lack of focus on the physical and social context. Situated Learning incorporates the ideas of Dewey that all learning happens during experiential transactions and Vygotsky’s ideas that learning happens within a social context.

Brown (2000) refers to Bruner’s observation that being a physicist is more than being able to recite and use the explicit knowledge of the field. There is a lot of implicit or tacit knowledge that physicists have. This includes things like being able to decide what is an interesting problem, being able to approach it as a physicist would and deciding whether a proof is just acceptable or excellent. To be a competent physicist one must be able to see the interaction between the explicit and implicit knowledge. This can only happen within a ‘community of practice’ where ideas and ways of working and approaching the subject are shared (Breslow, 2001).

In Situated Learning, enculturation is thus a very important concept and it focuses on participation in a community-based culture rather than on knowledge per se. Lave and Wenger (1989) have suggested that learning takes place on the edge of the community (‘legitimate peripheral participation’), e.g. schools and clubs. From the periphery, the learner moves slowly towards the centre.

There is debate as to how different scientific knowledge is from ordinary knowledge. Scientific knowledge does often seem different from ordinary
knowledge and, indeed, traditionally philosophers have attempted to search for a differentiation but without much success (Roschelle, 1995). A different view comes from others such as Latour (1987) and Knorr (1981) who maintain that the characteristics of scientific knowledge come from the shared practices of scientific communities. Scientific knowledge is not some different sort of knowledge altogether but it is the refinement of ordinary knowledge. Prior knowledge is moulded into scientific knowledge using the social interaction of the scientific community. This, of course, fits in with the ideas of Situated Learning; a learner is slowly transformed into a scientist by being part of that community.

Framework for this research

Figure 3 shows how the various constructivist theories discussed relate to each other. The stance for this research is from the theories of several constructivists already mentioned. Piaget’s concrete and formal operational stages are used as
being the levels of most of the 12-13 year-olds in the sample being studied. Learning is seen as taking place in a social context with teachers providing the Vygotskian scaffolding necessary to allow the pupil to successfully reach the next level. However, learning is also perceived as occurring during Dewey’s experiential interactions and reflections on them.

There were certain limitations as to how these constructivist theories could be used in the context of this research. The background of the author was in the physical sciences and a decision was taken to approach the research using a quasi-experimental design, that is, using control and experimental groups, interventions and controlling other variables as much as possible. The data produced would be subject to statistical analysis using t-tests. One of the disadvantages of this approach is the partial lack of social interaction. This is a major drawback since many modern constructivists such as Vygotsky and Bruner, who promote the idea of social constructivism, see the interaction in the classroom between teacher and pupil and between pupil and pupil as being of paramount importance. Since the groups are to be treated the same apart from the actual use of the bridging analogies, much of the normal topic discussion needs to be carefully controlled. Although the teacher will discuss the differences and similarities between the anchor, bridging analogies and the target with the pupils where appropriate, there can be no discussion between pupils. The pupils will not be able to discuss their thoughts and answers among themselves. This is not meant as a rejection of social constructivism but is a consequence of the methodological approach chosen. This limitation needs to be considered when the conclusions are drawn.

The use of bridging analogies (see chapter 1.7) in this research is seen as providing scaffolding in the Vygotskian sense to bridge the gap between the anchor at the pupil’s level and the target at a higher level to provide a basis for understanding a topic. However, they are not full explanations but these can be given when the topic is revisited in line with Bruner’s spiral curriculum.
1.2 Teaching and learning models and approaches

Constructivism and teaching

Although constructivism is a theory or, to be more exact, a collection of theories, of the development of knowledge, it does not dictate exactly how the knowledge should be taught. However, learning and teaching must be closely aligned and constructivism suggests several teaching strategies and ideas. Some of these are: reflection, metacognition, discussion, images, ideas in different contexts, questioning, hands-on investigation and analogies. Constructivism has paved the way for various teaching models. Conceptual change is the generally accepted term for learning science from the constructivist angle (Duit, 1999). Scott (1992) suggests that there are three levels involved for the teacher:

1. There must be a learning environment to support conceptual change.

2. Teaching strategies must be chosen.

3. Specific learning tasks must be selected which fit into the teaching strategy framework.

When considering the possible teaching strategies, prior conceptions and intended learning outcomes must be considered. In addition, the intellectual steps that the student ideally will actually make should be viewed.

Even when pupils have supposedly learned a new idea they will still tend to revert to their previous conceptions (Linn and Songer, 1993). It is as if they have accepted the new ideas superficially but their previous notions are too well embedded to be permanently changed. Posner et al. (1982) believe that several conditions must be met in order for a conception to be fully accepted and retained by a pupil. First, there must be some sort of dissatisfaction with the current
conception held. After that, they consider that the new idea must be intelligible, plausible and fruitful. In other words, the pupil must understand the concept and see that it makes sense as an alternative to his or her prior ideas. However, this on its own is not enough. The pupil must have some incentive to accept the conception. It must be able to explain or predict things in a better way than before. It is only then that the pupil will permanently replace his or her previous ideas with the new. In their theory, dissatisfaction must come first, followed by intelligibility. If the new concept is not intelligible, plausibility will not follow. Finally, the pupil will not find the idea fruitful unless it is intelligible and plausible.

There are two main types of strategy available for conceptual change as viewed from the constructivist angle (Duit, 1994):

1. **Discontinuous** - revolutionary - usually containing cognitive conflict

2. **Continuous** - evolutionary - starting from students’ conceptions and using, for example, bridging analogies or re-interpretation of students’ concepts (e.g. *electrical energy* is used up in a bulb, not *current*).

Scott *et al.* (1992) suggest that the former strategy stems from Piagetian theory of accommodation whereas the latter follows from the work of Vygotsky with its ‘scaffolding’ provided by the teacher.

1. Discontinuous

According to Posner *et al.* (1982), there are two main processes that are involved in conceptual change and these are assimilation and accommodation although it is to the latter that reference is usually made. In the traditional conceptual change method based on their work, the teacher makes the pupils’ conceptions explicit and then uses examples to promote cognitive conflict and dissatisfaction. After the
dissatisfaction is acknowledged, the correct, scientific explanation is given. In this way, accommodation takes place. Thus, the rather general Conceptual Change Model (CCM) sees learning as deconstructing misconceptions and constructing scientific conceptions instead.

In this model, a pupil’s ‘conceptual ecology’ is supposed to mediate intelligibility, plausibility and fruitfulness of a concept. Conceptual ecology was a term coined by Toulmin (1972) to cover the explicit and implicit beliefs held by the pupil. Strike and Posner (1992) extended this idea to encompass such things as “anomalies, analogies and metaphors, exemplars and images, past experiences, epistemological commitments, metaphysical beliefs and knowledge in other fields” (Duit and Treagust, 2003, p 674).

Pupils may even hold conflicting ideas about related phenomena (Driver et al, 1994) although Engel (1982), Hewson and Thorley (1989) and others do not believe that children can hold two conflicting ideas simultaneously. These two views may not be at odds since a pupil might not see the phenomena as being related and so having different explanations for each is simply an example of domain differentiation.

The CCM is deeply rooted in Piagetian constructivism ideas but is seen by some to be too narrow. Tobin (1989), from a radical constructivist position, points towards constant negotiation as the important process together with ‘minds-on’ activities and plenty of discussion. Driver and Oldham (1986) coming from a more sociocultural perspective produced the Constructivist Teaching Sequence (CTS) where pupils compare their ideas and the scientific ideas. The teacher’s role is to introduce concepts, symbols and conventions of the scientific community. First, the pupils are motivated to learn the topic and then they make their thoughts on the topic explicit through discussing, drawing posters or writing. Following this is the restructuring phase in which pupils and teacher exchange and elucidate views by discussing, promote conceptual conflict with demonstrations, and
evaluate different ideas. The pupils can then use the new ideas in different contexts, both fresh and familiar. Reviewing of the ideas then takes place so the pupils can see how their concepts have changed.

Recently, more emphasis has been put on amalgamating theories of learning; integrating ideas from radical constructivism and social constructivism (Duit and Treagust, 1998). Although each individual constructs his or her own concepts, it is against a backdrop of social and cultural factors. The individual is unique among many.

A selection of methods of teaching using this broad band of approach is summarised in Table 1 together with the general method.
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<td>Students' ideas made explicit;</td>
<td>by response to exposing event.</td>
<td>by worksheet and experiment.</td>
<td>by 'real' situations, exploring context of concept.</td>
<td>by each student presenting argument in support of their prediction.</td>
<td>by discussions, creation of posters, or writing.</td>
</tr>
<tr>
<td>Ideas challenged;</td>
<td>by attempt to explain discrepant event.</td>
<td>by same worksheet and experiment.</td>
<td>by debating pros and cons of current view with teacher introducing scientific view, if necessary.</td>
<td>by discussion and argument and introduction of scientific explanation after experiment is completed.</td>
<td>by demonstrations.</td>
</tr>
<tr>
<td>Cognitive conflict;</td>
<td></td>
<td>by teacher with pupils.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attempt to resolve conflict;</td>
<td>by guiding cognitive accommodation to give a new conceptual scientific model.</td>
<td></td>
<td>by further discussion of scientific concepts and their own original ideas.</td>
<td></td>
<td>by discussion, exchange of ideas and evaluation.</td>
</tr>
</tbody>
</table>

Table 1 A selection of teaching strategies in the 'discontinuous' method
A deviation from this general method was introduced by Rowell and Dawson (1985). This involves a direct comparison between students’ ideas and a scientific idea in trying to solve a problem. Further problems are then examined in as wide a range of contexts as possible.

The status a particular conception has in an individual’s mind is important. (Hewson, 1982; Hewson and Lemberger, 2000; Hewson and Thorley, 1989). It is useful when analyzing how students’ conceptions change over time. Hewson sees dissatisfaction as occurring when two conceptions are compared. If the new conception does not promote dissatisfaction, then it is assimilated in conjunction with the pre-existing conception (conceptual capture). However, if dissatisfaction does occur, then it will depend on which conception has the higher status as to whether there is conceptual exchange (accommodation). Even if there is, the original conception is never entirely extinguished and may be brought to the fore later. This sounds very similar to diSessa’s theory of p-prims (see section 1.4).

Furuya (1993) has found that many students are not aware of their misconceptions and their knowledge and ideas are isolated mini-concepts not building up to a whole theory. They are not consistent in their answers to different questions (in this case, mechanics questions). He proposed a strategy called the method of elaboration which included the following: prediction, reason, experiment, prediction, correct or not, and reason. This differs from normal procedure in the way that problems are treated simultaneously rather than consecutively to form a system of concepts rather than isolated ones.

2. Continuous

These methods are based on the students’ own correct, if naïve, conceptions. They are used as the starting point in the teaching process and are manipulated in such a way that they become more scientifically correct. The selection in Table 2 indicates the variety of approaches.
<table>
<thead>
<tr>
<th>General method</th>
<th>Analogy</th>
<th>Bridging analogies</th>
<th>Reinterpretation</th>
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<tr>
<td>Linking stages</td>
<td>Analogical relationship to unknown situation</td>
<td>(Correct) anchor conception</td>
<td>Reinterpretation</td>
</tr>
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<td></td>
<td></td>
<td>Bridges</td>
<td></td>
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<tr>
<td>Scientific conception</td>
<td>Scientific conception strengthened</td>
<td>Target conception now scientific</td>
<td>Scientific conception</td>
</tr>
</tbody>
</table>

Table 2  A selection of teaching strategies in the ‘continuous’ method
A rather different type of approach has been devised by Niedderer (1987). In this approach, established in the *New Philosophy of Science* (Brown, 1977), there is an attempt to allow pupils to realise that there is everyday knowledge and also specialized knowledge, for example, scientific knowledge (Scott *et al*, 1992). They learn the differences between the two and the approach consists of six steps:

1. Preparation: previous teaching about the topic and ideas and tools to be used.
2. Initiation: the problem (open-ended) is introduced.
3. Performance: this may include thinking of questions or hypotheses, planning and carrying out experiments, discussions of theory and bringing together findings.
4. Discussion of findings: this takes place as class discussion.
5. Comparison with science: A comparison is made with similar historical and/or modern ideas. Possible reasons for differences are discussed.
6. Reflection: pupils think about difficulties or questions that have occurred.

**Evaluation of teaching strategies**

McCasland (1987) found that ‘bright’ children resisted conceptual conflict curricula more than other pupils. This seems to be in direct contrast to Dreyfus, Jungwirth and Eliovitch (1990) who found that “bright successful students reacted enthusiastically to cognitive conflicts.” They especially liked the ‘flabbergasting effect’ of the approach. However, “unsuccessful students .... have been shown to develop negative self-images, negative attitudes towards school and school tasks and high levels of anxiety.” Because of this “they tried to avoid the conflicts. They were most characteristically apologetic when confronted with a conflict which, to them, seemed to represent just another failure” (pp 565-566). Stavy (1991) supports this latter view claiming that this type of approach can lead to loss of confidence for the pupil and also, sometimes, regression.
Cognitive conflict strategies do seem to be at odds with the ideas of constructivism. Constructivism depends on previous conceptions but if these are erroneous it is difficult to see how new correct knowledge can be constructed. This has been called the ‘paradox of continuity’ (Roschelle, 1991).

Some strategies require pupils to suggest alternative ideas and the teacher may have to suggest the scientific view, if it is not forthcoming from the pupils in order to bring it to the students’ notice. Far from being a disadvantage, Scott et al (1992) consider this to be a vital part of science education. Teachers have the task of initiating pupils to the ‘ways of science’.

The learning environment must be supportive of these strategies. Often, pupils who are not used to these teaching methods do not consider discussion of conflicting ideas as necessary or important since all they want to know is the correct answer (ibid, 1992).

A further problem in cognitive conflict strategies is whether the pupil appreciates that there is a conflict. Even minor changes in emphasis when discussing a problem can lead to pupils giving different explanations and they see no conflict in this (Minstrell, 1992).

It is relatively difficult to assess the success or otherwise of cognitive conflict methods since they are different in their aims from traditional methods. Wandersee et al (1993) are optimistic about such intervention studies but criticise the methodology in terms of “small sample sizes, untested methods, anecdotal records and relatively non-rigorous research designs lacking control group comparisons” (quoted in Duit, 1994, p 19). They add that hardly any of the studies have been replicated.

Continuous strategy methods are more teacher-led but include negotiation with pupils. This is a process providing scaffolding in the Vygotskian sense (see page
The pupils are carefully led to a deeper and broader understanding of scientific concepts from a rather tenuous but correct position. More details on the success or otherwise of this type of strategy, in particular, bridging analogies can be found in the section 2.1 which deals with previous research on this subject.

Guzetti and Glass (1992) seem confident of the success of this type of intervention (continuous or discontinuous), having carried out a meta-analysis of 70 intervention studies.

Most methods, whether of the continuous or discontinuous type, involve making the pupil aware of their conceptions. In contrast, Jung (1989) has investigated ways of changing conceptions without the pupil being aware of their preconceptions. However, Duit (1994) maintained that this type of strategy does not allow the students to be in control of their learning and to reflect on it in a metacognitive manner.

Metacognition

There are several interpretations of metacognition but the basic meaning is ‘thinking about thinking’, an ability associated with higher order thinking. It can be regarded in two main ways. One way is as a ‘going-beyond’ present reasoning ability. Adey and Shayer (1994) have suggested that this meaning is akin to ‘construction zone activity’. This term was introduced by Newman et al (1989) using Vygotsky’s idea of ZPD. However, Adey and Shayer have rejected this meaning and have concentrated on the notion of ‘going-above’ and being able to look at, name and reflect on one’s reasoning strategies. A possible reason for the confusion in meaning is that a ‘going-above’ often follows a ‘going-beyond’. A new rule or concept can be followed by a realisation of having discovered the rule.

An advantage of being able to metacognise is that a pupil can take strategies learned and used in one context and transfer them to another context. Without this
ability, complex thinking strategies would have to be reinvented for each and every context.

Review of Thinking Skills Instruction Programmes (Adey and Shayer, 1994)

Cognitive Research Trust (CoRT) - de Bono

de Bono (1976) introduced a set of 60 lessons for pupils aged 12+. It is based on a collection of heuristics for thinking which becomes part of a pupil’s strategy in solving new problems. It is context-independent and promotes divergent and lateral thinking. One problem with CoRT is that the pupils who would benefit most from the materials would be in the early formal operational stage or above i.e. an above average 14-15 year-old (at least one standard deviation above average), since it is only then that they could make good use of divergent thinking (Hudson, 1966). Although it became popular, the evaluations of the method have not yet proved it to be effective.

‘Philosophy for children’ – Lipman

Lipman, a philosopher who thought that reasoning patterns of discussion and argument lay at the heart of effective thinking, introduced ‘philosophy for children’ in America. It is based on a metacognitive approach where the child’s reasoning is made explicit and has remained popular since the early 1970s in the US. It is aimed at children of 10-16 years old. Evaluations have found it to be successful in teaching logical reasoning and there were significant (p < 0.001) gains in standard maths and reading tests (Lipman et al, 1980). However, there do not seem to have been any long-term follow-up evaluations.

Instrumental Enrichment (IE) – Feuerstein

This generally successful project was introduced to try to improve the self-concept, motivation and intellectual processing ability of Middle Eastern Jewish immigrants to Israel who had been traumatised by the holocaust. Feuerstein used the psychometric model of mental abilities (spatial relations, verbal reasoning etc.), Piaget, Information Processing Psychology, Cognitive Psychology and
Vygotsky’s idea of ZPD. The programme was context-independent but encouraged bridging to school subjects.

**Applied IE**

Context-delivered interventions include Mehl’s (1985) attempt to teach physics to a group of first-year medical students. This was based on an IE approach and was successful for the part of the course that had been treated this way. However, the students do not seem to have been able to generalise their thinking ability to other parts of the course.

Another example of applied IE is that of Strang’s study that supported Mehl’s results (Froufe, 1987; Strang and Shayer, 1993). This study concerned the teaching of chemistry to 14 year-olds using IE. They found that some of the pupils benefited a lot although some did not. The conclusions reached were that IE might have relevance in science teaching in concept understanding and in problem solving.

**Review of Intervention Studies (Adey and Shayer, 1994)**

There have been various intervention studies that have attempted to speed up the change from concrete to formal operational thinking. Many occurred due to the broader ability range of those entering universities in the US in the seventies. More students than before were still at the concrete level. These interventions were mainly Piaget based and included ‘Forum for Scientific Enquiry’ and ADAPT.

Some projects aimed to train pupils in one or two formal reasoning patterns and were not particularly successful in allowing pupils to transfer higher thinking patterns taught in one context to another.

Further studies have shown that, if pupils have the necessary thinking skills at concrete level but find these are not enough for solving a problem, they will
construct higher forms of reasoning that can be generalised. This is an example of metaconstruction where students construct their own ways of dealing with problems.

Cognitive acceleration through science education (CASE)

One of the more successful approaches towards improving achievement in science education has been through cognitive acceleration. CASE (Adey, Shayer and Yates, 1990) seems to have had far reaching effects beyond the implementation of the intervention in terms of both time and curriculum area. The project introduced activities taking up a quarter of the science timetable. These activities were science based although not necessarily part of the usual science curriculum. The pupils were aged 11-13 and covered a wide ability range. There were also control classes who carried on with their normal science lessons presumably being able to spend longer on each topic than the experimental classes. After two years there was no further intervention and all the classes were taught their normal curriculum, sometimes not as separate class groups and, indeed, sometimes not even in the same school.

Careful methodology was used in the project. Before embarking on the materials, both control and experimental groups were tested for their reasoning ability and again after the intervention, this time together with a science achievement test. In the long term, their GCSE (examinations taken at age 16) results were analysed for as many of the control and experimental pupils as possible. The results of their examinations in English and maths were included as well as their science results. The immediate post-test results were encouraging but it was the long term GCSE results which were most supportive of the intervention as the pupils of some of the experimental groups had, on average, achieved better grades than those in their matched control groups. This was significant for the girls who had started the intervention at age 11+ and for the boys who had started at 12+. This was true in all the subjects analysed.
The success of the project has led to many schools adopting the CASE philosophy or, at the very least, using some of the materials available (Adey, Shayer and Yates, 1989).

The key principles involved in the approach are based on the work of Piaget, Vygotsky, Feuerstein and others and are: cognitive conflict, reflection on thinking (metacognition), bridging (transference of a thinking skill learnt in one context to another context) and reasoning patterns. Higher-level thinking has been shown to have various characteristic sorts of reasoning. Some of these are control of variables, proportionality, equilibria, ascribing probability values to cause and effect relationships and understanding correlational relationships between variables (Adey, Shayer and Yates, 1990). The success of the approach owes much to the teachers having special training (Harlen, 1999).

Adey and Shayer (1994) have put together a set of desirable characteristics that any intervention to accelerate higher order thinking should have. These are (Adey and Shayer, 1994):

- Duration and density
- Concrete preparation
- Cognitive conflict
- Construction
- Metacognition
- Bridging

Summary
There are many aspects to consider in finding ways to permanently change pupils’ conceptions. Against a background of constructivism, there seems to be a choice between continuous and discontinuous methods. Both of these have advantages and disadvantages, and both have met with limited success. More general thinking skills need to be addressed including the concrete to formal operational thinking changeover.
1.3 Students’ conceptions and misconceptions

Kelly (1955) suggested that misconceptions are difficult to change since it would mean that one could not predict and have the possibility of controlling events if one were at some mid-way point between casting off the misconception and accepting the new conception. In fact, pupils may be reluctant to voice their ideas in case they had to test them before they were ready.

Smith, diSessa and Roschelle (1993), looking at research on misconceptions, put together several common threads (whilst recognising a wide diversity of ideas) as follows:

- Students have misconceptions.
- Misconceptions originate in prior learning.
- Misconceptions can be stable and widespread among students. They can be strongly held and resistant to change.
- Misconceptions interfere with learning.
- Misconceptions must be replaced.
- Instruction should confront misconceptions.
- Research should identify misconceptions.

The following misconceptions are under scrutiny in this research.

Heat misconceptions

Thermal equilibrium (Heat 1)

Scientific view - If objects are in a room of constant temperature for long enough, they will all attain and stay at room temperature. The objects will be in thermal equilibrium. A metal object may feel cold when touched because of heat transfer
from our warmer bodies to the colder metal object. Because metal is a good conductor of heat, heat transfer takes place quickly leaving our hand feeling cold.

Misconceptions - Many pupils do not subscribe to these ideas. Engel Clough and Driver (1985) studied 84 students over a full ability range (aged 12-16) from three city comprehensives in England. One of the tasks given was as follows. Students were presented with a metal and a plastic plate which they were told had been in the room overnight. Initially, they were asked whether a thermometer held in contact with the plates would read the same or differently. They were then asked to explain why the metal plate felt colder. For this task, only 6% showed an understanding that different substances feel different because heat travels through them at different rates. Some said that metal is naturally cold, possibly because of its smooth, shiny and hard surface. Some stated that the metal attracts cold or loses heat to the surroundings. Jara-Guerrero (1993), in his work with rural and urban elementary school children (aged seven to 11) as well as with high school students also identified the idea that objects have their own temperature. Brook et al (1984) found that students thought of the cold feel of the metal as being due to coldness entering the body from the metal. Of their sample of 300 fifteen-year-olds, 15% understood heat transfer when it was towards the body but only 6% understood it when it was away from the body. This may be partly due to everyday language. A person may say, “The oven burned me” which suggests that the oven has actively passed its heat to the person. No such statement applies to the passing of heat away from someone, in everyday language.

The conceptions of the older students were found to be more deeply rooted than those of the younger ones and thus more difficult to change. Jara-Guerrero (op. cit.) proposed introduction of the concepts at a much earlier stage than usual.
Radiation and absorption (Heat 2)

This misconception was chosen from direct experience. In tests and examinations, pupils often cannot recall the fact that good radiators of heat are also good absorbers of heat. Although this linkage can be demonstrated, it cannot easily be explained to 12-13 year-old pupils. This means that it is difficult for them to retain the information, as they have no model of what is happening. Pupils may associate it with ‘good conductors are poor insulators’ and retain the misconception of ‘good radiators are poor absorbers’ and vice versa.

Light Misconceptions

Reflection and scattering (Light 1)

Fetherstonhaugh and Treagust (1990) found, in their study of 47 pupils (aged 13-15), that approximately 25% believed that light remains on a mirror during reflection. Anderson and Smith (1983) discovered that, although about 60% of their sample of 227 thought that light does bounce off mirrors, they did not think that it bounced off other objects. Only two percent used the concept of scattering. This idea that mirrors reflect but other objects do not may come from everyday language in that people refer to reflections off mirrors but generally not to reflections of other objects. Guesne (1985) also found that most of the 13-14 year-olds in her sample thought that light is reflected by a mirror but stays on a piece of paper. However, in a written test situation, they were more likely to give a scientifically correct answer. In the interview situation they were relying predominantly on their visual perception as they were shown the mirror, torch and paper in action. This may be one example showing where practical work is capable of strengthening rather than replacing misconceptions. Alternatively, it may be a case of ‘teaching to the test’ or rather, in this case, the children giving the answer, in a test situation, that they think the ‘teacher’ wants even if it not really what they believe.
Teaching to the test

This is done to improve test results. If specifications are highly detailed, then there is a risk that:

we start out with the intention of making the important measurable and end up making the measurable important (Wiliam, 1998, p 165).

Teachers (and pupils) can make educated guesses at what will be asked since timed written assessment can test only certain aspects of certain topics (Wiliam, *ibid*) and this makes it very tempting to narrow teaching to only these few topics (Smith, 1991). Although this may have the desired short-term effect in that the results to that particular test may be improved there is no guarantee that the pupil has understood the relevant concept. He or she may just have been taught to answer a certain type of question. Certainly it is important to learn examination technique but if there is too close a match between teaching and testing this can destroy the measurement value of the test (Linn, 1981; Gipps, 1994). In order to retain it, then the concepts must be tested in new contexts. As Shepard (1991, p 9) says:

Tests ought not to ask for demonstration of small, discrete skills in isolation. They should be more ambitious instruments aimed at detecting what mental representations students hold of important ideas and what facility students have in bringing these understandings to bear in solving their problems.

Haladnya *et al* (1991) has pinpointed several sources of ‘test score pollution’ (where the test score is changed in a way which is not associated with the construct being measured) and one of these is how the teachers prepare students for tests.
That this practice does indeed increase test scores can be seen from the ‘Lake Wobegone’ effect. Cannell (1987) discovered that all 50 states in America had reported that their students had scored higher than average on the standardised tests, obviously a ridiculous state of affairs. Cannell suggested that one of the reasons for this might be teaching to the test and Phillips in his evaluation of the report (1990) agreed that test familiarity may well be one of the causes.

It is disputed as to whether teaching to the test is a good or bad practice. Tyler (1934) states that measurement of classroom achievement should be based on instruction (Airasian, 1988) whereas, since tests provide an idea of what is important, then ‘teaching to the test’ is sometimes acceptable (Airasian, 1987).

Crooks et al (1996) and others have used ‘impact’ to describe this process. They point out two threats to validity associated with impact. These are benefits which are not achieved such as progression, feedback and motivation and actual negative impact which might include a focus on learning facts at the cost of higher cognitive level results or, in other words, teaching to the test.

**Colour (Light 2)**

Zylbersztajn and Watts (1982) conducted a study where 150 thirteen-year-olds were asked why red light was seen to come from a red projector slide. Only two 2% used transmission ideas while about 50% assumed that the light had been changed somehow; some of these offering dyeing as a possible mechanism.

In Anderson and Smith’s (1983) study of 227 pupils, 61% thought that colour is just the property of an object and the light only helps our eyes to see the object. They thought that we see the object’s colour rather than the colour of the reflected light. Presumably, this is, at least partly, due to the fact that objects are commonly defined by their colour – people (even scientists) commonly refer to ‘a red car’ rather than ‘a car which is red when viewed in white light’.
Forces misconceptions

Balanced forces (Forces 1)

A principal difficulty with learning the scientific view about forces is the strength of the pupils’ existing conceptions. As has been indicated before, this is an area with which children are ‘familiar’ long before they come to school. It is this familiarity which has strengthened their misconceptions. In the topic of forces and motion much work has been carried out into children’s ‘alternative frameworks’ e.g. Driver (1989); Bliss et al (1989); Clement et al (1989); and Pfundt and Duit (1991). This topic of forces, probably more so than most other science topics, contains concepts that are almost contrary to common sense.

We should not express too much surprise at the ideas held by children and some adults since it is only relatively recently in the whole history of scientific thought that such notions have been replaced in scientists’ minds - notably by Newton. Earlier scientists and philosophers held views that were very similar to those held by pupils today.

Gunstone and Watts (1985) in Driver et al (1985) have reviewed the research work in this area and have picked out various similarities while at the same time acknowledging that there are many differences, not least in the psychology, philosophy and methodology used. These general similarities that they found were as follows:

- **Forces are animistic** An example could be that of an object ‘trying to fight its way upward against the will of gravity’ (Watts, 1983).

- **Constant motion needs a constant force** Newton’s 1st Law states that an object will continue in a straight line at a constant speed until acted on by another
force. Pupils ‘know’ that this is not true because they do not always recognise retarding forces such as friction (Gunstone and Watts 1985). Many pupils believe that a force is required to keep the object moving. It is not only children who have these ideas. Various studies with university physics students have shown evidence of this ‘rule’ (Viennot, 1979; Clement, 1982).

- A moving body has a force in the direction of movement. This can be thought of as similar to either Aristotle’s view or that of Buridan in the fourteenth century. If an object were thrown up into the air, Aristotle thought that the air around the object forced it on its way. Buridan’s idea was that the force was internal to the object and it was this ‘impetus’ which pushed the object until it was used up and the natural downwards motion took over.

- The amount of motion and force are directly proportional. Watts and Zylbersztajn (1981), for example, found that many pupils thought that as a ball is thrown upwards the force on it grows less until there is no force at all when the ball is momentarily stationary. Thereafter, gravity pulls the ball down. They see the force as having been ‘used up’ at the maximum height of the throw. In their study of 125, fourteen year-olds from comprehensive schools in Reading and London, England, they found that about 85% associated force and motion. This alternative framework Watts and Zylbersztajn have paraphrased as “if a body is moving there is a net force acting on it in the direction of movement. If a body is not moving there is no force acting on it” (p 362).

- A stationary body has no or only one force acting on it. Many pupils deny that forces are acting in an equilibrium situation. Since this is one area in which the research is focused, the existing literature will be reviewed in a little more detail. 76% of 112 American high school students (chemistry and biology students who could take a physics course the following year) thought that when a book was lying on a table, the table does not push up on the book (Clement, 1993). In their review of the literature, Driver et al (1994) found this notion to
occur in other studies. Even some of those who accepted an upward force thought the downwards force would be greater because otherwise the book would float away. Erickson and Hobbs (1978) found very few references to a 'reaction' force in their study of children's ideas about equilibrium.

Sometimes the 'reaction' force is associated with friction as Stead and Osborne (1981) discovered. Anecdotally, the author's own preliminary research showed this. Having studied a topic on friction the previous year, many were all too ready to suggest friction as being an opposing force to weight.

**Stretching (Forces 2)**

This misconception was chosen, again from direct experience. One of the GCSE (examination taken by sixteen year olds in England and Wales) coursework investigations in the sample school was concerned with stretching materials. Several pupils chose original length as the independent variable and extension as the dependent variable. Some were surprised to see that the extension and original length are directly proportional, thinking instead that the extension would be independent of the original length. In fact, most pupils avoided this choice of variable due to this misconception probably since they prefer there to be some interdependence of variables.
1.4 Misconceptions or phenomenological primitives (p-prims)?

Although the idea of misconceptions has been, at least until recently, uppermost in the field of research into pupil reasoning, there are questions as to whether it is the best tool for analysis and further investigation. Few would deny that misconceptions seem to exist but how have they arisen? In addition, misconceptions research does not help towards a theory of how pupils learn. Smith et al (1993) assert that much of misconceptions research is inconsistent with the ideas of constructivism. If we are to accept the idea that pupils construct new knowledge using existing knowledge, it is difficult to see how existing misconceptions can act as a basis for this. Nor does it explain how a small shift in emphasis in a question can lead to differing answers (Steinberg and Sabella 1997). Smith et al (ibid) suggest that one of the main faults of misconceptions research is the fact that it looks only at contexts where there is a failure in pupils’ conceptions and does not look at the large number of contexts where those same conceptions work adequately.

There are criticisms of misconception research for being embedded in the framework of scientists where scientific terminology and meanings are used rather than those of pupils (Vienneot, 1985). An example is the use of the concept force; this can mean different things to a novice and expert. It should not be interpreted that they mean the same thing by using the word.

Smith et al (1993) also criticised the ‘replacement of misconceptions with scientific conceptions’ idea. In their review of misconceptions research, they found much of it to either explicitly or implicitly refer to replacing conceptions. Often, this replacement is based on a one-to-one process but it is suggested that this is not sound. If there is to be a one-to-one replacement, then this can only take place if misconceptions are simple, neat, independent elements that can be replaced (Figure 4a). It is likely that they are more complex than this and cannot be simply replaced. In Figure 4b the ‘misconception’ is shown as being an overlap
of many related ideas. The ‘correct’ conception is also an overlap of related ideas although not all the same ones as the misconception.

Figure 4a Simple replacement view

Figure 4b More complex replacement view
1. “Students have misconceptions” becomes “novice conceptions are faulty in many specific contexts, but casting misconceptions as mistakes is too narrow a view of their role in learning” (p. 69). Smith et al (ibid) suggest that novice and expert knowledge systems share many features in terms of form and content and that comparisons have not been fairly conducted.

2. “Misconceptions originate in prior learning” becomes “misconceptions are faulty extensions of productive prior knowledge” (p. 70). It may be better to term students’ conceptions as productive or unproductive rather than right or wrong. The conceptions they have are right in certain contexts; it is just that they have, perhaps, overgeneralised the contexts in which they are relevant. This fits in with constructivism in that new knowledge is refinement of previous knowledge as the mind interacts with incoming information.

3. “Misconceptions can be stable and widespread among students. They can be strongly held and resistant to change” becomes “misconceptions are not always resistant to change. Strength is a property of knowledge systems, not individual misconceptions” (p. 71). It is not always difficult to change misconceptions with the right teaching approach as is shown, for example by Brown and Clement’s use of analogy (1989).

4. “Misconceptions interfere with learning” becomes “interference’ is a biased assessment of the role of novice conceptions in learning. Though they may be flawed and limited in their applicability, novice
conceptions are also refined and reused in expert reasoning” (p.71). It is possible to pick out productive conceptions and use them as anchors to further learning (Clement et al, 1989).

5. “Misconceptions must be replaced” becomes “replacing misconceptions is neither plausible nor, in all cases, desirable” (p.72). Mere replacement of concepts again goes against constructivist views as it presupposes that different conceptions can be added in a kind of tabula rasa way. Different conceptions will need to be added as modifications to present knowledge in a way such as bridging analogies with their anchoring conceptions. The present ‘misconceptions’ should not, even if it were possible, be erased as they will serve to be useful in different contexts.

6. “Instruction should confront misconceptions” becomes “instruction that confronts misconceptions is misguided and unlikely to succeed” (p.73). Pupils need to have confidence in their abilities and confrontation will not help this. Nor is it likely to succeed, as it will confuse them even more. Their conceptions are valid in some contexts. Surely it is more helpful to gradually lead them forward using more productive anchoring conceptions.

7. “Research should identify misconceptions” becomes “it is time to move beyond the identification of misconceptions” (p.74). Research is needed to find out how experts have come to their understanding in various areas.

Vosniadou (1994) and others believe that pupils have a set of specific well-developed coherent theories which interlink with other theories set against a background of a framework theory which regulates the way in which phenomena are processed. This framework includes pupils’ epistemological and ontological ideas about the world. Work has been done on naïve theories. For instance,
McCloskey (1983) stated “people develop on the basis of everyday experience remarkably well articulated theories of motion” (p 301). These theories are very similar to the impetus theory which was an acceptable theory in the Middle Ages. He came to this conclusion from several experiments that he and his colleagues carried out. They put together various problems on motion which they then tested on students who answered problems before being interviewed in depth. The students had studied physics to various levels. McCloskey maintains that 11 out of the 13 students interviewed had a well-developed, if naive (scientifically), theory of motion which they used in the explanations they gave. This theory he called a naive impetus theory and it is based on two main ideas about motion:

1. Setting an object in motion imparts an internal force or impetus to it which maintains the motion.
2. The object’s impetus gradually slowly dissipates of its own accord or due to outside influences. Because of this the object slows down and stops.

McCloskey quotes from the interviews to support the use of an impetus theory although he does suggest that there are individual differences in the students’ use of the theory. To exemplify the first idea:

Momentum is ... a force that has been exerted and put into the ball so this ball now that it’s travelling has a certain amount of force ... (p 307). (This was from a student who had completed one year of college physics).

A comment in accordance with the second idea is:

I understand that [friction and air resistance] adversely affect the speed of the ball, but now how. Whether they sort of absorb some of the force that’s in the ball ... I’m not sure. In other words, for the ball to plow through the air resistance or the friction, if it has to sort of expend force and therefore lose it, I’m not sure .... That seems to be a logical explanation. (p 307) (This was from someone who had never taken a physics course).
Vosniadou has similar ideas about children’s ideas. She claims that there is a *framework theory of naive physics* (Vosniadou, 1989b) which restricts the course of acquiring knowledge about the physical world. This framework is not open to the conscious mind or to hypothesis testing. Against this background are *specific theories* which are groups of interconnected propositions or beliefs about the properties and actions of material things. These specific theories are produced from observation or from information given by the culture surrounding the subject and lead to the beliefs which can, in turn, further constrain the knowledge acquisition process.

The specific theories lead to mental models which are used during problem solving activities. They are generated to give explanations and predictions. An example of the interrelationship of a framework theory, specific theory and mental model is shown in Table 3.

Misconceptions occur when pupils attempt to resolve contradictory bits of information, thus producing a faulty mental model (Vosniadou, 1994). One example of this is where some young children think that the Earth is a flattened sphere. This they get from trying to assimilate the idea of a sphere (that gravity is not up and down on the Earth but towards the centre) with their observations that the Earth is flat rather than curved. Assimilation will not work in this case; there needs to be a complete revision of basic tenets not a partial one. In other words, accommodation needs to happen.
Table 3 Hypothetical conceptual structure underlying initial mental models of force (Vosniadou, 1994, p 61)
However, diSessa believes that, although uniform results are sometimes obtained, mostly there is not the systematicity of a scientific theory (diSessa, 1993). Individuals are not systematic in their ideas and views differ between people. Even potentially promising candidates like the impetus theory are too limited in context.

There are other researchers, for example Hammer, 1996, diSessa, 1993 and Minstrell, 1992, who suggest that pupils, rather than accessing stored ideas or constructs as the misconceptions advocates believe, actually construct ideas at the time. These ideas will be based on other knowledge (Hammer, 1996). An example of this could be the ‘misconception’ that it is hotter in summer than winter because the Earth is nearer to the Sun in summer. For this to be a misconception, it must be part of the pupil’s knowledge system. Alternatively, it could be seen that the pupil uses elemental pieces of knowledge such as ‘moving nearer to a heat source (the Sun in this case) would make something (the Earth in this case) hotter’ to construct an answer there and then.

Work done by diSessa (e.g. 1993, 1996); Minstrell (1992); Tirosh et al (1998); and Hammer (2000) has suggested the use of these small elemental pieces of reasoning. These elements are, on the whole, common to both expert and novice alike; the difference comes from the ability to use the elements at the right time in the right context.

Minstrell (1992) denotes these pieces as facets which he draws from students’ comments as they reason, predict and explain and he places the facets into clusters for different topics. His facets are practitioner based with the idea of diagnosing faulty reasoning and with a view to remedying it. The facets can be content-based, strategy-based or reasoning-based. He clusters together facets which are associated with a particular idea. The goal facets are the scientific ideas being aimed for and the mental model facets are the general ideas which could be referred to as misconceptions. Alongside these are more specific facets originating from the
mental model or even resulting from a faulty understanding of instruction. An example of one of these clusters is shown below (Minstrell, 1999)

- 410 Balanced forces on an 'at rest' object (vector sum is zero).
- 411 At rest and constant velocity are relative.
- 412 "Balanced forces" cannot apply to both constant velocity and constant position conditions of motion.
- 418 Constant position requires a bigger "preventer force."
- 418-1 Requires a bigger "hold back" force.
- 418-2 Requires a bigger "hold up" (support) force.
- 419 Constant position requires a bigger "hold to/hold down" force.

He explains the apparent disparity between answers to questions that physicists would perceive to be almost identical by suggesting that different emphases in the questions promote the application of different facets. He concludes that there is a fair amount of consistency in pupils’ answers viewed from this angle rather than that of the physicist. An example he gives is as follows. One facet pupils may use is ‘passive objects do not exert force’. Minstrell and Stimpson (1986) analysed answers students gave to several questions involving the relative sizes of forces during interactions. One of the questions involved a bowling ball colliding with a bowling pin. Some students chose the answer ‘only the ball exerts a force’ and it was decided that these students had chosen this answer because the ball was considered to be active while the pin was passive, triggering the above facet. They then looked at how these students had answered the other six questions. The percentage of those who gave answers which suggested that particular facet averaged at 88% showing high consistency.

Minstrell claims that that many of pupils’ facets are useful and correct in some contexts but they tend to be over- or under-applied. Instruction can build on pupils’ present facets to limit or generalise their contextual use as appropriate. During instruction new facets may added, facets may be modified to extend or restrict their application and more complex interfacet relationships are built.
Minstrell has introduced the DIAGNOSER (2002) program to diagnose problems and prescribe routes of instruction.

diSessa (1993), along the same lines as Minstrell, concentrated on part of physics knowledge that he denotes as sense-of-mechanism. This is concerned with interaction with the physical world and allows us to predict and explain events.

He called his theory ‘knowledge in pieces’ and the knowledge elements that go to make up the sense-of-mechanism construction he called phenomenological primitives (p-prims). These are the very basic notions that pupils hold which have arisen from their interaction with the world. They are even more elemental than Minstrell’s facets. When faced with having to explain a phenomenon, p-prims are ‘cued to an active state’ depending on the context. Whether they remain active depends on the subsequent chain of mental events.

Each person has many hundreds or thousands of p-prims that can be cued quite readily. They can be thought of as primitive ‘explanations’ in that they are axiomatic and they are phenomenological in that they are based on our direct experience of the world. They probably arise from simple abstractions of a familiar event. Similar events are then ‘explained’ by the p-prim.
DiSessa (1993, 1996) has given a number of characteristics of p-prims and these are summarised below.

P-prims are:

- Small knowledge structures
- Invoked as a whole (non-splittable)
- Numerous
- Difficult to systematize
- Simply recognised/invoked in certain situations
- Sometimes quite context specific
- Plausible and feel natural
- Fluid. A change in direction of attention shows the fluidity of p-prims. A slight alteration in perspective may change the p-prim cued, sometimes, seemingly with no problem to the observer who may see no conflict in the inconsistencies present. This is another indication that p-prims do not coalesce to form concepts, beliefs or theories since, if they did, surely the inconsistencies would be apparent and thus cause conflict.
Data driven

Unable to resolve conflict even if it is noticed

Difficult to verbalise. P-prims are difficult to verbalise since they originate at a much more basic level than language. The level proposed is visual or kinaesthetic. This is perhaps why pupils learn much through experiment with the proviso that they are guided to observe relevant features and pick up the right clues; in other words, to cue the correct p-prims. Unguided experiments are likely to strengthen already strong and possibly incorrect p-prims.

Minimal abstractions in origin

Often superficial interpretations of experienced reality

Developed by reorganization

Not totally removed by learning

Strengthened or weakened in learning (sometimes new ones are produced)

'Explanations' in themselves for naïve subjects

Small, contextually bound parts of concepts and theories for experts

Possibly able to serve as examples of scientific principles for experts

Instrumental, e.g. push harder for greater effect, for naïve subjects

Able to cause surprise if violated and thus may promote learning for naïve subjects

Usually diverse but may be loosely related and may generate new p-prims called p-syllogisms. Families of p-prims may produce meta-p-prims which can cover a wide range of situations. It is possible that sometimes p-prims do come together to form relatively stable arrangements that give so-called intuitive theories such as the 'impetus' theory described by, for example, McCloskey (1983).

In changing from novice to expert (terms used by diSessa to roughly indicate competence levels), diSessa suggested that some p-prims become used more and some used less. With novices, the p-prims have different priorities but there are none with comparatively very high priority. DiSessa proposed that, during the
novice to expert change, some p-prims are greatly reduced and some greatly increased resulting in more structure round central high priority p-prims. New p-prims may develop and old ones are probably never completely extinguished but some may take on new functions, e.g. they may come to cue some formal knowledge or procedure (diSessa, 1993, Sherin, 1999). This is represented in Figure 6 where the novice has several p-prims associated with a particular topic which could be cued. They are all reasonably likely to be cued as they all have a similar strength. Which is cued will depend on several factors including the context and any particular emphasis in the question asked. In contrast, the expert’s p-prims are of different strengths and it is more likely that the correct one (high priority) will be cued. It will depend less on the context or emphasis in the question. Of course, the other p-prims still exist and could be cued in certain circumstances – experts are not infallible.
Figure 6 P-prims in novices and experts
Sherin (1999) stated the view that p-prims can come to cue actual equations, missing out the intermediate stage of formal argument. However, more generally, he suggested that ‘symbolic forms’ develop. These are a new type of knowledge which bridge p-prims and equations and are made up of a ‘conceptual schema’ - the idea to be expressed and a ‘symbolic template’ - how to show the idea in symbols. Symbolic forms generally apply to a wider set of contexts than p-prims and have less concrete meaning. The idea of proportionality is one example.

In conclusion, Sherin (1999) decided that, although intuitive ideas do need some changing, they do not need too much adjustment as physicists can use equations in problem solving. He seems to be suggesting that problem solving and modification of intuitive conceptions complement each other.

Concepts can be regarded as a set of coherent statements about things. Beliefs select what you believe to be true about the interactions of concepts and theories can be considered to be a “complex but connected fabric of concepts and beliefs” (diSessa, 1996, p 4 of manuscript). P-prims form a level beneath concepts and, until learning has taken place, it is unlikely that there will be enough strong p-prims in the same area to link together to form anything resembling a concept.

Since p-prims are so diverse, it is difficult to provide exemplars of them. However, some are more central and important than others. One such is Ohm’s p-prim which was discussed on page 17. P-prims pertinent to this research will be explained in section 6.2.

diSessa points out that deep conceptual learning is unlikely to occur unless there is extended, cumulative and systematic experience with a concept (1994). A short lesson aimed at conceptual change of an idea is obviously not going to be sufficient. The lessons planned for this research are short and can no more than scratch the surface. However, if more relevant p-prims can be cued, then it can be counted as a success.
P-prims are not the only knowledge type, argues diSessa (2002). There are also co-ordination classes which are much bigger and more complex than p-prims. They probably include p-prims and, unlike p-prims, can be considered as a model of at least one type of concept. They may not be present in naive thought as such. Their function is to enable one to extract and use information about the world. diSessa identifies two main categories of co-ordination class comprising readout strategies (methods of extracting information) and the causal net (possible inferences from the information). As diSessa (2002) points out; “the development of a co-ordination class is an extended and complex affair” (p 18). The present research is concerned with the cueing of p-prims using analogy rather than with the development of full-blown concepts and so the discussion of co-ordination classes will be left at this point, being aware that they exist but also that they are beyond the requirements and scope of this study.

**P-prims and constructivism**

If p-prims are to be considered a valid constituent of knowledge and learning and if a constructivist approach is taken as a backdrop to learning theory, then it is necessary to be assured that p-prims and constructivism are complementary. Smith et al (1993) suggest that this is so in the following two ways:

- **Conceptions must be functional in order to fit in with constructivism.** If misconceptions exist, then they must have been functional, that is, must have worked in some contexts. This is easy to see if ‘misconceptions’ are produced by p-prims being cued. The p-prim has come into being at a very early stage as an abstraction of a familiar event. It is then used to describe other events, sometimes correctly and sometimes wrongly.

- **Constructivism maintains that new knowledge is continuous with and therefore dependent upon previous knowledge.** Instead of the notion of
replacement of misconceptions there emerges the suggestion of knowledge refinement where pupils’ ideas are gradually used in correct contexts. In this view, there are no such things as misconceptions but just misplaced conceptions.

This latter point reinforces the efficacy of subscribing to the theory of p-prims in that it removes the ‘paradox of continuity’ (Roschelle, 1991). This, as has previously been stated, describes the following paradox: constructivism depends on previous knowledge but if this previous knowledge is erroneous it is difficult to see how new correct knowledge can be constructed. In the theory of p-prims, the correct knowledge is usually present but as a low priority p-prim. It is up to teachers to change the priority of the p-prim so that it becomes a high priority p-prim in that particular context.

Further assurance on the complementary nature of fine-grained theories such as p-prims and constructivism comes from Elby (2000). He points out that in this theory, pupils’ small unit ideas never entirely die out; in other words they will contribute something to experts’ reasoning.

At this stage it should be noted that there are other ways of viewing conceptions such as using ontological categories (Chi, 1992; Chi and Slotta, 1993; Ferrari and Chi, 1998; and Slotta et al, 1995). There are three main ontological categories: matter, processes and mental states. Each of these has sub-categories. There is evidence that pupils miscategorise conceptions. For example, heat flow is taken by scientists to fit into the process category where energy is redistributed but pupils may take the ‘flow’ to be more literal, describing something in the matter category. Another example, suggested by Vosniadou (2002) as being similar, is when children recategorise the Earth as an astronomical body rather than a physical body, similar to the shift from Ptolemy’s view to that of Copernicus.
These theorists do not argue with most of diSessa’s theory of p-prims, seeing them as examples reflecting ontological attributes (Nasr, Hall and Garik, 2003). They see ontological categories as adding more coherence and structure to p-prim theory.

Johnston (2000) has suggested that the mind organizes concepts, in ontological categories, in a way which is more systematic than p-prims would imply but looser than theoretical frameworks. These ontological categories might also suggest a basic similarity in how many misconceptions arise.

**Misconceptions or p-prims? – practical research**

There appears not to have been much empirical research done in this area. One piece that has been carried out was by Elby (2000) who considered how the two theories would or would not predict results that pupils would give to physics questions involving velocity-time graphs. Human beings are hard-wired to pick up on visual clues like edges, corners and motion (Churchland & Sejnowski, 1992) as they are useful to survival and these are known as compelling visual attributes. This reasoning can be applied to soft-wired perception mechanisms such as representational graphs.
The questions given were as follows (Elby, 2000, p.11):

![Speed-time graph of cars A and B](Image)

Figure 7 Motion of cars A and B (speed/time graph)

Cars A and B start at the same position and move according to the graph of speed versus time [Figure 7].

a. Is car A going forward or backward? What about car B?

b. What happens at time T1? Circle the correct response.
   
i. Car B is ahead.

   ii. Car A is ahead.

   iii. Neither car is ahead; car B and car A cross each other.

Elby argued that if the misconception theorists were correct then there could be no prediction made as to which question a pupil would answer wrongly if the other question was answered correctly. A misconceptions theory could predict only that the correct scientific conception would lead to two correct answers and the misconception to two wrong answers but that the ‘one right, one wrong’ would be random. On the other hand, if the fine-structure theorists were correct, for the ‘one
right, one wrong’ group more would answer the second question wrongly and the first question correctly than the other way round. This was because the most visually compelling attribute was the crossover (corner) and this would cue the wrong answer for the second question. His findings supported this latter view although his study was on, what he himself claims, a very small sample. Another, similarly small, sample gave comparable results. As another method of approach he used a transcript of an interview with two pupils looking at a slice graph of brightness on part of the Moon. Again the fine-structure theory would predict a definite pattern in pupils’ responses to questions and the interview answers did point to this interpretation.

It may seem that these two viewpoints (that of the misconception theorists and that of the fine-structure theorists) are contradictory but it may be that, with repeated usage, the explanations constructed from p-prims become stable cognitive structures. If the same p-prim is cued each time, it will strengthen to such an extent that, in effect, it becomes a stable cognitive structure (to become a misconception or correct conception). Perhaps it is when different p-prims have a similar strength and have a similar likelihood of being cued, depending on context, that no stable cognitive structures are formed and explanations are being constructed spontaneously. (See Figure 8) It may be that p-prims and misconceptions are just the extremes of a spectrum.
Implicit Learning

It is possible that cueing p-prims is linked with the 'implicit learning' which Cummings (1998) describes. This implicit learning is automatic and requires no effort. An instant response to a stimulus can follow from this type of learning. Driver (1983) and others talked about beliefs or intuitions as if they were deliberately constructed as the child tries to make sense of the world. However, Cummings argued that intuitions might have arisen through implicit learning. An example that Cummings used is that of thinking that a force is always needed to keep an object moving at a constant velocity. She suggested that the implicit learning has come about as a result of many kinaesthetic experiences.

Conclusions and framework for this research

This section has reviewed the ideas of misconception theorists and fine-structure theorists and has pointed out that misconception theories are less compatible with constructivism than are fine structure theories. It has reported practical research
which supports the fine-structure theorists. It has also been tentatively suggested that p-prims which are repeatedly cued could become misconceptions.

The framework taken for the present research is mainly that of the fine-structure theorists. However, it is accepted that there may be areas where some fairly stable naïve theories exist especially in the topic of forces and, in fact, this may influence the results gained from investigating the different topics.
1.5 Analogies in general

History of analogy

There are many examples of famous scientists using analogy. Amongst those most often quoted are Kepler who used the analogy of clockwork in explaining planetary motion and Priestley who linked electrical forces to the well understood law of gravitational forces by analogical reasoning (Glynn, 1991). Einstein used the analogy of a person riding in a lift to explain relativity so it could be understood without recourse to difficult mathematics.

Campbell argued that analogies are not merely aids to establishing theories but of absolute importance throughout the life of the theory (ibid). In addition, Oppenheimer viewed analogy as indispensable for coping with a new discovery since it is impossible to “deal with it except on the basis of the familiar and the old-fashioned” (Oppenheimer, 1956 (pp 129-130). He also recognised that mistakes would be revealed using analogy.

What is an analogy?

Analogy is a way of linking different concepts by pointing out the similarities between them. These similarities could be surface similarities, e.g. colour or shape or deep structure similarities, e.g. the similarity of both the retina in the eye and the film in the camera being light-sensitive surfaces. Glynn(1991) suggests that analogy leads to meaningful learning, which has been defined by Wittrock (1985) as a “student generative process that entails construction of relations, either assimilative or accommodative, among experiences, concepts and higher-order principles and frameworks” (pp 261-262).
The familiar concept is known as the analogue and the unfamiliar one as the target. The characteristics of the analogue and target are viewed and the similar ones identified and linked.

Both the analogue and target are subordinate to a superordinate concept which is sometimes easy to identify as in the water circuit / electrical circuit analogy where the superordinate concept would be ‘circuit’. However, it is sometimes more difficult to identify; an example being the analogy between the camera and the eye. Glynn (1991) maintains that naming the superordinate concept is important as it can suggest other analogies and also allow the student to generalise their ideas and to apply them to other contexts and domains.

Advantages of using analogies (Boo and Toh, 1997)

1. They are valuable tools in conceptual change learning.
2. They provide visualisation and understanding of the abstract by comparison with the concrete, real world.
3. They may motivate pupils.
4. They make the teacher take into account pupils’ prior knowledge.
5. They may reveal misconceptions.

Treagust et al (1990) give another advantage of analogies. They allow the target and analogue domain to be interchanged in order to further the teaching and understanding of both. They cite an example of a teacher who used the analogue of the gravitational field to introduce the electric field but then swapped the analogue and target roles quite a few times so the pupils could use characteristics of each type of field to work out characteristics of the other. Thus the learning of both types of field was facilitated by using them as analogues of each other.
What makes a good analogy?

Glynn (1991) gives three criteria for the success of an explanatory analogy:

1. As the number of features compared increases, this often improves the analogy.
2. As the similarity of the features compared increases, so does the analogy.
3. The greater the conceptual significance, the better the analogy.

Glynn (ibid) gave three requirements for pupils when using analogy:

1. The pupil must understand the analogue.
2. The pupil must agree with the plausibility of the analogy.
3. The pupil must be able to apply the findings from the analogue to the target.

English and Halford (1995) emphasise the need for clarity as to which features of the analogue and target can be mapped or even compared. Irrelevant features of the analogue can often lead to misconceptions. It is also important to make sure that the features which are compared are similar enough to be compared without confusion (Glynn et al, 1989).

Halpern et al (1990) discussed whether it is better to have the analogue and target from within domains or from different ones. They thought that the different domains would be better mainly because there was too much literal similarity when the analogy was across similar domains but presumably enough differences to make it confusing. They did find that the participants in their study did better when the analogue and target came from different domains and they suggested that when the analogy crossed domains it needed more mental effort from the subjects with more restructuring of schemata which leads to a greater degree of recall. However, analogies within the same domain are extremely useful for pupils so that they can connect associated concepts and construct conceptual systems (Glynn, 1991).
In addition to an analogy being an aid to understanding, it should be able to predict, as did Einstein's lift analogy that predicted that light should bend under the influence of gravity; a prediction which proved to be correct.

**Difficulties and disadvantages of using analogies**

In order to know whether an analogy is going to be useful, it is important to examine disadvantages of analogies. Thiele and Treagust (1995) have discussed some of these potential problems.

- Pupils may take the analogy too far and confuse the analogue and target. Teachers must be careful to point out where analogies collapse, as all do at some point. If this is not done, then pupils will start to infer similarities where none exist.
- Pupils may remember only the analogue and not the target.
- Pupils may concentrate on attributes of the analogue that are not pertinent and thus conclude wrongly about the target.

Duit (1991) points out several more difficulties which may occur. These are.

- Pupils may not understand the base domain well enough and may have misconceptions about it. These will leak over into the target domain. However Spiro *et al* (1989) point out that using multiple analogies may help in this respect in that they could avoid mistakes induced by a single analogy. Wong (1993) agrees with this. Multiple analogies are also useful as they may help with different parts of the target domain (Gentner and Gentner, 1983).
- If there is not enough teacher guidance, there may not be understanding of the analogy.
• Analogies are accessed through surface similarities and through deep structure similarities but it is only the latter which provide the inferential power of the analogy.

It is imperative that teachers think carefully about their use of analogy and how they present it to their pupils.

Theories of analogies

Structural theories

This research is not concerned with classical analogies (of the type A : B :: C : D1, D2) as such. It is dealing with A : B type analogies. However, it is important to review the research on this type of analogy as it provides more assurance that using analogy is valid in this research. Aristotle defined this sort of analogy as “an equality of proportions … involving at least four terms … when the second is related to the first as the fourth is to the third” (Aristotle, Metaphysics as quoted in Goswami (1992), p 4). The relationship between the A and B terms is identical to that between the C and D terms. Until recently, it had been accepted that there are two levels of reasoning involved in the use of analogy of the type A:B::C:D, e.g. pig : boar :: dog : wolf. The lower order is the relation between A and B and between C and D. The higher order is the link between the pairs in the analogy. The latter requires knowledge of relational similarity.

One of the main proponents of structural theory was Piaget. He proposed that from the onset of concrete operational reasoning at about age seven, children could start reasoning about relations between objects in class inclusion problems. They would be able to reason in a successive way. This means that they would see the link between A and B but go on to find possibly a different link between C and D (the term they have to choose). It would not be until the onset of formal operational reasoning at about 11, that they would be able to start reasoning about the
similarity between the pairs of terms and be able to use the relational similarity constraint.

If Piaget’s claims that only those at the formal operational stage should be able to reason analogically were correct, then the basis for using analogy in this research would probably not be valid. Although the pupils in the research are 12-13 years old, it is now generally acknowledged that the formal reasoning stage is reached much later than this age by many pupils and some never attain it. However, Piaget’s claims that analogical reasoning occurs only at this stage have been refuted by, for example, Goswami (1992) as indicated below.

The structural theories depend on several assumptions:

1. Higher and lower order relations can be easily distinguished.
2. Children know about the relations involved.
3. Children understand that they are supposed to use the idea of relational similarity.

These assumptions will now be discussed in more detail.

1. Goswami (1992) argues that it is not possible to distinguish higher and lower relations and that it can be said that all classical analogies have the same higher order relation in that it is the similarity of the lower order relations.

2. It cannot always be assumed that a child will know about the relations in an analogy. It would not be fair to assume that a child does not have the ability to think analogically unless we are sure that he or she has the necessary relational knowledge.

It has been found that even young children (three – four years-old) can understand physical causality such as cutting, wetting and melting (e.g. Bullock et al, 1982; Das Gupta and Bryant, 1989; and Schulz, 1982). This has been used as a basis to
test Piaget's claim that analogical reasoning is a formal operational skill. It was found that, as long as children have the necessary relational knowledge, they could solve analogies before reaching the formal operational level (Goswami and Brown, 1989).

3. It cannot be taken for granted that pupils know that they have to use the relational similarity constraint. Again, it would seem wrong to conclude that children could not think analogically just because they did not realise that the relational similarity concept was an integral step. It would be like concluding that children cannot play chess. Of course they cannot unless they have had the rules explained to them. Only then could you begin to gauge their ability.

Further arguments against Piaget include the idea that proportional reasoning is necessary for analogical solving. Levinson and Carpenter (1974) gave their subjects such analogies as ‘foot : inches :: minute : ?’. If the child could give the correct answer (seconds) and explain the links within and between each pair, they were deemed to understand proportional reasoning. However, this is only another way of testing whether the children can use the relational similarity constraint and is unlike Piaget’s proportional understanding. This was the awareness of the equality of two ratios, $x_1/y_1$ and $x_2/y_2$. Where researchers have tried to investigate the connection between Piaget’s proportional understanding and the ability to use analogy, there was still the problem that the children may not have had the relational knowledge necessary (Lunzer, 1965).

Research (Goswami, 1989) has found that, if perceptual understanding of proportion was involved, then there was a link with analogical reasoning and this could be shown at a young age (pre-formal operational). If it is a logical understanding of proportionality – definitely a formal operational skill, then there does not seem to be any close linkage in the development of these skills.
Young children will often accept counter-suggestions to their (correct) answer. Piaget thought that this meant that they do not understand the relational similarity constraint rule. However, it may be that children do not wish to contradict those whom they perceive as having superior knowledge (teachers, researchers or adults in general). The linked idea is that children solve analogies by associative rather than analogical reasoning. By including associative distracters in the set of possible answers, it was found that even young children tended to choose the analogous rather than the associative response (Goswami and Brown, 1990).

Knowledge-based accounts of analogical reasoning

The research mentioned above has refuted Piaget’s claims that reasoning by analogy is a formal operational skill. Indeed, very young children can reason analogically if they understand the relations involved and that they should be using the relational similarity constraint.

The knowledge-based theories of analogical reasoning put forward by such as Brown (1989); Gentner (1989); Goswami (1989); Goswami and Brown (1989); and Vosniadou (1989a) claim that it is the depth of a child’s conceptual knowledge that indicates the potential for analogical success. Apparent shifts are due to increasing knowledge of the child and these theories do not predict sudden changes but rather a gradual improvement. Goswami (1992) argues that the ability to understand relational similarity may be present in children from early infancy. The difficulty of the relations and performance factors, e.g. distraction by other test factors will apply more profoundly to younger children and will be the only limit to the child’s ability to apply the relational similarity constraint.
Information processing framework

The arguments above have related to the question as to whether children still in the concrete operational stage can understand and use analogies. The next problem is to look at how analogical reasoning works.

Sternberg (1977) is credited with the first Information Processing (IP) framework suggesting how analogical reasoning may work by postulating component processes. These components for A: B :: C: D1, D2 were encoding, inference, mapping (optional), application, justification and response.

1. Encoding This involves perceiving each term and accessing their attributes or properties in semantic memory. This is the part of memory which refers to a structural set of facts, skills and concepts that each person has accumulated.

   ![Diagram of Encoding]

   Perceive each term and access attributes

2. Inference This involves discovering the relationships between A and B from their attributes and holding them in working memory.

   ![Diagram of Inference]

   Discover relationships

3. Mapping (according to Sternberg (ibid), this step is not absolutely necessary in analogical reasoning). If used, it represents discovering the link between the A and C terms.

   ![Diagram of Mapping]

   Discover link
4. Application This involves applying an analogous relation from the inference step (2) to between C and the choices D1 and D2 to see which work.

\[ A : B :: C : D1, D2 \]

Use relationships inferred .... to test similar relationships

5. Justification The subject must justify any decision to his- or herself.

6. Response Finally, the subject must respond to the question.

Both inference and application are measures of relational knowledge and application is also a measure of the understanding of the relational similarity constraint.

Sternberg and Rifkin (1979) discovered that all age groups used encoding, inference, application and response but that younger children (aged eight) did not use the mapping component, which, according to them, involves a higher order relation between two relations. Thus, they came to the same conclusion as the structural theorists but for different reasons. However, Goswami (1992) argues that, as mapping is not necessary for analogical reasoning, then we cannot say that not using mapping means that the child cannot use relational similarity. She also maintains that mapping does not measure higher-order similarity and that it is the application step that most nearly resembles the use of the relational similarity constraint.
Models for teaching analogies

The general model of analogy teaching

Zeitoun (1984) developed a model for the use of analogy. This model involved several steps including the following:

- Assessing the pupils' prior knowledge about the topic.
- Analysing the learning material of the topic.
- Judging the appropriateness of the analogy.
- Determining the characteristics of the analogy.
- Selecting the strategy and medium of the presentation.
- Presenting the analogy.
- Evaluating the outcomes.
- Revising the steps.

Duit (1991) regards this model as being somewhat pragmatic and not linking well with the theory which he developed. Also, it does not communicate the importance of knowledge about the base domain. As Duit points out, this is of vital significance since misconceptions in the base will probably transfer misconceptions to the target. Duit's final comment refers to a shortage of examples given. There are not enough to make it possible to test the model's usefulness.

Gentner's structure mapping theory

Gentner (Gentner, 1989, Gentner and Markman, 1997) proposed a model for analogical reasoning that consisted of four steps. It is accepted that the person understands the relational structure of the base domain. This relational net is composed of various items. At the bottom, in the most basic level are the objects. If one were discussing the relational net for electric circuits, the objects would be
the physical parts of the circuit, e.g. the cell/battery, lamps and leads. At the next level are object properties, e.g. lamp brightness and first order relations, e.g. ‘consists of’ as in ‘the battery consists of a negative pole and a positive pole’. First order relations always connect objects. Further up in the hierarchy are the higher order relations, e.g. ‘causes’ as in a description of Ohm’s law. The higher order relations connect relations. (Paatz, Ryder, Schwedes and Scott, 2004)

When an analogy is being made, the base and the target should have an identical relational net for the features being compared although the objects will not be the same. However, the objects will be mappable. The steps involved are as follows:

1. **Activating a potential base domain** At this point the goals are explained which determine which parts of the target domain are to be looked at and therefore which base domain can be used. If the pupil is asked to consider the rules of electric circuit systems as the target domain, then the superordinate concept would be circuit and the base domain could be water circuits.

2. **Postulating local matches** This step requires the mapping of objects, properties or relations between the domains. These are rather isolated mappings at this stage.

3. **Connecting to a global match** Here further links are made, this time between the isolated objects or properties. The links between the objects or properties in the base domain are mapped onto the target domain. At the end of this stage the target net is similar to the base net but is less branched.

4. **Candidate inferences** It is at this stage that the pupil hypothesises about the target domain using information about the base domain. In this way the domains become more structurally equal.
Gentner (1980) used structure mapping theory to explain the difference between analogy and similarity. She uses similarity if the objects and relational structure overlap and the example she uses is of the helium atom and the neon atom. Here, both the objects and the relations between the two are the same. However, likening a hydrogen atom to the solar system is an analogy since the relations are similar but the objects are different.

Gentner and Markman (1994) carried out some research on differences between items using the structure mapping theory. Differences are either alignable or non-alignable. Alignable differences are those which are associated with the common structure and non-alignable ones are not. An example given by Iding (1997) is based on the camera-eye analogy. An alignable difference is the way each focuses when objects are at a different distance; the camera focuses by moving its lens and the eye by changing the shape of the lens. A non-alignable difference is that the eye has eye-lashes since this cannot be mapped on to anything in the camera. Gentner and Markman’s research found that it was easier to find alignable differences than non-alignable differences. Participants in the study found it easier to find differences between similar items which had alignable differences than between items which were vastly different where there were many differences but most of them were non-alignable. This research is important when it comes to analogy. When comparing the analogue and target, differences as well as similarities must be made and it is important for pupils to differentiate between differences which are relevant (alignable differences) and differences which are irrelevant (non-alignable differences). In this way, there is less likelihood of misconceptions being produced or of pupils taking the analogy too far.

Paatz et al (2004) found that Gentner’s structure mapping theory steps worked well in analysing an analogy teaching approach. An analogy was drawn between electric circuits as the target and water circuits as the base and the analysis was based on the learning development of a girl over several weeks. They point out that, although progress for the first three steps could be attributed to activities
provided during the teaching sequences, the student concerned made inferences unaided by teachers and activities.

Among the several models available for teaching analogy is the Teaching-with Analogies (TWA) model (Glynn, 1991).

In the production of the TWA model (Glynn, 1989 and Glynn et al, 1989) analogies in 43 science textbooks were reviewed to find which were most effective. Effectiveness includes analogies having multiple features to be mapped although it is sometimes adequate to have just a few principal features. The features in the analogue and target should be similar enough to avoid confusion when mapping and, in addition, it is important to consider the conceptual significance of the features to be compared. A model was then made for producing analogies (Glynn, 1991). It contained the following operations:

1. Introduce the target
2. Cue retrieval of analogue
3. Identify relevant, similar features of target and analogue
5. Draw conclusions about target.
6. Indicate where analogy breaks down.

Glynn et al (1989) point out that this is only a general structure and that the way the steps are carried out is important. For example, it is imperative that the pupil understands the analogy in the same way as the teacher does.

Figure 9 shows analogical steps for the camera – eye analogy. The steps shown bring together ideas from such as Gentner et al (1993) and Glynn et al (1995).
<table>
<thead>
<tr>
<th>Access Domains</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target domain</strong> - eye</td>
<td><strong>Base domain</strong> - camera</td>
</tr>
</tbody>
</table>

### Map Similarities

<table>
<thead>
<tr>
<th>Domain</th>
<th>Similarity</th>
<th>Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens and cornea</td>
<td>Focuses light</td>
<td>Lens</td>
</tr>
<tr>
<td>Choroid</td>
<td>Prevents reflection</td>
<td>Dark inner lining</td>
</tr>
<tr>
<td>Eyelid</td>
<td>Protects</td>
<td>Lens cover</td>
</tr>
<tr>
<td>Iris</td>
<td>Admits light</td>
<td>Aperture</td>
</tr>
<tr>
<td>Retina</td>
<td>Receives image</td>
<td>Film</td>
</tr>
</tbody>
</table>

### Assess differences

- Lens focuses by bending ↔ Lens is focused by being moved
- Cellular change in rods and cones ↔ Chemical change in film

### Address shortcomings

The analogy does not address binocular and stereoscopic aspects of human vision

### Evaluate new representation

- How complete is the understanding of human vision?
- Are there remaining sources of confusion?

---

Figure 9 Analogue steps for the camera–eye analogy (Iding, 1997, p 237)
Concretisation or abstraction?

Many have seen analogies as being a way of helping to construct more abstract representations but Brown (1989) maintains that one of the most important roles for analogy is that of concretisation, especially in conceptual change. An example he uses is that of the target being the 'book on the table' situation. The analogue is a hand pushing down on a spring. The idea of the analogy is to introduce the idea of springiness so that pupils can see that the table itself can have this property, a feature which is unobservable in the target but very observable in the analogue. The alternative view of the analogy would be that it helps the pupils to view the situation more abstractly by seeing the table and book having opposing forces in a similar way to the hand and spring having opposing forces (which can be felt in the latter case). While he argues that this is where the pupil should end up, he maintains that research has shown that this is not how this and similar analogies work.

Pupils may realise that an analogy suggests a particular answer but may be reluctant to accept it if it does not make sense to them or where there is a deep-seated idea to the contrary. An example used by Brown and Clement (1989) was one of Newton's third law involving the forces a moving and a stationary billiard ball have on each other. The analogy used here was that of Mr. T (an action hero on television) being tied to the front of a train which was to have a collision with another train. The student was happy that Mr T would feel the same force whether his was the moving train colliding with a stationary train or whether the other train was the moving one (at the same speed) and his was the stationary one and was also sure that the analogy was appropriate. However, he could not accept equal forces in the target case. The authors suggest two reasons for this. The first is that students have an entrenched conviction that moving objects contain and can apply more force than a stationary one and the second is that, although the analogy let the student make the correct abstract relational correspondences, it did not provide an explanation of the situation.
As has been previously cited, Posner et al (1982) believe that several conditions must be met in order for a conception to be fully accepted and retained by a student. The first of these is that the student must feel dissatisfaction with the current idea being held. There appears to be little problem to pupils when they do not ‘believe in’ Newton’s third law. Even if the student is prompted into being concerned by his or her own ideas (possibly by a teacher), the new idea has to be intelligible. It is difficult to make it intelligible without giving an explanation as to its origin and some analogies do not attempt to do this. Any analogy used should concretise the target situation bringing out features that will alter the model the student has of the situation (Brown, 1994).

If an analogy is given which can act as an explanation, then the results can be different. Clement et al (1987) used a different analogy for the same target as above. It was, in fact, a set of bridging analogies (see section 1.7). The anchor which was agreed by most of the pupils was that a spring compressed between both hands exerts an equal force on each. This is extended to a spring between colliding carts which, in turn, is extended to considering the microscopic springiness of the colliding carts. Again the concrete idea of springiness is introduced into the situation by use of an analogy where springiness is directly observable. An explanation of the origin of Newton’s third law, at least in the case of collisions has been given. This research was carried out with 150 American high school students who were studying a first year physics course. The control group consisted of 55 students. The results from this part of the research show a pre-test to post-test gain which is much greater for the experimental group (44.3%) than for the control group (14.5%). On a two-tailed t-test, $p < 0.0001$, showing a high degree of significance.
Analogy and unconscious contextual clues

Part of the current research discusses whether analogies can be used at a low-key level as a way of cueing p-prims. With this in mind, it is time to turn to a piece of research carried out by Kokinov and Yoveva (1996). They carried out some experiments where problems were given to volunteers. In the experimental condition, a diagram belonging to another question was also on the same page. The students were told to ignore any second question on the sheets and to answer only the first question. The control condition had only the first question and no other diagram. From the answers given, it was found that the students seemed to be influenced by the apparently irrelevant diagrams. The researchers concluded that particular memory elements had been cued and subsequently played their part in the problem solving procedure. Many of the participants said that they had not consciously been swayed by the second question in their answer, not even appreciating any connection. Work done by Kokinov et al (1997) gave further support to this by comparing four groups of subjects who had to solve a target problem. The first group was a control group which was given just the problem. The other three were experimental groups, one of which was given another diagram and told that it might be helpful. Another group was given the diagram but without any comment and the final group again had the diagram but this time it was given as part of another question which was not to be answered (remote condition). The results showed that being given the hint to make use of the diagram actually reduced the number of correct solutions compared with the control group but in the remote condition the number of correct solutions was increased. There was also an increase for the group which was not told anything about the diagram showing that they might also have picked it up unconsciously. The authors suggest that the reason the remote condition was more successful than the explicit hint was that the reasoning mechanisms involved for this particular problem in understanding the analogy provided by the diagram were too difficult as the shared relations in the structure correspondence were not obvious. At the same time other, potentially useful, mechanisms were inhibited by the analogical
reasoning processes. Such processes seemed to be encouraged by the unconscious picking up of cues.

The authors of the research mentioned above do not mention p-prims but there seems to be an obvious link. The correct solutions were being prompted by the use of an analogical diagram but without the structure mapping analysis that is necessary in an explicit use an analogy. This is similar to how p-prims are unconsciously cued by contextual clues.

Schunn and Dunbar (1996) undertook research on priming. This is where there is another encounter with an already known idea. This idea is then considered as primed and is then more readily accessible for use in another context. It is an implicit process as the pupil is unaware of what it is that has made them use that particular idea in the new context. They do not explicitly make an analogy. Their research involved problem solving and was carried out on the subjects over two days. Participants in the study had previously been taught the concept of inhibition which was primed on the first day when they had to solve a source problem on viruses. On the second day the students had to solve another problem (about genetics) which was, for them, unrelated to the first problem. In fact, this also required the idea of inhibition to solve it. In order to test whether any analogical link had been explicitly made, the researchers asked the subjects to give a running commentary on how they were solving the problems. If they were making an explicit link, then this would show up. They were also given a questionnaire after the second problem. The results showed that there was an improvement for the groups who had been primed. They did not seem to have made any explicit analogical links according to the commentaries that they gave and the questionnaires. Schunn and Dunbar regard priming as a lower level cognitive process whereas explicit analogy use is higher level reasoning. At first sight, it does seem odd that none of the participants made an explicit analogous link between the two problems. However, the researchers point out that there were no similar surface features between the two problems nor was there a similar
relational structure. The only similarity was the idea of inhibition. This actually makes this a poor candidate for a good analogy according to Gentner’s structure mapping theory and so it is less surprising that analogical links were not made. Another possible reason is that inhibition is a very general concept which had been learnt before the experiment. It is likely that the concept of inhibition is an idea that exists independently of its examples. It may be that less general concepts which are learnt with only one or two examples will only be accessed through more explicit analogy.

Textbook analogies

Textbooks are not always rigorous in their use of analogy (Parida and Goswami, 2000). They use analogy frequently but Glynn et al (1989), who analysed 43 science textbooks of various levels, point out that there was nothing in the introductions to help students work with the analogies given.

Thiele and Treagust (1995) acknowledged several characteristics of textbook analogies as they were analysing high school chemistry textbook analogies. These were as follows:

- **Visualisation effect** Analogy is an aid to prompting visualisation which is beneficial in cognition. It is usually considered better to have a pictorial form of analogy but most textbooks use a written form. Lin and Shiau (1996) found that low achievers gained more from being taught by pictorial analogy than did brighter pupils. This was possibly since the latter would be more likely to be at the formal operational stage and not need the concrete ideas as much (Gabel and Sherwood, 1980).

Parida and Goswami (2000) add an activity type of analogy to this since activity helps cognition and visualisation. Activity could include the pupils comparing the analogue and target.
• **The extent of mapping**  This can be of the following types:

Simple – In this type there is no amplification or explanation. There is just the statement that the target resembles the analogue.

Enriched - The enriched analogy indicates the shared characteristics between the target and analogue.

Extended – This uses several attributes of the analogue to be mapped to the target and can involve multiple analogies.

• **Analogue explanation**  As has already been mentioned, sometimes pupils do not fully understand the analogue domain. Good textbooks will include explanations about these so that the pupil can utilise the analogy better.

• **Analogy identification**  Students need to know when an analogy is being presented with word pointers such as like, similar and analogous.

• **Analogy limitation**  Good textbook authors point out the limitations of an analogy so that pupils are sure about which attributes are shared and which are not.

In their analysis of a science textbook used in India, Parida and Goswami (2000) found that many of the analogies used did not satisfy the above criteria. Some of these analogies were likely to cause misconceptions since there was not enough explanation of the analogue domain given nor were the limitations of the analogue discussed fully. This is in line with the findings of Thiele and Treagust (1994, 1995) in their research of analogies in high school chemistry textbooks.
Glynn et al (1989) found very few elaborate analogies; mostly they were of a simple type. They also found that there was a large range in the number of analogies used in different textbooks, even within the physics and physical science textbooks.

Curtis and Reigeluth (1984) carried out an analysis of 26 science textbooks and again found a large range in the number of analogies used in the different textbooks. They also point out that there was a lack of guidance in the use of analogies together with a lack of explanation of the analogue. They differentiated between analogies which were based on surface similarities (structural analogies) and those based on deep structure similarities (functional analogies) and concluded that the former were useful only for easy concrete topics but the more difficult, rather abstract topics required the latter.

Newton (2003) carried out research on science textbooks for seven-11 year-old pupils using Curtis and Reigeluth’s (1984) classification. She found that there was a preponderance of structural analogies and relatively few functional analogies. This was the reverse of the results Curtis and Reigeluth (1984) had found in their study of secondary school science textbooks. This fits in with their view that structural analogies are only useful for easier, concrete topics which might be expected at a more junior level.

Newton’s research found a higher proportion of simple analogies than extended analogies used in the elementary textbooks in contrast to Curtis and Reigeluth’s (1984) research which found a higher proportion of enriched analogies in the secondary textbooks. Thiele and Treagust (1994) noted the use of many simple analogies in the high school chemistry books they were reviewing.

This sort of analysis will be carried out on the analogies used in the present research (see section 4.2).
Analogies as advance organisations

An advance organiser is information given to a person before the main teaching/learning session to make it easier for him or her to organise and make sense of the information to be introduced. Ausubel (1968) said that the function of an advance organiser is “to provide ideational scaffolding for the stable incorporation of more detailed and differentiated material that follows” (p. 148).

Advance organisers may give prerequisite knowledge or link the information to other prior concepts. Ausubel was in favour of using abstract advance organisers that are given at a “higher level of abstraction, generality and inclusiveness” (Ausubel, 1968, p. 148) than the main block of information. Mayer (1979a) suggested that a successful advance organiser would be able to relate the new information to a person’s existing schema and thus assimilate it. Derry (1984) added that the learning would then bring about accommodation of the schema. Mayer (1979b), differing from Ausubel, proposed that concrete advance organisers would be more successful than abstract ones. Research by, for example, Royer and Cable (1975, 1976) and Mayer (1983) has shown that using concrete analogies as advance organisers is indeed better than abstract ones in the topic of electricity (conduction and Ohm’s law).

Analogies and models

Most models are analogical in nature and can include actual physical models, pictorial representations, equations, graphs or simulations. They are termed analogical since they describe abstract concepts using familiar objects and ideas (Harrison, 2001). Even equations can be a familiar enough idea, especially if they can be likened to other, more familiar equations of a similar form. Coll (2005) puts analogies as a subset of models.
Models are potentially useful for several reasons. According to Harrison (2001), they:

- are a way of pointing out the important characteristics of the target and they do this well when they remove unnecessary details and direct the attention towards the model’s significant characteristics.
- can exaggerate the important parts.
- are usually familiar to pupils.

According to Mayer (1989) a model is good if it meets the following conditions:

- They must be structurally complete - contain all the necessary parts of the target.
- They must be coherent – be appropriate in detail level.
- They must be considerate - contain the appropriate vocabulary and presentational form for their audience.
- They must be concrete in representation and the relationship of all parts of the model must be obvious. Mayer (ibid) felt that this is more likely with a concrete model than with an abstract model which may obscure the inner details.
- They must give a clear, conceptual account of the theory they are explaining.
- They must underline the correct comparisons which should be made so that the pupils do not take the analogy too far and cause misconceptions to arise.

Harrison and Treagust (2000) devised a classification of models used by teachers and textbooks. This was as follows.

**Pedagogical analogical models** These are models which are used for teaching and learning and can include the following:
• Scale models These precisely follow proportions but rarely indicate internal structure, functions and use (Black, 1962). Also, their constituent materials are different. Since scale models are often toy-like, this may hide some of the model-target differences (Goss light et al, 1991).

• Iconic and symbolic models These include chemical formulae and equations.

• Mathematical models Mathematical equations and graphs are used in physics to describe physical processes and relations (Black, 1962; Hodgson, 1995). However, they are not always easy to use in real situations. For example, when using $F = ma$, pupils must be made aware of the fact that friction must be taken into account. The meaning of equations should be made by the pupils themselves, using verbal or written explanations (Hewitt, 1987).

• Theoretical models These include analogical models such as electromagnetic lines of force and photons.

• Maps, diagrams and tables These tend to be simplified and sometimes exaggerated and are designed so that the patterns and relationships that they represent are easily visualised by pupils. However, care must be taken that pupils do not take part of the model literally, e.g. carbon atoms are generally represented in diagrams by black balls and some pupils think that carbon atoms are black. The size of molecules in comparison with the size of the beaker when drawing a diagram showing the pattern of molecules in different states is an example of the exaggerated nature of some diagrams. It is necessary but potentially confusing for the pupil. Pupils must realise that no model is the same as reality. Examples of this type of model are the periodic table and circuit diagrams.

• Concept–process models Much of science is concerned with processes, e.g. refraction and redox reactions. Concept-process models, sometimes multiple models, are used to try to represent and explain these processes. For example, refraction can be explained by vehicles or lines of soldiers.
moving from a hard surface to a muddy, soft surfaces, slowing down and usually changing direction (Hewitt, 1987, Harrison, 1994).

- **Simulations** These model complex processes. Some may be virtual reality as in computer games or learning to drive on a simulator and some depict situations such as potential nuclear accidents which require the participant to make decisions which dictate the next part of the simulation. Computer based simulations are becoming increasingly popular with the growth of the 'computer generation' and sometimes their modelling is so sophisticated that their analogical property is masked. They become almost a reality in themselves.

- **Mental models** It is difficult to define this term exactly as it is used in a variety of ways in the literature. Johnson-Laird (1983) portrays mental models as being cognitive representations of 'states of affairs' where there is, amongst other things, a similar relational structure. Mental models comprise elements which correspond to objects, and operations on the elements for constructing, revising and evaluating. Vosniadou states that they “refer to a special kind of mental representation, an analogue representation, which individuals generate during cognitive functioning” (Vosniadou 1994, p 48). They are unique to each person and develop “through interaction with the target system” (Norman, 1983, p 7). In addition, they can be “incomplete … unstable … unscientific … parsimonious” (*ibid*, p 8) and may be difficult to communicate to others (Harrison and Treagust, 2000).

- **Synthetic models** These are models which are produced by pupils when they amalgamate their own models and those which they are taught. These synthetic models may be the source of many misconceptions.
Scientists and teachers thus find models useful, for example, to explain ideas and to plan experiments. According to Grosslight et al (1991) there are three levels in modelling ability:

**Level 1** Pupils believe that there is a 1:1 correspondence between the model and reality; the model is a simple copy of what it is trying to model.

**Level 2** Pupils see models as not having to have a complete correspondence with reality but perceive the main use of a model to be explanatory rather than as a tool to explore ideas further.

**Level 3** At this level, models are seen in their multi-modal role as tools for thinking about and testing ideas and for developing ideas as well as explaining concepts. Also at this level multiple models are seen as useful.

According to Grosslight et al *(ibid)*, many pupils who are at the age of those in the present study would be at Level 1, showing that their ability to use and understand models is limited. The levels are based on how pupils describe and use models and could provide knowledge about conception status and level changes could mirror conceptual changes.

Harrison and Treagust (1996) suggest that pupils be given the chance to develop their ability at modelling, using models to explain ideas and learning to understand the strong points and restrictions of each model used. Teachers should make sure the analogue is well known and that the pupils know which are the shared attributes and which are the unshared ones.
1.6 Analogies and constructivism

The use of analogy fits in well with constructivism. As has been indicated, learning requires links to be made between what is being experienced and what is already known. In a similar way, analogies are links between a target and a base. Duit (1991) says that learning "fundamentally has to do with constructing similarities between the new and the already known. It is precisely this aspect that emphasizes the significance of analogies in a constructivist learning approach" (p 652).

He points out that more 'traditional' views of learning also see the need for linking new ideas with more familiar ones. However, this seems to be in the context of conceptual growth; a continuous set of enlargements presumably along the lines of Piaget’s assimilation idea. The constructivist view agrees that much learning is conceptual growth but the main difference is that it is a fully new construction of what is already known. This is more akin to Piaget’s accommodation process.

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Figure 10a Traditional view of conceptual development as a continuous set of enlargements

Figure 10b Constructivist view of conceptual development as fully new constructions
Analogies are examples of plausible reasoning processes in that:

- They allow the domain of applicability to increase.
- They could prove more useful than logical proof processes.

They are concerned with going from concrete ideas to abstract ideas, which is reminiscent of Piaget's concrete and formal operational thinking stages.

Vygotsky might see analogies as scaffolding which is gradually removed as the child becomes more competent. In Gentner's structure mapping theory the scaffolding might include the first three steps but being removed before the fourth step where the pupil makes their own inferences.

**Summary**

Since analogy plays such an important role in learning and since analogies can be easily accessed by pupils, it was decided to make use of them in the present research. Their close link with the ideas of constructivism makes them a good candidate for overcoming misconceptions on condition that their limitations are realised and confronted.

Although Piaget did not believe that children at the Concrete Operational Level are able to reason analogically, more recent research has led to the opposite view.

One of the questions this research is attempting to answer concerns whether any success using analogies as a low-key intervention can be explained in terms of cueing p-prims (an unconscious process) or in terms of a process involving more explicit analogical reasoning. Previous research has shown that analogies can be used as unconscious contextual clues although no research seems to have linked this with cueing p-prims.
1.7 Bridging analogies

It is easier to understand a close analogy than a distant one (Clement, 1998). Pupils may not be willing to accept straight away that A is analogous to C but, by introducing B, they may agree that A and B are analogues as are B and C. Thus, they may be more confident in the analogous relationship between A and C.

In a distant analogy the analogue and target are too dissimilar for pupils to make easy comparisons. There are probably too many non-alignable differences between the analogue and target. As has already been mentioned, it is easier to compare the similarity of items by comparing alignable differences than non-alignable differences. The closer the analogy is, the more alignable any differences are going to be. It is better to reduce the total number of differences between analogue and target but there will always be some remaining. If it is possible to lessen the number of irrelevant, non-alignable differences, it should be easier for pupils to ‘see’ the analogy.

The anchor-bridge-target model aims to start where the student is and finish where the scientist is having crossed the chasm using conceptual bridges usually going from the very concrete to the rather abstract. In order to start where the student is it is necessary to make sure that one of their intuitive conceptions which is more or less correct from the scientific point of view is chosen and these, in general will involve the easily observable, concrete phenomena (Clement et al, 1989). It is not always easy to decide what to choose as an anchor. Clement et al (ibid) define an anchoring conception theoretically as “an intuitive knowledge structure that is in rough agreement with accepted physical theory” (p 555). If the student confidently makes a correct response to the problem then that is an anchor for that particular pupil. The confidence that the student has in the answer is important as this is a means of differentiating between what the pupil really believes and what they think is the correct answer even if it makes little sense to them. Of course, in a class situation it is more convenient to use an anchor that most students can relate
to; Clement et al, in this paper, suggested 70% as being a reasonable starting point. They considered this figure to be arbitrary but practical.

Clement et al (ibid) carried out their study in three Western Massachusetts high schools on students who had not yet done any physics courses but who were doing chemistry, biology or general science. The respective average ages of the pupils in these groups were 17, 15 and 14 years old. The researchers found that anchoring examples were not always the ones expected and added to the body of knowledge about the subject in revealing that some anchors are ‘brittle’. These are anchors that at first glance seem suitable candidates but it is found that they cannot be extended to even the first bridging analogy. They are especially prevalent where the anchor involves a symmetric situation but the bridge/target is asymmetric. The breaking of symmetry provides a barrier for the student, as he or she believes this small change to be more important than it actually is and to alter the whole situation. An example of this breaking of symmetry causing a brittle anchor is given by Clement et al (ibid). It involves two carts tied together by rope, there being a compressed spring between the two (Figure 11a). Most pupils said, with a high degree of confidence that the carts would move apart with the same speed if the rope were cut. When the situation was changed to the spring being attached to one of the carts (Figure 11b), the percentage of pupils answering correctly dropped considerably together with their confidence rating. The asymmetry introduced into the problem caused too large a change in the pupils' minds for them to consider the two situations analogous.

![Figure 11a Spring not attached to carts](115)
The research dealing with bridging analogies will be looked at in more detail in section 2.1.

Clement (2004) has found that bridging analogies are useful in problem solving. His research involved experts in scientific fields who were asked questions about topics which were at the periphery of their knowledge. Analogies were generated by the participants to help to answer the questions. Earlier work by Clement (1989) had found that part of using analogies was in validating the analogies used. Bridging analogies can be used as a higher order strategy to make it easier to carry out validating methods. Although it adds more work since each pair of the bridging analogy sequence needs evaluating, presumably it makes each evaluation easier and promotes more confidence in the validity.
CHAPTER TWO

Design of pilot research

Introduction

The objectives of the pilot research were:

- To conduct similar research to previous work to establish whether equivalent results would be obtained.
- To check on the logistics of the research, e.g. whether it would fit into the classroom routine without too much disruption.
- To examine the potential for further research.

It was decided to use bridging analogies as the main method of teaching for meaningful learning. This was for the following reasons:

- Using bridging analogies is a constructivist approach, designed to instruct in a conceptual manner resulting in meaningful learning.
- Research has shown that this strategy has been successful and there have been various research projects on the topic of balanced forces using this method.
- Research has shown that it is a reasonably straightforward, self-contained method which can be implemented over a relatively short time-scale.
2.1 Previous research on bridging analogies

Brown’s (1994) research on bridging analogies points to their success. Rather than using any practical work, his study was conducted using a written explanation involving bridging analogies. The students taking part were 73 chemistry students in their junior year who would be taking physics the following year. The explanation was interspersed with questions which probed the pupil’s understanding of the target situation - whether a table exerts an upwards force on a book resting on it - as well as those which asked how confident the pupil was about their answers and how much sense the idea of a balanced force made. Out of the 40 students who had said, at the start, that the table did not exert an upward force on the book, 37 had changed their minds by the end. Although Brown recognised that his results did not show that every student had gone through a permanent conceptual change, he argued that students were not merely being trained to answer correctly by the fact that their ‘sense’ ratings increased during the session. However, being offered an explanation and then denying it makes sense would not be the usual behaviour of a pupil who would probably prefer to believe that they had understood. That the pupils could explain their answers by linking to their intuitive anchors does not seem surprising given that the explanation was already there. Brown did not, in this paper, report any follow-up testing to see how permanent these conceptual changes were.

Thijs and Bosch (1995) used the success of bridging techniques in their work to compare the relative usefulness of demonstration and small group practicals in teaching about forces on objects at rest. The students involved in their study were approximately 15 years old. The bridging steps used in this research involved work on the normal force and the force of friction. They found that bridging analogies are very successful especially in dealing with the normal force and that demonstration practicals are, for girls, more successful than small group practicals. They also found that retention was high for those tested three months later although they do point out that only pupils opting for physics in the following
academic year took the retest. The three-week teaching sequence included pre-
tests, anchor-bridge analogy practical sessions (small group and demonstration) 
and post-lab, final and, later, retention tests. Unfortunately their research related to 
only the top 40% - 50% of the ability range and it would be interesting to see if 
their conclusions apply to those of below average ability. As the research was 
designed primarily to compare the differences between teacher demonstrations and 
small group practicals there was no comparison between pupils using bridging 
analogies and those not doing so.

More recently, Clement (1998) has studied the similarities in generating analogies 
between students and experts and the research again supports the use of bridging 
analogies in the topic of balanced forces. His work included comparing the 
 improvement on identical tests before and after bridging analogy teaching for high 
 school students taking a first year physics course (150 in the experimental group 
 and 55 in the control group). The latter test was given approximately two months 
after the instruction thus testing retention. The control classes just used their 
normal curriculum. The results of the tests indicate that the experimental group 
gained more than the control group (of the order of one standard deviation in size). 
A two-tailed t-test gave a probability of < 0.0001 that these results were due to 
chance.

One of his conclusions was that students need to be encouraged to spend time 
discussing the analogies in order to evaluate them as experts do. There are no 
short cuts to the answer.

He suggested that bridging analogies might work because they gradually extend 
the domain where the student can apply a particular conception via a mental 
simulation. In contrast, many textbooks require pupils to see the connection 
between a set of unordered examples in order to understand the general principle 
(Brown and Clement, 1992).
Of course, one major difficulty of working with balanced forces is that of differentiating between balanced forces acting on an object and action-reaction pairs. This does not seem to be discussed in the literature even though the possible future confusion seems possible.
2.2 Implications for this study

From these pieces of research various important points have emerged. These are summarised below together with implications for this research.

- For girls demonstration work is more successful than small group practicals (Thijs and Bosch, 1995). This suggests that it would be advisable to include at least some demonstration work since it is only girls in the sample school.

- Discussion to evaluate analogies appears to be important (Clement, 1998). Pupils must be given the opportunity and the time to discuss whether the analogies make sense to them with the teacher acting Socratically.

- Written explanations are useful (Brown, 1994). If nothing else, they will allow pupils to follow through the reasoning as often as they need.

- If it is used in a whole class situation, it is more convenient if the anchor is applicable to the majority of the pupils (Clement et al, 1989). Also, one must be wary of ‘brittle’ anchors (ibid).

- Retention tests are essential since it is the permanent restructuring of schemata which is most important.

- The work of the control group is as important as that of the experimental group. Their curriculum should be of the usual textbook type - state principle (perhaps as the conclusion to an experiment), look at examples and work through similar examples as questions.
2.3 Pilot research methodology

A comparison was made between the effect of teaching using bridging analogies and a more traditional approach to overcome certain physics misconceptions. In order to measure the effectiveness of the two approaches, two Year 8 classes (12-13 year olds) were used. One class acted as the control, learning by the traditional approach and the other was the experimental group, learning by using bridging analogies.

Previous work on which this research was based

There were several works on which this present research was most directly based. The results and conclusions to these have been articulated above.

It was decided to style the bridging analogy sheets on the work of Brown (1994) who gave a written explanation including bridging analogies to 73 American high school students who had not already studied physics. The topic was Newton’s third law and the question posed was as to whether a table exerts an upward force on a book resting on the table. At the beginning and after each part of the explanation, the students were asked to say what they believed about the problem. They were also asked, at intervals, about their ‘sense’ ratings and also their ‘confidence’ ratings. The ‘sense’ ratings were designed to reveal what they intuitively believed and the ‘confidence’ ratings, what they thought was the ‘right answer, possibly based on what they may have been told in the past.

Present research

The bridging analogy sheets for the present research (see Appendix Ia) were printed with each part appearing on a separate sheet so that, as in Brown’s research, the pupils did not accidentally glance at the next part of the explanation.
In this part of the research, the pupils were asked how much sense it made that the table is pushing up on the book (on a scale of one to five).

It is easier to control and measure what is happening in demonstration conditions as the teacher is more experienced and there is more chance that the experiment will go according to plan. It also means that each pupil will have seen exactly the same experiment being performed although the sense they make of it may well differ. In addition, the teacher can limit the amount of discussion between pupils. Discussion is usually beneficial but it may lead pupils to give responses based on their peers’ ideas rather than their own. Thus it was decided to carry out most of the research as demonstrations. This would not be seen as out of the ordinary by the pupils as they are accustomed to both small group and demonstration practicals. This method is supported by Thijs and Bosch (1995), who carried out the investigation, mentioned above, into the relative merits of demonstration and small group practical work. They found that girls tended to fare better under demonstration conditions and as the present sample is all girls, there is no complication of bias.

Thijs and Bosch’s research involved pre- and post-tests together with retention tests for some of the pupils. Clement (1998), conducting a study of bridging analogies, used pre- and retention tests. It was decided to incorporate pre-, post- and retention tests in the present research with the retention tests being eight weeks after the post-test. This period of time was chosen since it was not feasible to use a longer time, as each part of the research needs to be completed during a school year. Two months was used by Clement although he does not give his reasons for this.
2.4 Sample

The school (fee-paying independent school in England) from which the sample was chosen is, in the senior (11-18) section, all girls. All the cohorts taking part in this research comprised two classes with approximately 24 in each class.

For each Year 8 cohort, there was similarity between the classes in terms of ability which can be shown by the physics examination results at the end of year seven. For all the cohorts for whom research was carried out, there was a maximum of 4% difference in the means of the two classes (see Appendix I).

The pupils have to pass an entrance examination and so are not representative of the population. How representative they are can be partly ascertained by comparing the Key Stage 2 results prior to entry to secondary school for this school and nationally. Pupils are tested in English, Mathematics and Science at the end of their primary school (10 -11 years-old). Not all the parents of pupils in the research classes volunteered information on their Key Stage 2 results and some pupils had not done the tests. Appendix Ig shows the national results and the results for those in the research school who had taken the tests and provided the information. It is clear that the pupils in the research school are generally of above average ability in the subjects tested. For example, in science, an average of 98% reached level four (target for the age group) or above for the research school compared with 86% nationally. Level five or above was reached by 36% nationally and 56% of the pupils in the research school. Pupils who reach level five are considered to have exceeded the targets for their age group.

Although the sample is not entirely representative of the general Year 8 population of all schools in England, the conclusions reached may be capable of transfer to the wider population. Even if this is not possible, the information should be of value to schools of its genre as it will give an indication as to whether the type of approach would be of use in the teaching of more able pupils (especially girls).
2.5 Statistics used

The t-test was used to show how likely it is that the results obtained are not due to chance alone. By using this test, we are testing the null hypothesis that there would be no difference between the test results for populations taught either way, i.e. \( H_0 : \mu_1 = \mu_2 \) where \( \mu_1 \) and \( \mu_2 \) are the hypothetical population means. In order for the results to be statistically significant, the null hypothesis must be rejected so it can be stated that \( \bar{X}_1 - \bar{X}_2 \) (the difference between the sample means) is too high to have happened by chance at a certain level of significance. If the level of significance is 0.1 then there is a 10% probability that the results happened by chance. 0.05 would mean a 5% probability. Obviously, the lower the number, the more confidence can be placed in the results. As the t-value increases, the probability that the results are due to chance decreases.

The basic t-test formula is as follows:

\[
t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s_1^2/n_1 + s_2^2/n_2}}
\]

\( \bar{X}_1 \) and \( \bar{X}_2 \) are the sample. \( s_1^2 \) and \( s_2^2 \) are the sample variances. \( n_1 \) and \( n_2 \) are the sample numbers and \( t \) is the t-value.

There are three separate factors that the t-test takes into consideration in order to decide whether the results are significant (Popham and Sirotnik, 1967).

Mean difference

The greater the difference between the means, the less the probability that the difference is caused by chance. This mean difference is in the numerator of the formula so a larger difference gives a higher value for \( t \) and therefore a lower probability of chance results.
Group variability

If the variance of the two groups is large (a great spread in the distributions), then even a fairly large difference in the means will result in a good deal of overlap. Could a valid assertion be made that both samples were not drawn from the same population? This idea is considered in the denominator. If the group variances are small, this will give a small denominator and therefore a large value of t.

Figure 12 Large and small variances (Lane, 2003)
Sample size

Increased sample size produces a more stable indicator of group performance. The larger the sample, the smaller the difference in means can be to be statistically significant. This is taken into consideration twice. In the formula, the sample size appears in the denominator of the denominator so that a large t is produced from a large sample size. In the t-table, a given t value is more significant when the sample size (degrees of freedom) is large. The degrees of freedom are the number of independent pieces of information about the population. When the mean is calculated, one degree of freedom is removed. So, if there are 10 in each sample, then the number of degrees of freedom is

\[(10-1) + (10-1) = 18.\]

Different t-tests

There are several formulae for the t-test, each differing slightly. Which one to use depends on three criteria.

Correlation

If matched pairs or two measures on each subject are involved, it is more likely that the scores for each subject will be more similar and the likelihood of the means of the groups being different is less. The t value is adjusted upwards accordingly. The formula used in this case is:

\[
t = \frac{X_1 - X_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} - 2r \left( \frac{s_1}{\sqrt{n_1}} \frac{s_2}{\sqrt{n_2}} \right)}}
\]

where \(X_1\) and \(X_2\) are the sample means, \(s_1^2\) and \(s_2^2\) are the sample variances, \(n_1\) and \(n_2\) are the sample numbers, and \(r\) is the correlation factor between the two sets of data.

Homogeneity of variances

If there is no correlation or if correlation cannot be assumed since there are no matched pairs, or there are not two measures on each subject, then homogeneity of variances needs to be considered.
The two sample groups are taken from two populations (real or hypothetical) and it is important to calculate statistically whether the variances of the populations are equal. This is done by calculating the F ratio.

\[ F = \frac{s^2(\text{larger})}{s^2(\text{smaller})} \]

As F increases, the probability increases that there is a statistically significant difference between the two variances and that the variances are non-homogeneous. Tables show the cut-off point for homogeneity.

If the variances are homogeneous, the formula is for pooled variances:

\[ t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\right) \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \]

If the variances are not homogeneous, the formula is for separate variances:

\[ t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s_1^2/n_1 + s_2^2/n_2}} \]

Number of subjects in the sample

Different formulae are used depending on whether there are equal numbers in each group or not (\(n_1 = n_2\) or \(n_1 \neq n_2\)). The correct formula to be used can be found by utilising the following flowchart.
Figure 13 Deciding on the t-test
Assumptions of the t-test (Popham and Sirotnik, 1973)

1. The samples are randomly drawn from their respective populations.
2. The scores are normally distributed.
3. The scores have the same variance in the populations.

Robustness of test

If statistical assumptions are violated but the test remains valid, the test is said to be robust (ibid). The t-test is such a test in that the assumptions of normality and equal variance can be departed from quite noticeably without the validity of the test being compromised. According to Ferguson (1981), for large samples of 25-30, non-normality is not usually a serious problem and he claims that there is evidence to suggest that even small samples of 5-10 are not usually seriously affected. However, a one-tailed test is more prone to influence. Pure randomness is difficult to achieve but, if it can be shown that the samples are not biased with respect to their populations, then the t-test can still be utilised.

Tails

A two-tailed test is used if there is no direction to the research hypothesis, e.g. that scientific conceptions will be retained at different levels by the experimental and control groups. A one-tailed test is used when there is a direction to the research hypothesis, e.g. that scientific conceptions will be retained at a higher levels by the experimental than by the control group.

Errors concerned with significance

There are two main types of error as shown in Table 4. Ideally, both types of error should be made as small as possible. Total control of Type I error is given to the researcher. He or she can reduce this error merely by reducing the level of significance. However, in reducing the probability of a Type I error, it increases the probability of a Type II error since there is now less likelihood of rejecting the null hypothesis. If the null hypothesis is really false, then a Type II error will have
been committed. The Type II error thus depends to a certain extent on the Type I error but it is also dependent on other experimental considerations such as sample size.

<table>
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</thead>
<tbody>
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</tr>
<tr>
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<td>TYPE (I) ERROR</td>
</tr>
<tr>
<td>Null hypothesis is really false</td>
<td>TYPE (II) ERROR</td>
<td>NO ERROR (1-β)</td>
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</table>

Table 4 Significance errors

Choice of t-test for pilot research
As the t-test is a robust test, it can be carried out on small sample sizes and it was assumed that the samples were not biased with respect to their populations. It was not feasible to use strict randomness in the choice of sample as the pupils were already in classes which were not being taught at the same time so random allocation of pupils to the control group or the experimental group was not possible. One class was the control group and the other was the experimental group. In the main part of the research, the classes alternated between being the control group and the experimental group for the different topics so that bias would be more easily noticed. In any case, an assumption of non-bias was made on the grounds of the year seven physics results of the examinations taken the summer prior to the research being carried out (see Section 2.4 and Appendix I).

For the initial analysis, there was assumed to be no correlation as there were no matched pairs or two measures on the same subject. The F-test revealed that
statistically $\sigma_1 = \sigma_2$ and $n_1 \neq n_2$ so the pooled variance for non-correlated samples was chosen. A one-tailed test was used as the research hypothesis was directional.

Statistics used in previous research

Clement et al (1989) and Brown (1994) used percentages in their results without any further statistical analysis.

Thijs and Bosch (1995) used percentage scores to indicate the number of pupils giving correct answers or the percentage scores of pupils at various stages of their study which looked at the relative merits of demonstration and small group practicals. They also used an analysis of covariance on the scores of the final and retention tests with the scores on the initial test as covariant. This analysis of covariance allows initial differences between experimental and control groups to be equalised. The factors distinguished in this study were type of strategy (small group practical or demonstration) and sex (boys or girls). The covariance analysis is designed to adjust observed scores in relation to differences in the covariant. Clement (1998) used the two-tailed t-test to report on the use of bridging analogies in a forces topic. The percentage gain during the experiment was stated together with the probability that the results were due just to chance rather than due to the experimental variable.
Analysis of pilot research

3.1 Results and analysis of pilot research

Research hypothesis

The experimental group will retain the scientific conceptions better than the control group and so their marks in the retention test will not have dropped as much (from their post-test results) as those from the control group.

Null hypothesis

\[ H_0 = \text{"Pupils taught by the bridging analogy method will not retain scientific conceptions any better than pupils taught ‘traditionally’."} \]

Table 5 shows the results for how pupils differed between post and retention tests according to their groups. For the experimental group there was an average drop of 2.1% between the post- and retention test. For the control group, it was 6.9%. The full results for the initial, post and retention tests can be found in Appendix Id and the questions themselves in Appendix Ic.
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Experimental group mean = 0.38  
Control group mean = 1.25  
standard deviation = 2.69  
standard deviation = 3.82  

p = 0.26

Table 5 Post- and retention test scores for the experimental and control groups
A one-tailed t-test for independent non-correlated data (equal variance) gave p > 0.1 (p = 0.26) showing the results to be not statistically significant at the 0.1 level of significance. There is a 26% probability that the results were produced by chance. The null hypothesis cannot be rejected.

Because these results were not statistically significant it was decided to analyse each question and how well it was answered as a comparison between post-test and retention test. Now the difference in marks between post and retention tests for each question became the subject and each question was being tested twice; once by the control group and once by the experimental group. This became two measures on the same subject and so correlation was assumed. The t-test for correlated samples was thus used.

**Research hypothesis**

The drop in number of pupils answering each question correctly between the post-test and the retention test will be greater for the control group than the experimental group.

**Null hypothesis**

H₀ = “If questions are used to test pupils in post and retention tests, there will not be any significant difference in the drop in number of correct answers between pupils taught by bridging analogy and those taught more traditionally.”
Table 6 shows the results for the fall in correct answers between post and retention tests for each question. Again, for the experimental group there was an average drop of 2.1% between the post- and retention test. For the control group, it was 6.9%.

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<table>
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<td>2.28</td>
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<tr>
<td>p</td>
<td>0.20</td>
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Table 6 Post-retention test scores for each question.

The one-tailed test for dependent (paired) samples gave \( p > 0.1 \) (\( p = 0.20 \)) showing the results to be not statistically significant at the 0.1 level of significance. There is a 20% probability that the results were produced by chance. Again the null hypothesis cannot be rejected.
Which test is more valid?

The second test used concentrated on the individual questions and how well they were answered. The data points out the questions which are either too easy or too difficult to be influenced by the teaching method and clearly shows those questions which are influenced by the mode of instruction. The questions which are too easy are always going to be answered correctly whereas the most difficult questions may be approached with guesswork. This guesswork may cancel out when a question is answered by many children. However, if each pupil is the subject, as in the first test, the guesswork may follow a particular pattern depending on their answer to the first difficult question that they come across. This answer may be randomly different each time the test is attempted and this would lead to biased results.

Example
A pupil who does not understand about balanced forces on a stationary object may guess an answer as being ‘the down force is greater than the up force’. On subsequent questions, the pupil is more likely to give similar answers. When the test is repeated, the pupil might guess that the answer is ‘down force is equal to the up force’, repeating with similar answers to the other questions. This would show a vast improvement in the pupil’s score between the two tests. Conversely, if it were to happen the other way round, then there would be a large drop in the scores. This would produce a large variance, a smaller t-value and less statistically significant results.

If each question is taken to be the subject, the difficult questions may be answered randomly, but by the argument above, the number of pupils answering wrongly is more likely to cancel with the number answering correctly. Thus, the variance should be less leading to a larger t-value and more statistically significant results.
Both methods of analysis will be used in the main research. The number of questions for each topic will be much less so the sample size for the second type of analysis will also be reduced.

Analysis of each question (see Appendix Ic for questions)

<table>
<thead>
<tr>
<th>Question 1</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>15</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Control group</td>
<td>67</td>
<td>58</td>
<td>17</td>
</tr>
</tbody>
</table>

Question 1 (apple hanging from tree) showed a substantial increase for the experimental group from initial to post whereas the control group performed worse after the teaching than before and even worse in the retention test eight weeks later. The success of the bridging analogy approach is indicated and could be explained by the pupils having a clearer idea of the forces being balanced in the vertical direction in a similar way to the forces being balanced for the book on the table.

<table>
<thead>
<tr>
<th>Question 2</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>23</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>Control group</td>
<td>25</td>
<td>58</td>
<td>67</td>
</tr>
</tbody>
</table>
Question 2 concerned the 'book on the table' problem and it is not surprising that there was again a substantial increase for the experimental group from the initial test to the post-test since this was the target question in the bridging analogy teaching approach. There was also not much of a drop to the retention test, showing that they had retained the concept well. The control group also increased their score from initial to post-test and this can be explained by the fact that they had had this as an example during their teaching. The control group went on to increase their score in the retention test.

<table>
<thead>
<tr>
<th>Question 3</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>85</td>
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<td>100</td>
</tr>
<tr>
<td>Control group</td>
<td>58</td>
<td>100</td>
<td>75</td>
</tr>
</tbody>
</table>

Question 3 asked about the forces on a book on an outstretched hand. Both groups increased their scores from initial to post-test. This is a similar problem to the book on the table which both groups had seen the week before their post-test and this explains the increase. More importantly, the control group had a substantially reduced score in the retention test whereas the experimental group did not decrease their score. This suggests a better concept retention for the experimental group than the control group.

<table>
<thead>
<tr>
<th>Question 4</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Control group</td>
<td>92</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Question 4 (a squashed spring exerting a force on a hand) was the anchor in the bridging analogy approach and it was expected that most pupils would get this right, even in the initial test as the anchor was chosen so that most pupils would ‘agree’ with the correct answer.

<table>
<thead>
<tr>
<th>Question 5</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Control group</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tbody>
</table>

Both experimental and control groups scored 100% in all tests on question 5 which was about the forces on a rope during a tug-of-war, indicating that it might prove useful as an anchor question.

<table>
<thead>
<tr>
<th>Question 6</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
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<td>77</td>
<td>77</td>
</tr>
<tr>
<td>Control group</td>
<td>17</td>
<td>67</td>
<td>50</td>
</tr>
</tbody>
</table>

Question 6 concerned a boy pulling on a tree and, although all the pupils had responded correctly in the previous question where two people were pulling on a rope, this time there were far fewer correct responses from either group. This can be explained by the fact that many pupils do not think that inanimate objects such as trees can exert forces (Dykstra, 2000). Having been taught about balanced
forces, both groups increased their scores from initial to post-test, the control
group considerably so. This may represent a case of a short-lived ‘teaching to the
test’ effect as the control group dropped their score in the retention test in
comparison with the experimental group who had retained the concept well.

<table>
<thead>
<tr>
<th>Question 7</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
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</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>92</td>
<td>69</td>
<td>92</td>
</tr>
<tr>
<td>Control group</td>
<td>50</td>
<td>75</td>
<td>42</td>
</tr>
</tbody>
</table>

For question 7, about trying to push a large box on wheels which will not move, for the control group, there was an expected rise from initial to post-test together with a drop to the retention test. However, the results for the experimental group were unexpected. There was a drop from the initial to the post-test and then a rise to the retention test. Also, when asked the name of the forces acting on the crate, several, who had mentioned friction in the initial test, became confused in the post-test, having the idea that the crate itself was exerting a force. This is possibly explained by the ‘book on the table’ problem where the table pushes on the book and no friction is involved.

<table>
<thead>
<tr>
<th>Question 8</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>69</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Control group</td>
<td>17</td>
<td>58</td>
<td>67</td>
</tr>
</tbody>
</table>
Question 8 concerns a block being pushed against a wall where no motion is involved. Both groups showed increases throughout the tests. The experimental group had had this as a target in another set of bridging analogies (not discussed in this research) and the control group had it in one of the examples in their teaching sequence.

<table>
<thead>
<tr>
<th>Question 9i</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
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</tr>
<tr>
<td>Control group</td>
<td>67</td>
<td>92</td>
<td>92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 9ii</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
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</tr>
<tr>
<td>Control group</td>
<td>42</td>
<td>92</td>
<td>67</td>
</tr>
</tbody>
</table>

Question 9 asked about the forces on a lift which was not moving. The experimental group scored 100% in each test for drawing two opposing forces (9i) and increased their score from initial to post-test for indicating the forces were of equal size (9ii). There was then a drop to the retention test. The control group increased their score for drawing opposing forces from the initial to post-test, maintaining this score for the retention test. They also increased their score for indicating the forces were the same size between the first two tests but this dropped quite substantially for the third test showing a poor retention of the concept.
<table>
<thead>
<tr>
<th>Question 10i</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
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<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Control group</td>
<td>50</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 10ii</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>62</td>
<td>69</td>
<td>77</td>
</tr>
<tr>
<td>Control group</td>
<td>17</td>
<td>58</td>
<td>67</td>
</tr>
</tbody>
</table>

Question 10 concerned the forces acting on a swimmer floating in the water. The experimental group’s results were similar to, if mostly lower, than their scores in question nine. The control group’s results increased from initial to post-test for drawing two opposing forces (10i) and then stayed the same for the retention test. For the size of the forces (10ii), there was an increase throughout the tests.

<table>
<thead>
<tr>
<th>Question 11i</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>92</td>
<td>85</td>
<td>92</td>
</tr>
<tr>
<td>Control group</td>
<td>75</td>
<td>67</td>
<td>83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 11ii</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>69</td>
<td>85</td>
<td>69</td>
</tr>
<tr>
<td>Control group</td>
<td>33</td>
<td>58</td>
<td>83</td>
</tr>
</tbody>
</table>
Question 11 was about a stationary floating boat. There was a decrease for both groups from initial to post-test for drawing two opposing forces (11i) followed by a rise to the retention test. For indicating that the forces are the same size (11ii), the control group there was an increase in their scores throughout the tests whereas the experimental group increased and then decreased their score.

<table>
<thead>
<tr>
<th>Question 12c</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
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<td>100</td>
</tr>
<tr>
<td>Control group</td>
<td>100</td>
<td>100</td>
<td>83</td>
</tr>
</tbody>
</table>

Similar results were obtained by both groups for question 12 about which way a chair spring pushed a woman on the chair except that the control group decreased their score in the retention test. This was similar to question four and could act as an anchor.

<table>
<thead>
<tr>
<th>Question 13b</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>62</td>
<td>85</td>
<td>77</td>
</tr>
<tr>
<td>Control group</td>
<td>58</td>
<td>83</td>
<td>75</td>
</tr>
</tbody>
</table>

There was not much difference between the groups for question 13 which asked about what would happen to the motion of a rocket on a launch pad if the upward force equalled the weight of the rocket.
<table>
<thead>
<tr>
<th>Question 14i</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>62</td>
<td>100</td>
<td>85</td>
</tr>
<tr>
<td>Control group</td>
<td>67</td>
<td>83</td>
<td>92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 14ii</th>
<th>Initial (% correct)</th>
<th>Post (% correct)</th>
<th>Retention (% correct)</th>
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</thead>
<tbody>
<tr>
<td>Experimental group</td>
<td>23</td>
<td>92</td>
<td>69</td>
</tr>
<tr>
<td>Control group</td>
<td>42</td>
<td>58</td>
<td>25</td>
</tr>
</tbody>
</table>

Question 14 asked about the forces on a stationary submarine on the seabed. This is very similar to the ‘book on the table’ problem and for drawing the opposing forces (14i) the results followed a similar pattern. The experimental group increased more than the control group in going from initial to post-test which would support the bridging analogy approach but the control group then went on to further increase their score for the retention test whereas the experimental group decreased their score in this test. For drawing the forces the same size, the patterns of both groups were similar in that there was a rise and then a fall but the rise for the experimental group was larger than for the control group and the subsequent drop was smaller, again supporting the bridging analogy approach.
3.2 Conclusions and evaluation of pilot research

The pilot research showed there was potential for further research. There was a trend in the results to indicate that using bridging analogies is a successful way of changing misconceptions. This is in agreement with the literature as shown at the beginning of this chapter.

Most of the studies already carried out concentrate on the topic of forces and especially Newton’s third law and it was decided to continue the research but covering more topics. One reason for this was to look more closely at the ‘sense’ levels during the different bridging analogies (see Chart 1 below). An interesting feature of the bridging analogy used in the pilot study was that the average sense level actually dropped during the bridging analogies and only rose to more than its initial level after the final explanation. This could have been due to the fact that the analogous nature of the experiments was not explained to the pupils sufficiently. However, it could be due to a more fundamental reason in that there is a state of flux or confusion while basic concepts are changing towards a more scientific view. It was proposed that a similar analysis should be carried out on the bridging analogies used in the main body of research.

![Chart 1 Analysis of 'sense' ratings for bridging analogies for the 'book on table' problem](image-url)
Although each topic, on its own, may not produce statistically significant results, it is possible that the accumulated results of all the topics may be statistically significant.

Method of testing

The pre-test, post-test and retention test became, for the pupils, very tedious since they were each so long. It was decided to shorten the tests from 14 to three questions in order for them to become a more positive experience for the pupils. This coincided with the decision to widen the area of research to cover several topics.

There were problems with lack of feedback since it was not possible to discuss the questions until after the retention test. The pupils were used to being given feedback almost immediately. It was felt to be unlikely to be able to overcome this problem entirely although a fuller explanation of the rationale behind the tests could be given.

The pupils were also not used to being given questions about a topic that they had not already covered and they needed a lot of reassurance with the pre-test. It was important not to raise levels of anxiety with the tests and to this aim they were not referred to as tests but merely some questions that were not going to be given a mark or used as assessment.

Introducing video cameras was considered but it was felt that this could cause too much disruption as the pupils were not used to being videoed. It was felt that keeping the lessons as normal as possible would help to keep the research valid. It was envisaged that pupils would be even more likely to give answers that they thought the teacher would want rather than those based on their own ideas if they were being videoed.
CHAPTER FOUR

Main research (part 1)

4.1 Methodology

For each topic, one of the classes acted as the control group and the other was the experimental group. The classes alternated between being control and experimental to try to reduce bias or, at least, make it more noticeable.

Both groups underwent a pre-test just before the topic, a post-test the week after the topic and a retention test eight weeks after the post-test. These tests were identical. The questions asked in the tests can be found in Appendix IIc. Typically, they included a question which was closely aligned to and contextually similar to the target and other questions on a similar theme but set in a slightly different context. An example is shown below of the questions given for the Forces 2 (stretching) topic.
SOME QUESTIONS ON STRETCHING

1. Sarah found that a 5cm spring stretched to 7cm when she hung a weight on it. She took a 10cm spring (identical to the first one except for the length) and hung the same weight on it. What do you think the new length was?

2. The graph shows the length (not the extension) of a spring with different weights on it.

![Graph of length of spring against weight](image)

Sketch on the graph what you would find if your spring was only 2cm long to begin with. The first dot is shown.

3. Alex has a box with a lid which she wants to hold secure with a rubber band. She finds that a 20cm rubber band is just the right tightness when stretched round the box. It has to stretch to 30cm.

![Diagram of rubber band](image)

She then takes another box and finds that the rubber band has to stretch to 60cm. She wants the same tightness of rubber band as for the first box. All the rubber bands she has are exactly the same except for their original length. Should she choose:

a. a 50cm rubber band because to be the right tightness, the band will need to stretch 10cm so a 50cm band will stretch to 60cm.

b. a 40cm band because to be the right tightness, the band will stretch by 10cm for each 20cm of band so a 40cm band will stretch to 60cm.
The first question is almost identical to the target concept of the same weight producing twice the extension for a double length but otherwise identical spring. The other two questions required use of the concept of original length and extension being directly proportional but these two questions are set in different contexts.

The control group were taught the topic in a traditional style which usually comprised an experiment with conclusion and explanation, followed by more examples and questions. The control group work for each topic can be found in Appendix IIa.

The experimental group were presented with a *target question* which included a known misconception in the topic. They were given two possible explanations/statements to the question and asked to score a mark out of five as to how much sense each explanation/statement made. They were also asked to say which they thought was the more likely to be correct. The sense scoring was to elicit their conception whereas their likely answer could have been based on the answer that they thought the teacher might require. Following this there was an analogous experiment/question (the *anchor*). This was designed so that most of the students would be able to answer it correctly. It was a concrete analogy to fit in with the concrete operational stage at which many of the pupils would be working. A class discussion was then held to decide how similar the anchor and target were. The target question was then repeated. A *bridging analogy* was then introduced, typically less concrete than the anchor but more concrete than the target. A discussion about the similarities and differences between the anchor and bridge and between the bridge and target followed. The target question was repeated and then an explanation given before the final time of asking the target question.
This can be summarised as follows.

The first target question, anchor, bridge and explanation were on separate pages to reduce the risk of reading ahead. The pupils worked by themselves apart from the class discussions and were encouraged to feel that it was acceptable to change their minds about the target question answers as they went through the work but that they must not go back and change what they had previously written. Details of the experimental group work can be found in Appendix IIa.

In using the bridging analogies, the pupils were not specifically told that an analogy was being used. This was so that the pupils would not feel that they had to use the analogies in their answers. If they were told that the anchor was analogous to the target then that may have influenced their answers to the ‘sense’ explanations/statements and ‘which explanation/statement they thought was correct’ question. However, the anchor, bridging analogies and target situations were compared to elicit their similarities and differences.
4.2 Bridging analogies used and their analysis

A brief explanation of the anchor and bridge analogies being used in this part of the research are given together with a short analysis partly based on Thiele and Treagust (1995) and Parida and Goswami (2000) – see pp 106-107.

Heat 1 (thermal equilibrium)

Target
Metal often feels colder than cork because it removes heat from your body and conducts it away quicker than cork.

Anchor

Which pea drops off first?

Bridge

Which cools quicker – a beaker of hot water on a cork mat or one on a metal mat (both beakers have lids).
Analysis

Visualisation effect  These analogies (anchor and bridge) contain pictorial forms to aid visualisation. The process also includes activity (comparison of analogues and target) to help cognition.

The extent of mapping  These are enriched analogies since they contain several features common to both the analogue and target.

Analogue explanation  In this case, the anchor and bridge analogues are fully explained in terms of conducting ability.

Analogy identification  The analogue and target features are compared.

Analogy limitation  The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target.

Target and analogue domains  For this topic the target and analogue (anchor and bridge) come from the same domain of heat conduction.

Superordinate concept  The target and analogues (anchor and bridge) belong to the superordinate concept of heat flow.
Heat 2 (radiation and absorption)

Target
Good absorbers are good radiators of heat.

Anchor
The pupils decide that, in general, people who are good at throwing balls are good at catching them.

Bridge
The pupils are asked to think of the balls as packets of energy that can be thrown and caught.

Analysis

Visualisation effect These analogies are not shown in a pictorial form but the anchor is easy to visualise. In the next part of the research, a diagram was included to further aid visualisation. The process also includes activity (comparison of analogues and target) to help cognition.

The extent of mapping These are enriched analogies since they contain several features common to both the analogue and target.

Analogue explanation In this case, the anchor analogue is part of the pupils’ direct experience.

Analogy identification The analogue and target features are compared.

Analogy limitation The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target. In fact, long discussions ensued as to whether the anchor statement was
valid but in the end it was decided that, if one were in a netball team, for example, then you would have to be good at both throwing and catching a ball.

**Target and analogue domains** For this analogy the target and analogues come from different domains. The target comes from electromagnetic radiation and absorption and the anchor analogue comes from the domain of game playing.

**Superordinate concept** The target and analogues (anchor and bridge) belong to the superordinate concept of giving and receiving.

**Light 1 (reflection and scattering)**

**Target**
We see objects, which do not produce their own light, by reflection.

**Anchor**
This involves rolling a ball towards a straight barrier at different angles and marking where the ball reflected. The position of the ‘image’ is then found.

**Bridge**
The anchor is repeated but this time the ball is rolled towards two barriers, touching but at an angle to each other to simulate roughness of a surface. It is then shown that the ‘image’ could not be found although there is reflection.

**Analysis**

**Visualisation effect** These analogies (anchor and bridge) contain pictorial forms to aid visualisation. The process also includes activity (comparison of analogues and target) to help cognition.
The extent of mapping  These are enriched analogies since they contain several features common to both the analogue and target.

Analogue explanation  In this case, the anchor analogue has been explained in a previous lesson and the pupils have had experience of image finding in mirrors. In retrospect, however, this was felt to be rather too difficult for the particular age group to fully comprehend and the anchor and bridge were changed in the following part of the research to ensure that the analogue was more comprehensible.

Analogy identification  The analogue and target features are compared.

Analogy limitation  The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target.

Target and analogue domains  For this analogy the target and analogue come from different domains. The target comes from reflection of light and the anchor and bridge analogues come from the domain of ‘reflection’ of balls from hard surfaces.

Superordinate concept  The target and analogues (anchor and bridge) belong to the superordinate concept of reflection.

Light 2 (colour)

Target
Colour filters remove colours from white light.

Anchor
Filter paper is used to separate sand and water.
Bridge

A colour filter is placed between a spectrum producer and a screen so that only the filter colour is seen on the screen.

Analysis

Visualisation effect These analogies are experimental demonstrations to aid visualisation. The process also includes activity (comparison of analogue and target) to help cognition.

The extent of mapping These are enriched analogies since they contain several features common to both the analogue and target.

Analogue explanation In this case, the anchor analogue has been fully explained in a previous (chemistry) lesson.

Analogy identification The analogue and target features are compared.

Analogy limitation The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target.

Target and analogue domains For this analogy the target and analogues come from different domains. The target and bridge come from absorption of light and the anchor analogue comes from the domain of separating mixtures.

Superordinate concept The target and analogues (anchor and bridge) belong to the superordinate concept of separation by filtering.
Forces 1 (balanced forces)

Target
There are balanced forces acting on the book – gravity causing the weight of the book and the force of the table pushing up on the book.

Anchor
This involves the pupils feeling the force of a squashed spring on their hands.

Bridge
This involves the pupils seeing a book squashing a spring and thus inferring that the book is pushing on the spring.

Analysis

Visualisation effect The anchor analogy is a kinaesthetic experiment and the bridge is an experimental demonstration. Both of these aid visualisation. The process also includes activity (comparison of analogue and target) to help cognition.

The extent of mapping These are enriched analogies since they contain several features common to both the analogue and target.

Analogue explanation In this case, the anchor analogue is experienced and does not need an explanation as such.

Analogy identification The analogue and target features are compared.

Analogy limitation The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target.
Target and analogue domains  For this analogy the target and analogues (anchor and bridge) come from the same domain of the action of forces.

Superordinate concept  The target and analogues (anchor and bridge) belong to the superordinate concept of objects exerting forces.

Forces 2 (stretching)

Target
Doubling the length of a spring doubles the extension for the same stretching force.

Anchor
For this, the pupils pull a short piece of elastic as hard as they can. Then they have to imagine pulling a longer piece of elastic using the same force and decide whether the stretch would be more than or the same as for the short piece of elastic.

Bridge
The pupils watch a piece of elastic being pulled by a force of 4N using a newtonmeter. This is repeated using a piece of elastic of twice the length to give twice the extension. Some may argue that this is not a true analogy but merely a demonstration of the experiment. This may be partly valid but the bridge follows on from the anchor which was an analogy in that the anchor used is merely a reminder of everyday situations such as a short elastic band not stretching as much as a long elastic band. The target is specifically referring to springs but the anchor and bridge are about elastic.
Analysis

**Visualisation effect**  The anchor includes an experiment and the bridge is a demonstration experiment, both being designed to enhance visualisation. The process also includes activity (comparison of analogues and target) to help cognition.

**The extent of mapping**  These are enriched analogies since they contain several features common to both the analogue and target.

**Analogue explanation**  The anchor refers to everyday experiences and does not need an explanation as such and the bridge is a more mathematical demonstration, again not really needing an explanation at this stage.

**Analogy identification**  The analogue and target features are compared.

**Analogy limitation**  The limitations of the analogies used are discussed as part of the exercise of examining the similarities and differences between the analogues and target.

**Target and analogue domains**  For this analogy the target and analogues (anchor and bridge) come from the same domain of stretching forces.

**Superordinate concept**  The target and analogues (anchor and bridge) belong to the superordinate concept of the idea that each part of the length of an object ‘feels’ and is affected by a stretching force.
4.3 Results of pre-, post- and retention tests (2000-20001)

The full test results are shown in Appendix IIId. The results shown below are:

a. The total post-test score for each question - the total retention score for each question. The total here refers to the correct answers given by the whole group, either the experimental or the control group. The probability of the test results happening by chance is given. This was calculated by doing a one-tailed t-test on correlated data.

b. The total post-test score for each pupil - the total retention test score for each pupil. The total here refers to the correct answers given for all the questions in the topic. The probability of the test results happening by chance is given. This was calculated by doing a one-tailed t-test on non-correlated data. The t-test for equal and unequal variance gave the same result to two decimal places for each topic except Light 1. The variance for these sets of results was calculated using the F ratio and they were found to be of equal variance.

c. A graph showing the average test mark for the two groups for the three tests is given.
Heat 1 (thermal equilibrium) test results

a.

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Note that a negative number indicates an improvement from post-test to retention test.

p = 0.22

Table 7 The total post-test score for each question - the total retention score for each question (Heat 1)

b.

Experimental 0 1 0 0 0 -0.5 0 0 0 1 0.5 -0.5
Control 0.5 0.5 -0.5 0.5 0.5 1 0 0.5 -1 0 0.5

Experimental -0.5 0 0 0 0 1 -1 0 0 0 0
Control 0.5 -1 -0.5 0 1.5 1 1 0.5 -1.5 1 0

p = 0.10

Table 8 The total post-test score for each pupil - the total retention test score for each pupil (Heat 1)

Chart 2 To show average test marks for experimental and control groups for the three tests (heat 1)
Heat 2 (radiation and absorption) test results

a.

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-2.5</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Note that a negative number indicates an improvement from post-test to retention test. 

\[ p = 0.29 \]

Table 9 The total post-test score for each question - the total retention score for each question (Heat 2)

b.

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Control</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>question 1</td>
<td>-1</td>
<td>0</td>
<td>-1.5</td>
<td>0</td>
</tr>
<tr>
<td>question 2</td>
<td>-0.5</td>
<td>0</td>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td>question 3</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>question 4</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ p = 0.30 \]

Table 10 The total post-test score for each pupil - the total retention test score for each pupil (Heat 2)

Chart 3 To show average test marks for experimental and control groups for the three tests (Heat 2)
Light 1 (reflection/scattering) test results

a.  

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-1.5</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Note that a negative number indicates an improvement from post-test to retention test.  

$p = 0.11$

Table 11 The total post-test score for each question - the total retention score for each question (Light 1)

b.  

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

$p = 0.28$

Table 12 The total post-test score for each pupil - the total retention test score for each pupil (Light 1)

Chart 4 To show average test marks for experimental and control groups for the three tests (light 1)
Light 2 (colour) test results

a.

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Note that a negative number indicates an improvement from post-test to retention test.

For post-retention (experimental group)

1

2

3

p = 0.40 but in the wrong direction (the control group’s marks did not reduce as much as the experimental group’s marks from post-test to retention test).

Table 13 The total post-test score for each question - the total retention score for each question (Light 2)

b.

<table>
<thead>
<tr>
<th></th>
<th>1.5</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>-1</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

p = 0.41 (again in the wrong direction)

Table 14 The total post-test score for each pupil - the total retention test score for each pupil (Light 2)

Chart 5 To show average test marks for experimental and control groups for the three tests (light 2)
Forces 1 (balanced forces) test results

a. Note that a negative number indicates an improvement from post-test to retention test.

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>-2</td>
<td>-3</td>
</tr>
</tbody>
</table>

Table 15 The total post-test score for each question - the total retention score for each question (Forces 1)

b. p = 0.50

<table>
<thead>
<tr>
<th>Experimental</th>
<th>-1 0 0 0 -1 0 0 0 -1 0</th>
<th>Control</th>
<th>0 0 0 0 0 0 1 0 0 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>0 -1 0 0 0 1 -1</td>
<td>Control</td>
<td>1 -1 -1 0 -1 0 0 0 -1</td>
</tr>
</tbody>
</table>

Table 16 The total post-test score for each pupil - the total retention test score for each pupil (Forces 1)

Chart 6 To show average test marks for experimental and control groups for the three tests (forces 1)
Forces 2 (stretching) test results

a.

<table>
<thead>
<tr>
<th>question number</th>
<th>post - retention (experimental group)</th>
<th>post - retention (control group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-2</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>-3</td>
<td>0</td>
</tr>
</tbody>
</table>

Note that a negative number indicates an improvement from post-test to retention test. 

\[ p = 0.43 \]

Table 17 The total post-test score for each question - the total retention score for each question (Forces 2)

b.

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ p = 0.47 \]

Table 18 The total post-test score for each pupil - the total retention test score for each pupil (Forces 2)

Chart 7 To show average test marks for experimental and control groups for the three tests (forces 2)
4.4 Analysis of pre-, post- and retention tests

There was an increase from pre-test to post-test for all the topics for both groups. There was greater improvement for the control classes than the experimental classes. This was not unexpected as the control classes had seen more examples and practised more and a greater variety of questions than the experimental group. The post-test was only one week after the topic so this may have been similar to a 'teaching to the test' situation. The experimental group had spent most of their time working through the anchor, bridge and target questions.

The relative success of the bridging analogy approach for the different topics can be quantified in the following way. The average retention test result (%) is subtracted from the average post-test result (%) for both the experimental and control groups. This shows how much their test results have dropped and a negative number indicates an improvement. The difference in this number between the experimental and control group is then calculated. The higher the number, the more successful was the experimental approach compared with the control approach.

As far as this research is concerned, the most interesting feature was the difference between the post-test and retention test (see Table 19). For the control groups, the retention test score, for each topic, was lower than the post-test score for four out of the six topics. Again, this was expected since it is likely that pupils may revert to their original conceptions after a gap of two months. The experimental group, however, maintained their post-test score in one topic (Heat 1) and in four cases, even increased their marks (Heat 2, Light 1, Forces 1 and Forces 2). In Light 2 they did decrease their score.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Post-retention test Experimental (E)</th>
<th>Post-retention test control (C)</th>
<th>C – E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat 1</td>
<td>0.0</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Heat 2</td>
<td>-2.0</td>
<td>2.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Light 1</td>
<td>-1.1</td>
<td>1.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Light 2</td>
<td>3.8</td>
<td>2.2</td>
<td>-1.6</td>
</tr>
<tr>
<td>Forces 1</td>
<td>-6.7</td>
<td>-6.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Forces2</td>
<td>-3.5</td>
<td>-2.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 19 To show relative success of the bridging analogy approach for the different topics

A one-tailed t-test (correlated data) carried out on the results shown in Table 19 returned a probability of 0.08 that these results are due to chance alone so, although the results are not statistically significant at the 0.05 level they are sufficiently meaningful as to warrant further research.
4.5 Results and analysis of bridging analogies

In order to analyse this approach, it was decided to make use of the 'sense ratings' the pupils had given to each possible answer to the target question. The target question appeared four times; initially, after the anchor, after the bridge and after the explanation. The sense rating that the pupil gave the 'misconception answer' was subtracted from the sense rating of the 'scientific answer' to give numbers which were averaged (maximum 4, minimum -4). These numbers represent the relative strength of two conceptions during the course of the approach. The higher the number, the stronger the 'scientific conception'. The results are shown in Table 20 and in Chart 8a. Chart 8b shows how the percentage of correct answers given differed through the stages.

<table>
<thead>
<tr>
<th>topic</th>
<th>initial</th>
<th>after anchor</th>
<th>after bridge</th>
<th>after explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat 1</td>
<td>-1.7</td>
<td>-1.46</td>
<td>-1.46</td>
<td>0.23</td>
</tr>
<tr>
<td>heat 2</td>
<td>-0.67</td>
<td>0.33</td>
<td>1.1</td>
<td>2.86</td>
</tr>
<tr>
<td>light 1</td>
<td>-0.75</td>
<td>-0.5</td>
<td>0.64</td>
<td>2.08</td>
</tr>
<tr>
<td>light 2</td>
<td>-0.39</td>
<td>0.68</td>
<td>1.66</td>
<td>2.21</td>
</tr>
<tr>
<td>forces 1</td>
<td>-0.62</td>
<td>-0.32</td>
<td>0.45</td>
<td>1.82</td>
</tr>
<tr>
<td>forces 2</td>
<td>-0.9</td>
<td>-1.14</td>
<td>-0.81</td>
<td>-0.52</td>
</tr>
</tbody>
</table>

Table 20 To show the average 'sense of 'scientific conception' answer - 'sense of 'misconception' answer'
Chart 8a Progress during the bridging analogies

Chart 8b To show % of correct answers at each stage
The probability of these results happening by chance and not because of the bridging analogies used was calculated in two ways.

- A one-tailed test (correlated data) was carried out using the topics as the subjects with the two measures being the 'initial sense rating the pupil gave to the scientific answer' - the 'initial sense rating the pupil gave to the misconception answer' and the sense rating the pupil gave to the scientific answer' - the 'sense rating the pupil gave to the misconception answer' for after the bridge. This returned a probability of 0.01 and therefore significant at the 1% level.

- A one-tailed test (correlated data) was carried out for each topic using the pupils as subjects with the two measures being as above. The results were as follows:
  
<table>
<thead>
<tr>
<th>Topic</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat 1</td>
<td>0.202</td>
</tr>
<tr>
<td>Heat 2</td>
<td>0.003</td>
</tr>
<tr>
<td>Light 1</td>
<td>0.025</td>
</tr>
<tr>
<td>Light 2</td>
<td>0.003</td>
</tr>
<tr>
<td>Forces 1</td>
<td>0.019</td>
</tr>
<tr>
<td>Forces 2</td>
<td>0.431</td>
</tr>
</tbody>
</table>

The only two of these which failed to be significant at the 0.05 level were Heat 1 and Forces 2.

It can be seen from the table and graphs that there was a general increase (or, at least, no decrease) throughout the stages in all topics except Forces 2. Even when there was no increase or decrease in the sense ratings, the percentage giving the correct answer rose and similarly, when there was no increase or decrease for the percentage giving the correct answer, the sense ratings rose. The increases show
that all the parts (anchor, bridge and explanation) are useful in this approach. The method seems to be quite successful in changing their ideas, although these results do not attempt to reveal any long-term effects since each topic took no longer than 30 minutes to work through.

The dip in the Forces 2 topic on stretching, between the initial response and after the anchor, could indicate that the anchor has no relevance to the target question for the pupils and has, in fact, caused some of them to cast doubt on what they first thought. The lack of relevance could be due to the emphasis in the target on the weight required and the emphasis in the anchor on the extensions when the same force is used. The bridging analogy also uses the same force but here the pupils can see mathematically the relationship between initial length and extension and it may be this which increases the sense ratings and percentage of correct answers given.

It is difficult to compare the relative success of the bridging analogy approach between topics as much must depend on the starting point of each. If the initial sense of the scientific conception is low then this can mean one of two things:

- The misconception is entrenched and therefore difficult to change.
- The misconception makes more sense than the scientific conception but it is quite easy to change a pupil's mind by a small change in how the problem is viewed perhaps by giving even a low-key clue, e.g. Kokinov and Yoveva (1996); Kokinov et al (1997).
CHAPTER FIVE

Main research (part 2)

Introduction

It was thought that the bridging analogies used within a topic were not close enough to each other and it was decided to introduce another bridging analogy into each topic. Reducing the number of differences between the steps should make it easier for the pupils to understand the target. In Piagetian terms, there will be more assimilation involved and less accommodation than going straight from anchor to target. In Vygotskian terms, the bridging analogies act as the scaffolding necessary in the Zone of Proximal Development. An analysis of the bridging analogies is shown below.

The first four topics were used in this part of the research. The Forces 1 (balanced forces) had been looked at using more than one bridging analogy in the pilot research and the results are discussed in this section together with those from the other four topics. The sixth topic on stretching forces (Forces 2) does not lend itself to having any extra bridging analogies since the anchor and target are already quite close.
5.1 Analysis of bridging analogies

The following analysis looks at the similarities and differences between the anchor, bridging and target parts of the analogy. The first comparison is between the anchor and target, the second is between the anchor, bridge and target using just one bridge and the final comparison is between the anchor, bridges and target when two bridging analogies are used.

Heat 1

Target
Objects in thermal equilibrium are at the same temperature or, in pupils’ terms, a piece of metal and a piece of cork are at the same temperature if they have been in the same place for a while. The common misconception is that the metal feels colder because it is naturally at a lower temperature. The scientific conception is that the metal feels colder since metal conducts heat away from our hand more quickly than cork does.

Anchor
Most pupils are happy about the fact that metals are good conductors of heat. If the following apparatus is set up, most will, quite correctly, predict that the pea on the metal rod will drop off first.
For pupils, this analogy may be too distant from the target and a bridging analogy is required. In order to see why the analogy could be too remote, it is necessary to look at the relevant features for both the target and analogue.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Heat flow involved</em></td>
<td><em>Heat flow involved</em></td>
</tr>
<tr>
<td>Temperature of Bunsen is greater than that of rods*</td>
<td>Temperature of hand is greater than that of plates*</td>
</tr>
<tr>
<td>Metal / glass</td>
<td>Metal / cork</td>
</tr>
<tr>
<td>Mode of heating is the Bunsen</td>
<td>Mode of heating is the hand</td>
</tr>
<tr>
<td>Inanimate (Bunsen)</td>
<td>Animate (hand)</td>
</tr>
<tr>
<td>Emphasis on heating</td>
<td>Emphasis on cooling</td>
</tr>
<tr>
<td>Focus is on temperature of metal/glass near peas**</td>
<td>Focus should be on temperature of hand but probably is on temperature of metal/cork**</td>
</tr>
</tbody>
</table>

Features in italics are similar features

Table 21 Comparison of features of anchor and target (Heat 1)

*Although this is a similarity, it may not be perceived as such by pupils. They may not think of themselves as being warmer than their surroundings (although they know it as a scientific fact). Normal conversation is that we feel hot or cold and when pupils feel cold, do they perceive themselves as being at a lower temperature than their surroundings?

**When pupils touch a piece of metal, the focus is on the apparent temperature of the metal – the metal feels cold. However, the focus should be on the temperature of the hand at the point of contact – the hand feels cold. This analogy does not help in this case. In fact, it positively hinders since the focus in the anchor analogy is also on the temperature of the conductor (metal or glass).
What is needed is a bridging analogy (or possibly two) in order to turn the differences into similarities and to overcome the problem identified above. The bridging analogy used is that of two beakers of hot water cooling, identical in every respect except that one beaker is on a metal plate and the other is on a cork plate. The temperatures of the two lots of water are taken as they cool to identify which cools quicker.

Figure 15 Bridging analogy (Heat 1)
<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat flow involved</strong></td>
<td><strong>Heat flow involved</strong></td>
<td><strong>Heat flow involved</strong></td>
</tr>
<tr>
<td>Temperature of Bunsen is greater than that of rods*</td>
<td>Temperature of water is greater than that of plates*</td>
<td>Temperature of hand is greater than that of plates*</td>
</tr>
<tr>
<td>Metal / glass</td>
<td>Metal / cork</td>
<td>Metal / cork</td>
</tr>
<tr>
<td>Mode of heating is the Bunsen</td>
<td>Mode of heating is the hot water</td>
<td>Mode of heating is the hand</td>
</tr>
<tr>
<td>Inanimate (Bunsen)</td>
<td>Inanimate (hot water)</td>
<td>Animate (hand)</td>
</tr>
<tr>
<td>Emphasis on heating</td>
<td>Emphasis on cooling</td>
<td>Emphasis on cooling</td>
</tr>
<tr>
<td>Focus is on temperature of metal/glass near peas**</td>
<td>Focus is on temperature of water**</td>
<td>Focus should be on temperature of hand but probably is on temperature of metal/cork**</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features

Table 22 Comparison of features of anchor, bridging analogy and target (Heat 1)

*The introduction of the bridging analogy has not removed this difficulty but has possibly lessened it since the temperature of hot water is much less than that of the Bunsen and nearer to body temperature.

**The introduction of the bridging analogy has possibly helped the pupils to focus less on the apparent temperature of the metal/cork and more on the temperature of the hand at the point of contact.

Leaving aside the last feature compared, between the anchor analogy and the target there are four differences and two similarities. After introducing the bridging analogy, there are three differences between the anchor analogy and the
bridge and three similarities. There are two differences between the bridge and
target and four similarities. As we can see, we are reducing the number of
differences between the steps in the process. It would improve the process further
if we introduce another bridge to reduce the number of differences between the
steps as much as possible. This extra bridge could be similar to but precede the
present one and consist of taking the temperatures of the metal and cork plates as
the hot water cools. This would wipe out one of the differences between anchor
and bridge – the emphasis on cooling would be changed to an emphasis on heating
as in the anchor.

Figure 16 Extra bridging analogy (Heat 1)
<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy 1 features</th>
<th>Bridging analogy 2 features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat flow involved</td>
<td>Heat flow involved</td>
<td>Heat flow involved</td>
<td>Heat flow involved</td>
</tr>
<tr>
<td>Temperature of Bunsen is greater than that of rods</td>
<td>Temperature of water is greater than that of plates</td>
<td>Temperature of water is greater than that of plates</td>
<td>Temperature of hand is greater than that of plates</td>
</tr>
<tr>
<td>Metal / glass</td>
<td>Metal / cork</td>
<td>Metal / cork</td>
<td>Metal / cork</td>
</tr>
<tr>
<td>Mode of heating is the Bunsen</td>
<td>Mode of heating is the hot water</td>
<td>Mode of heating is the hot water</td>
<td>Mode of heating is the hand</td>
</tr>
<tr>
<td>Inanimate (Bunsen)</td>
<td>Inanimate (hot water)</td>
<td>Inanimate (hot water)</td>
<td>Animate (hand)</td>
</tr>
<tr>
<td>Emphasis on heating</td>
<td>Emphasis on heating</td>
<td>{Emphasis on cooling}</td>
<td>Emphasis on cooling</td>
</tr>
<tr>
<td>Focus is on temperature of metal/glass near peas**</td>
<td>Focus is on temperature of the metal/cork**</td>
<td>Focus is on temperature of the water**</td>
<td>Focus should be on temperature of hand but probably is on temperature of metal/cork**</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features. Where brackets are used, the similarities are within rather than between the brackets.

Table 23 Comparison of features of anchor, bridging analogies and target (Heat 1)
To summarise:

1. Anchor → Target
   - 2 similarities
   - 4 differences

2. Anchor → Bridge 1 → Target
   - 4 similarities
   - 2 differences

3. Anchor → Bridge 1 → Bridge 2 → Target
   - 4 similarities
   - 1 difference
   - 2 differences
Heat 2

Target

Objects that are good at absorbing heat radiation are good at radiating it. This is the scientific conception. The common misconception is that good absorbers must be poor radiators and vice versa.

Anchor

Most pupils will agree that, generally, people who are good at throwing a ball will be good at catching it and those who are poor at throwing will usually be poor at catching. This analogy may be too distant from the target and a bridging analogy is required. In order to see why the analogy could be too remote, it is necessary to look at the relevant features for both the target and analogue.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idea of good/poor</strong></td>
<td><strong>Idea of good/poor</strong></td>
</tr>
<tr>
<td><strong>Idea of something traveling from/to something</strong></td>
<td><strong>Idea of something traveling from/to something</strong></td>
</tr>
<tr>
<td>Object being thrown/caught</td>
<td>Waves being radiated/absorbed</td>
</tr>
<tr>
<td>Visible action</td>
<td>Invisible action</td>
</tr>
<tr>
<td>Person</td>
<td>Non-living object</td>
</tr>
<tr>
<td>Throwing/catching</td>
<td>Radiating/absorbing.</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features

Table 24 Comparison of features of anchor and target (Heat 2)
What is needed is a bridging analogy (or possibly two) in order to turn the differences into similarities and to overcome the problem identified above. The bridging analogy used is to imagine an object throwing/catching very small balls/particles in a similar way to a person throwing/catching balls.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea of something travelling from/to something</td>
<td>Idea of something travelling from/to something</td>
<td>Idea of something travelling from/to something</td>
</tr>
<tr>
<td>Idea of good/poor</td>
<td>Idea of good/poor</td>
<td>Idea of good/poor</td>
</tr>
<tr>
<td>Object being thrown/caught</td>
<td>Object being thrown/caught</td>
<td>Waves being radiated/absorbed</td>
</tr>
<tr>
<td>Visible action</td>
<td>Invisible action</td>
<td>Invisible action</td>
</tr>
<tr>
<td>Person</td>
<td>Non-living object</td>
<td>Non-living object</td>
</tr>
<tr>
<td>Throwing/catching</td>
<td>Throwing/catching</td>
<td>Radiating/absorbing</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features.

Table 25 Comparison of features of anchor, bridging analogy and target (Heat 2)

Between the anchor analogy and the target there are four differences and two similarities. After introducing the bridging analogy, there are two differences and four similarities between the anchor analogy and the bridge. There are two differences and four similarities between the bridge and target. As we can see, we are reducing the number of differences between the steps in the process. It would improve the process further if we introduce another bridge to reduce the number of differences between the steps as much as possible. This extra bridge could be to
imagine an object throwing out little packets of energy (waves) instead of particles.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy 1 features</th>
<th>Bridging analogy 2 features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea of something travelling from/to something</td>
<td>Idea of something travelling from/to something</td>
<td>Idea of something travelling from/to something</td>
<td>Idea of something travelling from/to something</td>
</tr>
<tr>
<td>Object being thrown/caught</td>
<td>Object being thrown/caught</td>
<td>Waves being radiated/absorbed</td>
<td>Waves being radiated/absorbed</td>
</tr>
<tr>
<td>Visible action</td>
<td>Invisible action</td>
<td>Invisible action</td>
<td>Invisible action</td>
</tr>
<tr>
<td>Person</td>
<td>Non-living object</td>
<td>Non-living object</td>
<td>Non-living object</td>
</tr>
<tr>
<td>Throwing/catching</td>
<td>Throwing/catching</td>
<td>Throwing/catching</td>
<td>Radiating/absorbing</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features. Where brackets are used, the similarities are within rather than between the brackets.

Table 26 Comparison of features of anchor, bridging analogies and target (Heat 2)
To summarise:

2 similarities
Anchor → Target
4 differences

4 similarities
Anchor → Bridge 1
2 differences

4 similarities
Bridge 1 → Target
2 differences

4 similarities
Anchor → Bridge 1
2 differences

5 similarities
Bridge 1 → Bridge 2
1 difference

5 similarities
Bridge 2 → Target
1 difference
Light 1

Target
Objects that do not produce their own light can be seen because they reflect light hitting them. However, the light is scattered since their surfaces are usually rough (on the microscopic scale). This is why we cannot see our reflection in these objects. A common misconception is that light falls on the objects and stays there even though many pupils accept the idea that mirrors reflect light.

Anchor
The anchor had to be changed from the one used in the previous part of the research since it was felt to be too difficult as it involved finding the position of the images using reflection. This is not usually done until year 11 (15-16 year olds). The replacement anchor did not involve finding the position of the images.

Two mirrors at an angle produce more than one image and the pupils will readily agree. However, this is a very distant analogy and in order to see why the analogy is too remote, it is necessary to look at the relevant features for both the target and analogue.
<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Can see mirrors</em></td>
<td><em>Can see paper</em></td>
</tr>
<tr>
<td>One bend</td>
<td>Many ‘bends’</td>
</tr>
<tr>
<td>Bend obvious</td>
<td>‘Bends’ <strong>not</strong> obvious</td>
</tr>
<tr>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp <strong>not</strong> seen</td>
</tr>
<tr>
<td>Reflection of self seen</td>
<td>Reflection of self <strong>not</strong> seen</td>
</tr>
<tr>
<td>Two mirrors</td>
<td>One piece of paper</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features

Table 27 Comparison of features of anchor and target (Light 1)

There is one similarity and five differences. What is needed is a bridging analogy (or possibly two) in order to turn the differences into similarities. The bridging analogy used is of crumpled foil.
<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can see mirrors</td>
<td>Can see foil</td>
<td>Can see paper</td>
</tr>
<tr>
<td>One bend</td>
<td>Many bends</td>
<td>Many ‘bends’</td>
</tr>
<tr>
<td>Bend obvious</td>
<td>Bends not obvious</td>
<td>‘Bends’ not obvious</td>
</tr>
<tr>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp not seen</td>
</tr>
<tr>
<td>Reflection of self seen</td>
<td>Reflection of self not seen</td>
<td>Reflection of self not seen</td>
</tr>
<tr>
<td>Two mirrors</td>
<td>One piece of foil</td>
<td>One piece of paper</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features

Table 28 Comparison of features of anchor, bridging analogy and target (Light 1)

There are now two similarities and four differences between the anchor and bridge and five similarities between the bridge and target with only one difference. The number of differences between the anchor and bridge is still high so another bridge is introduced. This is of a smooth piece of foil with just one bend in it. This is inserted between the anchor and the original bridge and becomes bridging analogy 1.
<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy 1 features</th>
<th>Bridging analogy 2 features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can see mirrors</td>
<td>Can see foil</td>
<td>Can see foil</td>
<td>Can see paper</td>
</tr>
<tr>
<td>{One bend}</td>
<td>{One bend}</td>
<td>{Many bends}</td>
<td></td>
</tr>
<tr>
<td>Bend obvious</td>
<td>Bend obvious</td>
<td>{Bends not obvious}</td>
<td>{‘Bends’ not obvious}</td>
</tr>
<tr>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp seen</td>
<td>Reflection of lamp not seen</td>
</tr>
<tr>
<td>{Reflection of self seen}</td>
<td>{Reflection of self seen}</td>
<td>{Reflection of self not seen}</td>
<td>{Reflection of self not seen}</td>
</tr>
<tr>
<td>Two mirrors</td>
<td>One piece of foil</td>
<td>One piece of foil</td>
<td>One piece of paper</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features. Where brackets are used, the similarities are within rather than between the brackets.

Table 29 Comparison of features of anchor, bridging analogies and target (Light 1)
To summarise:

1 similarity
Anchor → Target
5 differences

2 similarities
Anchor → Bridge 1
4 differences
5 similarities
Bridge 1 → Target
1 difference

5 similarities
Anchor → Bridge 1
1 difference
3 similarities
Bridge 1 → Bridge 2
3 differences
5 similarities
Bridge 2 → Target
1 difference
Light 2

Target
Colour filters absorb some colours of light and allow only some through. They do not, as some pupils think, add colour to white light.

Anchor
When a mixture of sand and water are filtered, the sand is held by the filter paper and the water goes through.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Separation</em></td>
<td><em>Separation</em></td>
</tr>
<tr>
<td><em>Something left behind</em></td>
<td><em>Something left behind</em></td>
</tr>
<tr>
<td>Can see what is left behind</td>
<td>Cannot see what is left behind</td>
</tr>
<tr>
<td>Sand and water are never seen as fully mixed as the sand sinks too quickly</td>
<td>White light is fully mixed colours</td>
</tr>
<tr>
<td>Not to do with light and colour</td>
<td>To do with light and colour</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features

Table 30 Comparison of features of anchor and target (Light 2)

There are two similarities and three differences. What is needed is a bridging analogy (or possibly two) in order to turn the differences into similarities. The bridging analogy used is of a suspension being filtered.
Features in *italics* are similar features

*Feature* = partial similarity/partial difference of feature (counted as a half difference/half similarity). This is because the bridging analogy used calcium carbonate powder in water. When shaken, the separate components cannot be individually identified but the calcium carbonate settles when undisturbed so the two components are seen as being separate. This means that it can be seen as either different from or similar to both the anchor and target depending on when it is viewed. The pupils saw it at both stages.

Table 31 Comparison of features of anchor, bridging analogy and target (Light 2)

There are now four and a half similarities and half a difference between the anchor and bridge and two and a half similarities between the bridge and target with two and a half differences. The number of differences between the bridge and target can be reduced further if another bridge is introduced. This is showing how a filter affects a spectrum of colours.
can be reduced further if another bridge is introduced. This is showing how a filter affects a spectrum of colours.

<table>
<thead>
<tr>
<th>Anchor analogy features</th>
<th>Bridging analogy 1 features</th>
<th>Bridging analogy 2 features</th>
<th>Target features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation</td>
<td>Separation</td>
<td>Separation</td>
<td>Separation</td>
</tr>
<tr>
<td>Something left behind</td>
<td>Something left behind</td>
<td>Something left behind</td>
<td>Something left behind</td>
</tr>
<tr>
<td>Can see what is left behind</td>
<td>Can see what is left behind</td>
<td>Cannot see what is left behind</td>
<td>Cannot see what is left behind</td>
</tr>
<tr>
<td>Sand and water are never seen as fully mixed as the sand sinks too quickly</td>
<td>Solid and liquid can be seen as an intimate mixture or separate components</td>
<td>Colours of light can be seen as an intimate mixture (white light before the prism) or separate components (after the prism)</td>
<td>White light is fully mixed colours</td>
</tr>
<tr>
<td>Not to do with light and colour</td>
<td>Not to do with light and colour</td>
<td>To do with light and colour</td>
<td>To do with light and colour</td>
</tr>
</tbody>
</table>

Features in *italics* are similar features. Where brackets are used, the similarities are within rather than between the brackets.

--- = partial similarity/partial difference of feature (counted as a half difference/half similarity see previous page for explanation).

Table 32 Comparison of features of anchor, bridging analogies and target (Light 2)
To summarise:

- Anchor to Target:
  - 2 similarities
  - 3 differences

- Anchor to Bridge 1 to Target:
  - 4½
  - ½ difference
  - 2½
  - 2½ differences

- Anchor to Bridge 1 to Bridge 2 to Target:
  - 4½
  - ½ difference
  - 3 similarities
  - 2 differences
  - ½ difference
5.2 Methodology

For this part of the research both classes used the bridging analogy method so that more data could be taken on the pattern of results during the bridging analogy process. In using the bridging analogies, the pupils were not specifically told that an analogy was being used. This was so that the pupils would not feel that they had to use the analogies in their answers. If they were told that the anchor was analogous to the target then that may have influenced their ratings for the explanations/statements and ‘which explanation/statement they thought was correct’ question. However, the anchor, bridging analogies and target situations were compared to elicit their similarities and differences.
5.3 Results

<table>
<thead>
<tr>
<th>Topic</th>
<th>Start</th>
<th>After anchor</th>
<th>After bridge 1</th>
<th>After bridge 2</th>
<th>After explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat 1</td>
<td>0.09</td>
<td>0.60</td>
<td>1.55</td>
<td>1.64</td>
<td>2.17</td>
</tr>
<tr>
<td>Heat 2</td>
<td>0.59</td>
<td>1.68</td>
<td>2.14</td>
<td>2.18</td>
<td>2.77</td>
</tr>
<tr>
<td>Light 1</td>
<td>0.87</td>
<td>1.09</td>
<td>1.00</td>
<td>1.67</td>
<td>1.61</td>
</tr>
<tr>
<td>Light 2</td>
<td>-1.37</td>
<td>-0.88</td>
<td>-0.35</td>
<td>0.13</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Table 33 To show average scientific explanation 'sense' rating – misconception explanation 'sense' rating for different topics
Chart 9a Progress during the bridging analogies

![Graph showing progress during the bridging analogies.](image)

Stage of approach

Chart 9b To show % of correct answers at each stage

![Graph showing % of correct answers at each stage.](image)

Stage of approach
5.4 Discussion of results

The important results are the difference between the ‘start’ and ‘after bridge 2’. On average, this has risen from 0.05 to 1.41 for the sense ratings (scientific explanation ‘sense’ rating – misconception explanation ‘sense’ rating) and from 51.8% to 76.8% for the percentage giving the correct answer. The probability of these results happening by chance and not because of the bridging analogies used was calculated in two ways.

- A one-tailed test (correlated data) was carried out using the topics as the subjects with the two measures being the ‘initial sense rating the pupil gave to the scientific explanation’ - the ‘initial sense rating the pupil gave to the misconception explanation’ and the sense rating the pupil gave to the scientific explanation’ - the ‘sense rating the pupil gave to the misconception explanation’ for after the second bridge. This returned a probability of 0.03 and therefore significant at the 5% level.

- A one-tailed test (correlated data) was carried out for each topic using the pupils as subjects with the two measures being as above. The results were as follows:
  
  Heat 1 \( p = 9.92 \times 10^{-7} \)
  Heat 2 \( p = 0.0008 \)
  Light 1 \( p = 0.0112 \)
  Light 2 \( p = 0.0001 \)

  The only one of these which failed to be significant at the 0.01 level was Light 1 and that was significant at the 0.05 level.

It is thought likely that, for at least some pupils, p-prims were being cued as this happens at an unconscious level and many pupils seemed not to know why they
had changed their minds about the target question as they went through the bridging analogy process. As was pointed out on page 151, the pupils were not specifically told that analogies were being used so as not to influence their answers to the ‘sense’ explanations/statements and ‘which explanation/statement they think is correct’ question.

The following is a brief analysis for each topic of the comments given by the pupils as to why they had or had not changed their minds during the bridging analogy process (excluding the final explanation).

Heat 1
Of the 11 pupils who changed their minds from the misconception to the scientific explanation of the more likely explanation/statement, six either wrote that they did not know why they had changed their minds or left the answer blank indicating the same thing. One pupil claimed that “the experiments have sort of explained it” without any further elaboration and only four pupils picked up on the idea of metal being a good conductor of heat.

Out of the 19 whose sense rating of the scientific explanation/statement – sense rating of the misconception increased at some point during the bridging analogy from what it had been at the start but who did not change their minds on the likely explanation/statement, 12 wrote nothing or nothing relevant at the point when they changed the difference in their sense ratings. The other seven did mention the experiment/analogy.

Heat 2
Of the five pupils who changed their minds from the misconception to the scientific explanation of the more likely explanation/statement, two wrote nothing or nothing relevant, indicating that they did not know why they had changed their minds. One pupil just stated that “this page made me change my mind” and the other two commented on the catching and throwing of the ball.
Out of the 11 whose sense rating of the scientific explanation/statement – sense rating of the misconception increased at some point during the bridging analogy from what it had been at the start but who did not change their minds on the likely explanation/statement, eight wrote nothing or nothing relevant. Of the other three, only one directly referred to the analogy although two possibly indirectly referred to it. For example, one wrote, “Because if it’s good at letting in heat it should be good at letting it out”.

Light 1

Of the 11 pupils who changed their minds from the misconception to the scientific explanation of the more likely explanation/statement, two wrote nothing and one claimed not to have changed her mind even though she had. One pupil made no reference to the experiments done (analogies) but concentrated on the actual statements and one referred to “this showed me that what I thought was wrong”. One made a reference to smooth and shiny objects being able to reflect. The other five did make specific reference to the experiments.

Out of the 12 whose sense rating of the scientific explanation/statement – sense rating of the misconception increased at some point during the bridging analogy from what it had been at the start but who did not change their minds on the likely answer/statement, nine wrote nothing or nothing relevant. One made an ambiguous remark that could have referred to the experiment/analogy and the other two made a specific reference to the experiment/analogy.

Light 2

Of the 15 who changed their minds from the misconception to the scientific explanation of the more likely explanation/statement, five wrote nothing or nothing relevant. One pupil said that “the experiment explained in a clearer way” and one said, “The experiment showed this”. One did not change her mind until
the second bridge when she saw some of the colours had been taken away. The
other seven specifically mentioned the experiments (analogies).

Out of the 12 whose sense rating of the scientific explanation/statement – sense
rating of the misconception increased at some point during the bridging analogy
from what it had been at the start but who did not change their minds on the likely
explanation/statement, only one made a definite reference to the experiments
(analogies) carried out.

In total for all the topics, there were 42 instances of pupils who changed their
minds from the misconception to the scientific explanation of the more likely
explanation/statement. In less than half (43%) of these cases was there a specific
mention of the experiment/analogy. There were 54 whose sense rating of the
scientific explanation/statement – sense rating of the misconception increased at
some point during the bridging analogy from what it had been at the start but who
did not change their minds on the likely explanation/statement. Only 11 (20%)
made a specific reference to the experiment/analogy. This shows that most of the
changes in the pupils’ answers had come about without them really knowing why
they had changed their minds. This suggests unconscious thought processes and is
indicative of the cueing of p-prims.

It is important to look at the intermediate results as these indicate the contribution
of the individual bridging analogies. It can be seen that, in the Light 1 topic there
is a dip in the sense ratings at some point of the bridging analogies (see Chart 9a).
This is similar to the results gained in the pilot research in the Forces 1 topic (see
Chart1 reproduced below).
A discussion of the position of the main dips within the bridging analogy process and their possible reasons follows for each of the topics where they occurred.

**Light 1**
There is a slight dip between after the anchor and after the first bridging analogy. The only differences between the anchor and first bridge were that the anchor referred to images of an object in two mirrors and the first bridge referred to their own images in a folded piece of foil. Perhaps the anchor cued the reflection p-prim since it involved a mirror but the first bridge did not since, although it did involve reflections, it did not involve mirrors as such which are the usual reflectors as far as pupils are concerned. It may be that, by the time the second bridge was reached, the fact that light from the lamps could be seen reflected but not as whole reflections cued the idea of paper reflecting in a better way than linking the idea of paper reflection to a situation where whole reflections could be seen such as in the first bridge. There was also an unexplained slight drop between after the second bridging analogy and after the explanation. This would need further exploration.
Forces 1

In the pilot research, there was not a comparison between the sense that the scientific statement made and the sense the misconception made; it was just the former. There was a drop after the initial question and, in fact, the recovery took until the explanation of the third experiment. This could be because the spring pushing back on the hand was not seen to be similar to a table pushing back on a book and the book on the spring and the book on the ruler were not analogous enough to the book on the table to cue p-prims. This particular problem is probably not open to treatment by cueing p-prims as discussed on page 266. If it is a model being built up, it may be that all parts of the bridging analogies and the explanation are needed before the new model is complete and understood.
Main research (part 3)

Introduction

It has been discussed how the bridging analogy approach was used in parts 1 and 2 of the main research. The pupils were not told overtly that analogies are being used. They were just looking at different situations and comparing their similarities and differences to see if this made any difference to their thoughts about the target question. For some pupils it did and for some it did not.

It was thought likely that p-prims were being cued as this happens at an unconscious level and many pupils seemed not to know why they had changed their minds about the target question as they went through the bridging analogy process. The next step was to investigate the p-prim idea in more detail.
6.1 Methodology

In order to gauge whether p-prims can be cued using analogies, it was necessary to make the analogies as low-key as possible so the pupils were not told and could not guess that an analogy was being used. It was decided to ask the target question only twice, before the bridging analogy process and after. The target questions were first asked at the beginning of the academic year for all the topics together. This was because if the target question for each topic had been asked just prior to the bridging analogies, this may have made the analogies less low-key as it may have alerted the pupils to the process. It was felt that the benefits of separating the times of asking the target questions as far as possible outweighed the disadvantages which were as follows:

- The pupils had time to change their minds due to other experiences, teaching or otherwise in the time interval. This could have happened but it is likely that the control class would have changed their minds by the same amount and it is the two classes which are being compared.
- It is possible that one class may have had different experiences to sway their ideas. However, it is unlikely that this would have come from anything other than physics lessons except possibly for one or two individuals. Great care was taken to keep the teaching of both classes as similar as possible. This was done by having the same teacher (the researcher) and the same order of topics, etc.

Since the analogies were going to be very low-key, this meant changing the analogies used somewhat. There was more of a gap between the second bridging analogy and the target. This was inevitable as in the previous research the second bridging analogy was too similar to the target to be low-key enough.

If using analogy in this way was successful and the pupils did not know why they have decided on the correct idea, it may be safe to assume that the analogy had
unconsciously cued the right p-prim. If the pupils were aware that it was the analogy which had made them decide on the correct idea, then it is probably due to more conscious thought rather than cueing of p-prims. However, if the wrong idea was chosen, then the analogy had not worked, either as a p-prim cue or as a conscious thought promoter.

A comparison was made between pupils that had been taught using a short bridging analogy approach to the target problem (without being told that they are analogies) and those who had gone straight to the problem. The bridging analogies were based on known or postulated p-prims. For the problem, the pupils were asked to read two alternative explanations of, or statements about, a phenomenon. They gave each a ‘sense’ rating (1-5) and also decided which statement or explanation was the more likely to be correct.

The results were analysed using t-tests to see if the findings were statistically significant. The sample size for each group was only small (a maximum of 24) but, by aggregating the results for the different topics, it was effectively increased. The experimental and control groups were swapped for each topic to reduce the effect of any intrinsic differences between the classes.

There was a question for both groups to ask about their thinking for the answers they have given, designed to try to identify any thought processes the pupils had during the lesson and thus to reveal whether using analogy in this low-key way causes conscious or unconscious thought processes. This was given either as a question at the end of the target questions or as a separate questionnaire (What did you learn today? - see Appendix IVd).
6.2 Misconceptions, scientific conceptions, p-prims, analogies and mode of teaching

This section outlines the misconception considered for each topic, together with a possible p-prim for the misconception. The correct scientific conception is then given together with the probable p-prim. Finally for each topic the analogies to be used and the target questions are given.

Heat 1 (thermal equilibrium)

Misconception
Metals feel colder than many other items because they are naturally at a lower temperature.

Possible p-prim for misconception
There may be a context-dependent meta p-prim; ‘objects have their own temperature dependent on the material they are made from (so long as they are not near any perceived heat source)’ This would be got from sensory data when very young – it feels cold so it is cold.

diSessa calls this a meta p-prim (personal correspondence, 2003-2004) but he points out that this is probably contextual in that many people also believe that metal that has been in the oven (for a long time) is hotter than wood that has had similar treatment, for example.

Scientific conception
Metals feel colder than many other materials because they are good conductors and take away heat from your body rapidly leaving your hand feeling cold.

P-prim needed to be cued for scientific conception
This may be a type of ‘equilibration’ p-prim (diSessa, 1993). He states, “An absence or sparseness of material next to an abundance leads, primitively, to flow and re-equilibration” (p.141). However, he feels that, in order to appreciate what is happening in this situation, the pupils need a new model of sense experience. “Objects have to heat your hand in order to heat the nerves, in order to feel hot. So, the conductivity is part of sensing. THEN you can see that it is plausible that wood is actually the same temperature as metal, but does not conduct enough heat, quickly enough (some subtleties here) to ‘feel’ the temperature that it is. Not everything is a p-prim. Sometimes when you change people’s models of what is going on, p-prims automatically shift in salience” (personal correspondence, 2003-2004).

Using the proposed p-prim, objects (including metal ones) that start off at different temperatures will come to be the same temperature (before a person becomes involved) due to equilibration. When a person is introduced into the situation, the pupils will need to know that:

- A person is a heat source.
- Hotter things warm up cooler things
- Metals are good conductors of heat

These pieces of knowledge will have been covered in previous lessons.

They will then be able to understand that metals feel cold because the heat from a person’s hand is conducted away quickly. This means that the basic problem is that the ‘same temperature’ idea needs to be cued rather than the ‘feels cold so it is’ idea.
1. If I push down on side A of this see-saw and then let go, what happens? Discuss and agree on the answer that side A goes down and then goes back up to reach equilibrium again. The idea of this question is to get across the idea of things tending to reach equilibrium. With the experimental group, this acts as the anchor analogy and sets the scene for the rest of the work. This works as the anchor as it automatically makes the pupil think about re-equilibration.

2. Discuss and show what happens to water when poured – it flows downhill. Treacle also does this but more slowly. This would not be used as an overt analogy as it may strengthen an idea that heat is a kind of matter that can flow like water. This acts as the bridging analogy for the experimental group. It is closer to the target than the anchor analogy is in that it introduces the idea that re-equilibration can be reached quickly or more slowly. The water is lifted up and poured and it ‘goes back’ to its original level quickly but the treacle does it more slowly.

3. Remind class that hot water cools down until it reaches room temperature (they will already have seen this). This is possibly acting as a further bridging analogy for the experimental group and as an introduction for the control group. It would be unfair not to remind pupils in this group of the ‘cooling water’ situation as both groups should be treated as equally as possible except for the independent variable which, in this case, is the use of bridging analogies. Although the ‘cooling water’
situation is one of the bridging analogy steps for the experimental group, by itself it does not constitute the bridging analogy approach nor is it a p-prim cue. The p-prim cue for the scientific concept is the see-saw returning to equilibrium as this is a more basic idea.

The two groups are then given the target questions as follows:

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense')?

When I touch a piece of metal, it often feels colder than, say, a piece of cork. Do you think that this is because:

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. \[\square\]

b. The metal feels colder because it is naturally at a lower temperature than the cork. \[\square\]

Which do you think is the more likely explanation (a or b)? \[\square\]
Heat 2 Radiation/Absorption

Misconception
Black surfaces are good absorbers of heat so they must be poor radiators of heat.

Possible p-prim for misconception
This could be the idea that, if something is good at doing one thing then it must be bad at doing the opposite. This may be emphasised by ‘good conductors are bad insulators’. diSessa (personal correspondence) sees it as something similar but more reliant on agency. He argues that people see things as “somehow actively achieving the things they achieve”. So, if something achieves good absorption, then, in order to gain good radiation, it would have to change and want the opposite.

Scientific conception
Black surfaces are good absorbers of heat and good radiators of heat.

P-prim needed to be cued for scientific conception
If something is good at one thing, it can be good at the opposite.

Analogies to be used
1. ‘People who do well in a subject are good at taking in information and good at giving it out again’. This is the anchor for the experimental group.

2. ‘In a netball team, players are good at throwing a ball and good at catching it’. This is the bridging analogy for the experimental group and is closer to the target than the anchor is in that there is the idea of something moving between two things as heat electromagnetic radiation moves between objects.

The work will carry on from a lesson on absorption of heat so the pupils will be familiar with the terminology being used. The control group will also have had the
lesson on heat absorption but will go straight to the target questions without the analogy sequence.

The two groups are then given the target questions as follows:

Objects can radiate and absorb heat. Think about sitting in front of a warm fire; the fire is radiating heat and you are absorbing it. However, you are radiating heat all the time as well as absorbing it. Thermal cameras sense the amount of heat given off by different objects and human bodies give off quite a lot.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’)?

An object that is better at absorbing heat than another object is:

a. Better at radiating heat [ ]

b. Worse at radiating heat [ ]

than the other object (both at the same temperature).

Which do you think is the more likely statement to be true (a or b)? [ ]
Light 1 Reflection

Misconception
Light goes onto a surface of an object and stays there to light it up.

Possible p-prim for misconception
Seeing needs illumination to ‘light up’ objects. We cannot see in the dark but we can see in the light so the important factor must be the light. diSessa (personal correspondence) agrees with this interpretation but thinks that something more like a model is at issue. “Things are seen because they need light on them. Once light is on them, then they are seen (by direct perception).”

Scientific conception
Light goes to a surface and is reflected (more accurately described as scattered) and some enters into our eyes.

P-prim needed to be cued for scientific conception
Reflection is probably not a central, strong p-prim but could it have been encompassed into the p-prim system by the age of 12? Bouncing is a p-prim which diSessa describes (1993, p.220) as follows. “An object comes into impingement with a big or otherwise immobile other object, and the impinger recoils.”

Analogies to be used
1. ‘What happens when we drop a bouncy ball?’ This is the anchor analogy for the experimental group. Children are familiar with this phenomenon from an early age – they drop something and it falls and then sometimes bounces (depending on the object).

2. ‘What happens when we hit a snooker ball against the cushion (side of the snooker table)?’ This is the bridging analogy for the experimental group. It is closer to the target than the anchor is since it encompasses the idea that bouncing or reflection does not always take place in a vertical direction with something
being dropped. The control group will go straight to the target question without the analogy sequence.

The two groups are then given the target questions as follows:

When it is absolutely dark, we cannot see anything but when it is light, we can see objects.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’)?

We can see objects because light from a light source:

- a. Hits the object and stays there, lighting the object up.  
- b. Hits the object and is reflected.

Which do you think is the more likely statement to be true (a or b)?
Light 2 Colour

Misconception
Colour filters add colour to white light.

Possible p-prim for misconception
Change implies doing something positive, adding something. Adding something, i.e. the coloured plastic, suggests adding colour or, in other words, you cannot take away something by adding something. diSessa (personal correspondence, 2003-2004) maintains that white (and black) are perceived as colourless; as an absence of something. He suggests that this might come from language and culture or neural mechanisms. It could come from the idea of bleaching to remove colour or dyeing to add colour.

Scientific conception
Colour filters absorb colours and let only certain ones through.

P-prim needed to be cued for scientific conception
This could be a ‘separation (in this case, filtering)’ p-prim. Early on, children have the idea of being able to separate and sort items into sets (Vygotsky, 1962 and Inhelder and Piaget, 1964). So if this idea could be cued, it may be possible to implant the correct concept for the action of colour filters.

Analogies to be used

1. ‘Do you remember doing a filtration experiment in chemistry. Watch the mixture being filtered. The solid is caught in the filter paper and not allowed to go through but the water can.’ This acts as the anchor for the experimental group. It is obvious that there are two things in the mixture as each can be seen (sand and water). This gives a clue as to how they should be separated.
2. ‘This time the solid is not at the bottom of the beaker but spread about in the water. However, when filtered, the solid is again caught in the filter paper and not allowed to go through but the water can.’ This acts as the bridge for the experimental group. It is closer to the target than the anchor is since it is not possible to see the separate solid and liquid in this case when they are too well mixed together. This is similar to the mixing of the colours to make white light in that they cannot be seen separately.

The pupils will already have been introduced to the idea that white light is made up of different colours where they had seen a prism splitting white light into its constituent colours and they are reminded of this as they are asked to observe what happens to the spectrum when a piece of green plastic is put between the prism and screen. This can act as another bridge for the experimental group and as an introduction for the control group.

The two groups are then given the target questions as follows:

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’)?

When white light is shone through a piece of green see-through plastic, green light is seen on the screen. This is because:

a. The green colour has been added to the white light by the piece of plastic.  

b. The other colours have been taken away by the piece of plastic leaving only green.

Which do you think is the more likely explanation (a or b)?
Forces 1 Balanced Forces

Misconception
If objects are stationary, then no forces or only one force (gravity) acts on them. A book on a table has either no forces acting on it or just the force of gravity acting on it. The table simply stops the book falling further.

Possible p-prim for misconception
This may be the ‘supporting’ p-prim (diSessa, 1993). Since inanimate objects are not seen as being able to provide force, the table is merely seen as being in the way (Dykstra, 2000). In this p-prim, there is no idea of a force being involved. The strong object underneath merely keeps the upper object in place.

Scientific conception
Stationary objects have balanced forces acting on them.

P-prim needed to be cued for scientific conception
Perhaps this is a type of ‘springiness’ p-prim. A spring can push back on you so the table is acting like the spring and pushing back on the book.

Analogies to be used
1. ‘Push down on a spring. What do you notice (e.g. does the spring squash and does the spring push back on you?)’ This is the anchor analogy for the experimental group. It is expected that the pupils will feel the spring pushing back as they squash it.

2. ‘Balance a book on the spring. What do you notice?’ This is the first bridging analogy for the experimental group. It is somewhat closer to the target than the anchor is in that it involves a book resting on top of the spring as the book rests on top of the table in the target.
3. ‘Look at the book on ruler. What do you notice?’ This is the second bridging analogy for the experimental group and it is even closer to the target in that the book is now resting on something which the pupils see to be similar to a table and the only difference is that the ruler visibly bends and the table does not.

The two groups are then given the target questions as follows:

Gravity is a force that causes objects to fall down. If a book is on a table, then gravity is pulling on it so why does it stay where it is and not fall down?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’)?

a. There is gravity acting downwards on the book and the table is just in the way to stop the book falling.

b. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount.

Which do you think is the more likely explanation (a or b)?
Forces 2 Stretching Springs

Misconception
Springs that are identical, except for length, will stretch by the same amount when loaded equally.

Possible p-prim for misconception
This may be the ‘Ohm’s’ p-prim (diSessa, 1993). The factors involved in stretching would be weight, stiffness of spring and extension. The pupils know that pulling harder or a bigger weight extends a spring more and also that extension depends on the stiffness of the spring. Perhaps, if this idea is cued then pupils do not see that the extension could also depend on original length. This view is supported by diSessa (personal correspondence, 2003-2004) who agrees that it is Ohm’s p-prim that is involved and the pupils do not see the effect that length has. As he says, “strength is more ‘obvious’ in thickness.”

OR

It could be the ‘force as mover’ p-prim (diSessa, 1993). Greater force is needed to move more massive objects and in this case, the longer spring is more massive so it will need more force to extend it by the same length or the same force certainly will not double the extension.

Scientific conception
Extension is proportional to original length.

P-prim needed to be cued for scientific conception
Perhaps a sort of ‘more things present, more things affected’ p-prim is required here.
Analogies to be used

1. 'A teacher tells a line of five children, who are queuing up in the playground to be quiet. They all 'feel' the same effect of her voice.

Figure 18a Teacher/children analogy (short line)

If there were ten children in the line they would still all 'feel' the same effect of her voice (so long as they can all hear her).

Figure 18b Teacher/children analogy (long line)

Discuss limitations of this and come to the conclusion that some things can have the same effect if there are only a few people or if there were lots of people. This acts as the anchor for the experimental group. It is visual and easily understood. Be aware of, but do not discuss with the pupils at this time, the possible complications caused if springs in parallel were being considered where a
different p-prim would have to be cued such as a ‘sharing a job reduces the amount of work each person needs to do’.

2. ‘Hang a weight on a spring. Are the coils at the top and at the bottom stretched apart or just those at the bottom? Point out that the weight is having an effect on all the coils rather than just the bottom coils but do not discuss how much effect as this is giving the answer to the target question.’ This is the first bridge for the experimental group. It is closer to the target than the anchor is in that it is referring to something stretching as the elastic does in the target.

3. ‘Hang two springs end to end and then hang the same weight on the end of the bottom spring. Do the coils on both springs stretch or just the coils of the bottom spring? These springs should be identical with each other but different from the first spring used so the pupils do not see that two springs extend twice as much as one spring.’ This is the second bridge and is even closer to the target as the there are two identical length springs in a similar way to there being a double length elastic in the target.

The control group are given the two bridges. However, these bridges are not acting as bridging analogies for the control group since the anchor is not present. They could be seen as being analogies in their own right for the control group but it was felt to be necessary for this group to see these experiments, as some pupils in the experimental group may be able to find the correct answer to the target by viewing these rather than by having p-prims cued. Both the experimental and control groups need to be treated as equally as possible except for the bridging analogies.
The two groups are then given the target question as follows:

1. Hang a weight on a spring. Are the coils at the top and at the bottom stretched apart or just those at the bottom?

   *All the coils are stretched apart*

2. Hang two springs end to end and then hang the same weight on the end of the bottom spring. Do the coils on both springs stretch or just the coils of the bottom spring.

   *The coils on both springs are stretched apart*

A 2N weight is hung on a piece of elastic that extends by 5cm. The 2N weight is then hung on a similar piece of elastic that is twice as long to begin with. How much will this piece extend? Circle the correct answer.

a. 5cm   b. 10cm
6.3 Results and analysis for each topic

Heat 1 (thermal equilibrium)

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Key S is the scientific answer/explanation M is the misconception

Table 34 To show the ‘sense’ ratings and the percentage of pupils giving the correct answer for the experimental and control groups pre- and post-test (Heat 1)

Chart 10 Change in sense of scientific and misconception answers for HEAT 1
There was an increase in the average ‘sense’ score of the scientific answer for the experimental group together with a small decrease for the misconception answer. For the control group there was also an increase for the scientific answer but only a small one. There was a very slight increase for the control group’s misconception answer.

The probability that these results were not due to chance was calculated by carrying out a one-tailed t-test (correlated data) where the subjects were the pupils. The measures carried out for the experimental group were the sense ratings at the beginning of the academic year and after the low-key bridging. The measures for the control group were the sense ratings at similar timings to the experimental group although the control group did not have the bridging analogy intervention. This test was done for both the scientific statement and the misconception statement. A similar t-test was carried out for both groups for the answer they thought was correct. The t-tests returned probabilities as follows:

- Experimental group – scientific statement  $p = 0.047$
- Experimental group – misconception statement  $p = 0.431$
- Experimental group – ‘correct answer’  $p = 0.500$
- Control group – scientific statement  $p = 0.465$
- Control group – misconception statement  $p = 0.340$
- Control group – ‘correct answer’  $p = 0.288$

The only results of significance at the 0.05 level were those relating to the experimental group’s sense ratings of the scientific statement.

In this topic, the pupils could have worked out the correct answer if they had put together the previous work that they had done. This probably explains the slight increase for the control group’s ‘sense’ rating for the scientific answer.
There was not much change in the answer that the pupils thought was correct between pre-test and post-test for either group.
Heat 2 Radiation/Absorption

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**Key**  
S is the scientific answer/explanation  
M is the misconception

Table 35 To show the ‘sense’ ratings and the percentage of pupils giving the correct answer for the experimental and control groups pre- and post-test (Heat 2)

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**Chart 11 Change in sense of scientific and misconception answers for HEAT 2**

There was a slight increase in the average ‘sense’ score for the misconception answer for the experimental group and a slightly larger increase for their scientific answer. The results for the control group showed a substantial drop for the
scientific answer together with a small increase for the misconception answer. 8% more chose the correct answer for the experimental group between the pre-test and the post-test compared with an 11% decrease for the control group.

The probability that these results were not due to chance was calculated in a similar way to Heat 1. The t-tests returned probabilities as follows:

- Experimental group – scientific statement \( p = 0.164 \)
- Experimental group – misconception statement \( p = 0.391 \)
- Experimental group – ‘correct answer’ \( p = 0.269 \)
- Control group – scientific statement \( p = 0.047 \)
- Control group – misconception statement \( p = 0.198 \)
- Control group – ‘correct answer’ \( p = 0.133 \)

The only results of significance at the 0.05 level were the control group’s sense of the scientific statement.

This topic was difficult to work out the correct answer based on the previous work. It seems as though, having seen the absorption experiment, the control group become surer that good absorbers are poor radiators. This is supported by the low \( p \) value for this change. Their replies as to why they had given the answers that they had included the following:

\[
\text{M is a more likely explanation because it is the opposite and absorbing and radiation are opposites. (Italics added)}
\]

Other replies were similar in nature without actually using the word ‘opposite’. None of the replies from the experimental group mentioned the analogy directly although several used the word ‘you’ as in:

\[
\text{I think this because when you are good at something, radiating,}
\]
you are usually good at the other, absorbing heat. (Italics added)

This use of a personal pronoun possibly indicates an unconscious link with the analogy meaning that the p-prim has been cued without conscious thought.
Light 1 Reflection

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**Key**  
S is the scientific answer/explanation  
M is the misconception

Table 36 To show the ‘sense’ ratings and the percentage of pupils giving the correct answer for the experimental and control groups pre- and post-test (Light 1)

Chart 12 Change in sense of scientific and misconception answers for LIGHT 1

As expected, a slight rise occurred for the experimental group’s sense rating of the scientific explanation together with a small drop for the misconception
explanation. Also, there was an increase for the control group’s misconception answer sense rating with a drop for their scientific answer. This is surprising as, for this topic, the control group had had no further relevant teaching since the pre-test, it being the beginning of the topic.

With the experimental group, there was no change in the percentage who chose the correct answer but there was a drop of 10% for the control group.

The probability that these results were not due to chance was calculated in a similar way to Heat 1. The t-tests returned probabilities as follows:

- Experimental group – scientific statement $p = 0.179$
- Experimental group – misconception statement $p = 0.203$
- Experimental group – ‘correct answer’ $p = 0.500$
- Control group – scientific statement $p = 0.118$
- Control group – misconception statement $p = 0.273$
- Control group – ‘correct answer’ $p = 0.165$

There were no results of significance at the 0.05 level. Because of this, firm conclusions could not be drawn for this topic.
Light 2 Colour filters

<table>
<thead>
<tr>
<th></th>
<th>Light 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ave. sense S</td>
<td>ave. sense M</td>
<td>% S</td>
</tr>
<tr>
<td>ave. sense S</td>
<td>ave. sense M</td>
<td>% S</td>
</tr>
<tr>
<td><strong>pre-test</strong></td>
<td>1.90</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>2.32</td>
<td>3.45</td>
</tr>
<tr>
<td><strong>post-test</strong></td>
<td>3.38</td>
<td>2.71</td>
</tr>
<tr>
<td></td>
<td>3.09</td>
<td>3.45</td>
</tr>
</tbody>
</table>

**Key**  
S is the scientific answer/explanation  
M is the misconception

Table 37 To show the ‘sense’ ratings and the percentage of pupils giving the correct answer for the experimental and control groups pre- and post-test (Light 2)

Chart 13 Change in sense of scientific and misconception answers for LIGHT 2

There was a pleasing increase in the experimental group’s scientific answer but this should be weighed against an increase in the control group’s scientific answer.
The increase for the experimental group was, however, greater than that for the control group (1.48 as opposed to 0.77). The increase for the control group is to be expected as they saw the experiment showing that a colour filter blocks the passage of the other colours of the spectrum. The control’s group sense of the misconception answer remained constant while there was a good decline in the experimental group’s sense of the misconception answer.

There was a substantial increase in the percentage choosing the correct answer for the experimental group (57%) compared with an increase of only 27% for the control group.

The probability that these results were not due to chance was calculated in a similar way to Heat 1. The t-tests returned probabilities as follows:

- Experimental group – scientific statement \( p = 5.09 \times 10^{-5} \)
- Experimental group – misconception statement \( p = 0.022 \)
- Experimental group – 'correct answer' \( p = 2.36 \times 10^{-5} \)
- Control group – scientific statement \( p = 0.005 \)
- Control group – misconception statement \( p = 0.500 \)
- Control group – 'correct answer' \( p = 0.015 \)

The only results not of significance at the 0.05 level were those relating to the control group’s sense of the misconception statement.

Support for the p-prim for the misconception being an ‘adding’ idea, i.e. adding the coloured plastic necessarily means adding colour rather than taking colours away, comes from replies from pupils as to why they gave the answers that they did. They include the following:

- Because when you put a red piece of plastic you are adding it.

And
Because the red piece of plastic has been added to the light …..

And

Because the red plastic has been put in so it’s been added …..

Interviews were conducted with pupils (see Appendix V) who had changed their minds between pre-test and post-test from misconception to scientific conception. When asked why they had given their pre-test answer, the following comments were elicited:

In art, sort of, white is nothing and adding to me seemed simpler than taking things away.

And

Well, it sounds a bit funny for things to be taken away.

No-one mentioned the analogy directly, either in the written replies or interviews, endorsing the idea that this was a low-key analogy. Comments given by pupils who chose the scientific statement as the more likely explanation were:

….. So I think the other colours are blocked by the red plastic.

And

Because the plastic blocks the other colours coming through.

The latter statement was written by a student who had chosen the misconception in the pre-test as being the more likely correct answer.

It should be noted that these comments came from a later cohort of pupils who, on the whole, were not as successful in changing their ideas using the low-key analogy. This particular cohort had not seen the effect of putting a filter in the path of the colour spectrum. It may be that this is required in order to make the most of the analogy. It could be argued that this part of the procedure helps the pupils to work out what is happening and, indeed, this probably accounts for the increase in the sense of the scientific explanation for the control group as has already been
mentioned. However, the increase for the experimental group is larger and also they decreased their sense of the misconception whereas the control group did not. The probability levels support these conclusions.
Forces 1 Book on table

<table>
<thead>
<tr>
<th></th>
<th>experimental</th>
<th>control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ave. sense S</td>
<td>ave. sense M</td>
</tr>
<tr>
<td>pre-test</td>
<td>3.05</td>
<td>4.24</td>
</tr>
<tr>
<td>post-test</td>
<td>2.14</td>
<td>4.05</td>
</tr>
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</table>

**Key**  
S is the scientific answer/explanation  
M is the misconception

Table 38 To show the ‘sense’ ratings and the percentage of pupils giving the correct answer for the experimental and control groups pre- and post-test (Forces 1)

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Chart 14 Change in sense of scientific and misconception answers for FORCES 1

![Chart 14](chart14.png)
This was an unusual set of results and did not follow the usual pattern. Rather than an increase for the sense for the scientific answer, there was a decrease for the experimental group. There was no indication given by the pupils as to why they thought what they did. This topic is discussed in more detail on page 262 onwards.

The probability that these results were not due to chance was calculated in a similar way to Heat 1. The t-tests returned probabilities as follows:

- Experimental group – scientific statement $p = 0.011$
- Experimental group – misconception statement $p = 0.265$
- Experimental group – ‘correct answer’ $p = 0.134$
- Control group – scientific statement $p = 0.333$
- Control group – misconception statement $p = 0.473$
- Control group – ‘correct answer’ $p = 0.214$

The only results of significance at the 0.05 level were those relating to the experimental group’s sense of the scientific statement.
Forces 2 Stretching

The final topic was on stretching and did not ask for sense ratings as there were no explanations/statements given but just the choice of extension answer.

<table>
<thead>
<tr>
<th>Forces 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>experimental</td>
<td>control</td>
</tr>
<tr>
<td>% S</td>
<td>% S</td>
<td></td>
</tr>
<tr>
<td>pre-test</td>
<td>47.6</td>
<td>31.6</td>
</tr>
<tr>
<td>post-test</td>
<td>68.2</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Key S is the scientific answer/explanation

Table 39 To show the percentage of pupils giving the correct answer pre- and post-test (Forces 2)

As can be seen from the table, there is an increase (21%) in those choosing the correct answer from pre-test to post-test for the experimental group together with a decrease for the control group (12%). This followed the pattern of the first four topics.

The probability that these results were not due to chance was calculated in a similar way to Heat 1 for the answer the pupils thought was correct. The t-tests returned probabilities as follows:

- Experimental group – ‘correct answer’ p = 0.107
- Control group – ‘correct answer’ p = 0.081

Neither of these results was significant at the 0.05 level.
In the experimental group, of the seven pupils who changed their minds between pre-test and post-test from the misconception to the scientific conception, none could explain why they had written that particular answer. Two wrote nothing or nothing relevant and the other five just gave statements such as:

I think this because if it is twice as long it will extend twice as far.

And

The spring will stretch further because it is longer so it will have further extension.

There were no references to the analogy in any of the comments made.
6.4 Discussion of results

The first four topics show a cumulative effect in sense ratings as shown in the following graph (the final topic did not ask for sense ratings).

The probability that these cumulative results (pre-test to post test change for the scientific statement) happened by chance was calculated as follows. Using a 1-tailed t-test for correlated data, with the topics as subjects, \( p = 0.005 \); this is statistically significant at \(< 0.01\). Using a 1-tailed t-test for non-correlated data for the individual pupils' results was 0.003; statistically significant at \(< 0.01\).

The first four and the final topic show a similar cumulative effect when the percentage of pupils choosing the correct answer is considered.
<table>
<thead>
<tr>
<th></th>
<th>Average percentage choosing correct answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental pre-test</td>
<td>50.8%</td>
</tr>
<tr>
<td>Control pre-test</td>
<td>43.5%</td>
</tr>
<tr>
<td>Experimental post-test</td>
<td>67.7%</td>
</tr>
<tr>
<td>Control post-test</td>
<td>41.4%</td>
</tr>
</tbody>
</table>

Table 40 Cumulative average percentage choosing the correct answer for the first four and final topics (pre-and post-test for experimental and control groups)

The results show that this is a relatively successful method for cueing the correct p-prims for these topics. However, the results for the 'book on table' topic show that the low-key use of the bridging analogy plainly did not work for this topic. It is thought that the reason for this is because of the deeply entrenched idea that inanimate objects such as a table cannot produce forces and merely block the way. This supporting or blocking p-prim totally eclipses any attempt at trying to cue alternative p-prims. A longer approach is indicated for this sort of problem. This is discussed in more detail on page 266.
CHAPTER SEVEN

Analysis of outcomes by topic

7.1 Heat 1

The first part of the research used the single bridging analogy approach. Chart 2 is repeated below, showing the results.

The two groups attain approximately the same average mark for the pre-test and this increases substantially for the control group for the post-test. The reason given for this increase was that of 'teaching to the test'. The first question given in the
test was very similar to one of the control group's practice questions. It was also similar to the target question in the bridging analogy approach and the question posed at the start of the control group's work.

The first question in the test was: Sonia touched a metal clamp stand in the lab and noticed that it felt colder than the bench it was on. She wondered why as she had not started doing any experiments and neither had anyone else. She decided to try other objects and she found that all the metal objects felt colder than all the wooden objects. Why do you think this was?

The control group's similar practice question was: Why does a garden spade's wooden handle feel warmer than the metal spade part?

The target question for experimental group was: Touch a piece of metal and a cork mat. Which one feels warmer? Why does metal feel colder than the cork?

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

It could be argued that both groups had had access to the answer to the first test question, but it should be remembered that the control group had also discussed the target questions and had been given the same explanation as the experimental group had but without the bridging analogies. The control group then went on to practise questions similar to this one in the test.

It was this first question that was the most significant when it came to the retention test. The control group's (23 pupils) total for this question dropped by 3.5 between the post-test and the retention test but the experimental group's (24 pupils) rose by 2.0. From this it may be considered that the 'teaching to the test' effect for the control group lasted for only a short while but the effect of the
bridging analogy for the experimental group was longer lasting. For all three questions together, there was no change for the test mark for the experimental group between post-test and retention test but the mark for the control group dropped noticeably.

It was rather surprising that there was not a drop between the post-test and the retention test for the experimental group since the bridging analogy approach had not seemed to work particularly well in this topic. There was a slight rise between initial thoughts and those after the anchor but the main rise did not appear until after the explanation (see Chart 16 for this topic). This may provide evidence of the pupils reviewing in an unconscious manner the bridging analogy work when doing the post-test and the retention test.

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Chart 16 To show progress during single bridging analogy for HEAT 1

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In the next part of the research another bridging analogy was inserted to make the steps involved closer together. This time there was a rise between each step of the process for the sense ratings with the explanation now providing a smaller percentage of the total increase (see Chart 17 for this topic). This indicates that the bridging analogies were being more successful as the steps became closer together. It should be pointed out that the overall increase in both cases was approximately the same albeit starting from different points. However, this included the explanation, which, although vital, did not constitute the bridging analogy part of the process. The probability of these results happening by chance (between initial thoughts and after the bridge (or second bridge for the extended bridging analogies) was much less for the extended bridging analogies than for the single bridging analogy approach and therefore these results give firmer conclusions.

![Chart 17](image)

In the final part of the research which involved cueing p-prims using analogy given in a very low-key way, the findings are not conclusive. Chart 10 (reproduced
below) shows the small increase in the sense rating of the scientifically correct statement (p = 0.047) together with the very small drop in the sense of the misconception statement (p = 0.431) after the analogy intervention. The control group shifted very little in their sense ratings. It may be that this misconception requires a longer approach to overcome it. In the first part of the research it had been the strongest misconception (according to the initial sense ratings) and in the second part it had been the second strongest. This could indicate its entrenchment.

If this is a particularly strongly entrenched misconception, then its strength may be explained because of its sensory origins. This is supported by Driver et al (1994) who attribute many conceptions that children develop to sensory experiences. The metal object is felt to be cold and this is naturally interpreted as the object being cold. Of course, what is being felt is the lowering of temperature as body heat is being removed by the conducting object. The perception would be similar to touching an object that was at a lower temperature than the metal object but not quite so well conducting. The perception of coldness is seen as being due to the temperature of an object which is caused, at least in part, by the material from which it is made. It is not seen as being caused by the flow of heat from one’s
body to and through the object. An example of this is the apparent drop in
temperature due to the ‘wind chill’ factor. Weather forecasters need to remind
people that it will indeed feel colder when it is windy (due to the increased heat
flow from us). Children (and adults) need to rely on their senses so if something
feels cold then it is natural and sensible to perceive it as being cold. It does not
really matter about the exact temperature when people go out; it matters more how
quickly their body heat is going to be lost. It can even be essential to survival. This
being said, it would be no surprise to find this misconception being strong and
resilient.

If pupils were to be taught how senses work, then this misconception might be
overcome. This is supported by diSessa (personal correspondence, 2003-2004)
who suggests that the pupils need a new model of sense experience involving
knowledge of how the nerves in the hand need to be heated in order for something
to feel hot. Then it becomes more reasonable to think that cork or wood, etc. is the
same temperature as the metal but just does not conduct as quickly.

Based on these results, it can be seen that cueing p-prims is only partially
successful as is using bridging analogies. The more overt bridging analogy
approach is more likely to succeed when there are more bridging analogies
included. More understanding could be reached if a model of sense perception
were included which would help to remove the idea that temperature is due to an
object’s natural propensity.

It is likely that even the more overt bridging analogies used were working by
cueing p-prims as only just over one third of the pupils who had either changed
their mind as to the probable correct statement (from misconception to scientific
conception) or at least increased their sense rating of the scientific conception
compared with the misconception, specifically mentioned the analogy when asked
about their answers.
7.2 Heat 2

Chart 3 (reproduced below) shows the results for the tests for the single bridging analogy approach.

There is not much difference for the two groups. They both show a similar increase between pre-test and post-test but the experimental group demonstrates a small rise in proceeding to the retention test while the control group shows a slight decrease. This is indicative of the analogy approach working at a deeper and more lasting level than the traditional approach of doing the experiment, writing a conclusion and practising some questions. In this case it may give some mental model of ‘catching’ and ‘throwing’ the heat energy. It may not be a sophisticated or even scientifically correct model but few models are, at least, in their simplified form.

The single bridging analogy approach (see Chart 18) shows a rise in the sense ratings for each part of the approach, indicating that each step is of help. This is
similar to the percentage of pupils giving the scientific statement as being likely to be the correct one.

When another bridging analogy was introduced (see Chart 19) there was an increase in the sense ratings for each step, again indicating that each step is of help. The percentage giving the correct answer followed the same pattern.

It is thought likely that p-prims were being cued as this happens at an unconscious level, as many pupils seemed not to know why they had changed their minds about the target question as they went through the bridging analogy process.

It is hard to compare the overall efficacy of the two bridging analogy approaches (single and extended) as they start from different points on the sense ratings scale.
For the final part of the research which involved cueing p-prims using analogy given in a very low-key way, the findings have been discussed (see pages 226-228 and Chart 11 reproduced below). In summary, it can be said that without the analogy intervention, there is a significant marked drop in the sense rating given to the scientific statement ($p = 0.047$) together with a comparable, but not significant at the 0.05 level ($p = 0.198$), rise in the sense rating given to the misconception. The intervention overcomes this and actually reverses the trend.
From these results for this topic, it seems as if both a more overt bridging analogy approach and cueing p-prims are successful in changing pupils' ideas about radiation and absorption. It should be emphasised that even when the more overt analogy approach was being used, the pupils were not told it was analogies that were being used. They were given the analogous situations and discussed the similarities and differences but were not told they had to make use of them when answering the target questions. That the pupils had not consciously taken them to be analogies became obvious when they were asked why they had given the answers they had, for example in the extended bridging analogy approach. In total, out of the sixteen pupils who had either changed their mind as to the probable correct statement (from misconception to scientific conception) or at least increased their sense rating of the scientific conception compared with the misconception, only three specifically mentioned the analogy. This reinforces the idea that the pupils were having p-prims cued.

This is not likely to be a misconception that is particularly difficult to change. In the first part of the research it was found that, of all the topics researched, this misconception was least strong. It has not originated in a sensory manner unlike
some of the others and probably has only been considerably strengthened because of the conduction/insulation topic. For the first two parts of the research (single and extended bridging analogy approaches) the conduction/insulation topic had been studied prior to the pre-test so the strengthening of the misconception by this topic was not observed. It was only shown by the results of the control group in the low-key analogy approach. In this part of the research the conduction/insulation topic was studied between the pre-test and the post test. The sense rating the control group gave to the scientific conception decreased considerably mirrored by an increase in the misconception sense rating. A small cue was enough to reverse this trend for the experimental group.

In summary, this topic lends itself to this type of approach. The more overt use of bridging analogies led to a small long-term effect and the cueing of p-prims led to a good short-term effect compared with no cueing. A combination of the methods using bridging analogies that were pointed out to the pupils and cueing p-prims as reminders seems optimal for this topic.
7.3 Light 1

A similar pattern to Heat 2 emerges for this topic for the pre-, post- and retention tests for the single bridging analogy approach (see Chart 4 reproduced below). There is an increase for both groups going from pre-test to post-test (larger for the control group) followed by a drop between the post-test and the retention test for the control group together with a rise for the experimental group. Again, this adds credence to the idea that the bridging analogies are working at a deeper level than the traditional method although the traditional method is certainly more successful in the short (one week) term.

![Chart 4 To show average test marks for experimental and control groups for the three tests (light 1)](chart)

During the single bridging analogy approach there was a substantial increase for each step of the analogy process for the sense values indicating that each step was useful. This can be seen in Chart 20. The percentage giving the correct answer followed a similar pattern.
When more steps were used it was decided to make use of the mirror anchor rather than a ball bouncing off a board. This was mainly to simplify the analogies as explained on page 186. Chart 21 shows that there was reasonable success here although there was a drop in the sense ratings and the percentage giving the correct answer between ‘after the anchor and after the first bridging analogy’ and also between ‘after the second bridging analogy and after the explanation’. These dips were discussed on page 202.
The overall increase seemed better when only one bridge was used. This could have been due to the analogies used or it could have been because the starting sense ratings were different. One class in this cohort had been taught about reflection the previous year. This meant that they were more likely to give the scientific statement as the one they thought was the most likely answer. However, the sense ratings still showed an increase during the bridging analogy approach for this class. It was felt not to matter too much that this class had viewed this topic previously, as, for this part of the research, there was not a control group. It is interesting to note that the class who had not done this topic before did not have this dip in their sense ratings. It could be that the other class thought they knew the right answer because they had ‘done it before’, were encouraged by the anchor but then wavered somewhat as they began to doubt themselves. This is, of course, only conjecture, based on a very small sample.

One interesting observation is that, when pupils were asked how we can see a piece of paper, many answered correctly that it reflects light. However, when asked how much sense the alternative statements made, several decided that the
‘misconception’ statement made more sense and was the probable answer, not realising that they had contradicted their previous answer.

In the final part of the research where the analogies were used in a very low-key manner the analogies used were based on the more overt single bridging analogy approach that had seemed more successful than the extended bridging analogy approach. It was, however, much simpler than the analogy approach in that it did not involve the position of images to be found.

Chart 12 (reproduced below) indicates an increase in the sense of the scientific conception for the experimental group and a comparable decrease in the sense of the misconception. As in the Heat 2 topic there is a worrying drop in the sense of the scientific conception for the control group together with a rise in the sense of the misconception. One explanation is that half of this year group had already covered the topic of reflection the previous year. The pre-test was given at the start of the academic year whereas the post-test was given some months later so it is possible that there was some reversion to the misconception during those months. It should be observed, however, that there were no results of significance at the 0.05 level for this part of the research in this topic.
The results from the research for this topic show that this topic is open to bridging analogies, both more overt and low-key. Even in using the more overt analogies, it is likely that p-prims were being cued. For the extended bridging analogy approach, of the pupils who had either changed their mind as to the probable correct statement (from misconception to scientific conception) or at least increased their sense rating of the scientific conception compared with the misconception less than one third made specific references to the analogy. This indicates that most pupils were not viewing the experiments as analogies but there was unconscious cueing taking place.
7.4 Light 2

There was an increase in the pre-test to post-test scores for the experimental group but this was outweighed by the increase for the control group (see Chart 5 reproduced below). The control group’s retention test score dropped as in the other topics but the experimental group’s score had a greater drop. As far as this test part of the research is concerned, this was not an overall success for the bridging analogy approach.

![Chart 5 To show average test marks for experimental and control groups for the three tests (light 2)](image)

Although the test results for this topic were not promising for the bridging analogy approach, an analysis of the approach itself is interesting. Chart 22 shows a substantial increase at each stage of the process. From an initial preference of the misconception making more sense, after the anchor we find that the scientific conception makes more sense. Certainly within the approach, there is success.
This success is repeated in the next part of the research when another bridge is introduced (see Charts 23). Again, each of the stages produced an increase in the sense ratings. The large increase in the correct answer being given, from approximately 36% to 86% (initial to after bridge) for the single bridging analogy approach and 15% to 45% (initial to after bridge 2) for the extended bridging analogy approach, is not reflected in the test results and it is possible that this may be explained by cueing p-prims.
For the extended bridging analogy approach, of the pupils who had either changed their mind as to the probable correct statement (from misconception to scientific conception) or at least increased their sense rating of the scientific conception compared with the misconception less than one third made specific references to the analogy. This again indicates that most pupils were not viewing the experiments as analogies.

It can be seen from Chart 13 (reproduced below) that the low-key analogies seemed to work well in strengthening the scientific conception in the short term. It gave the largest increase of all the topics. The Light 2 topic gave the smallest increase in going from the post-test to the retention test – in fact it was a decrease for the single bridging analogy approach. This seems to suggest that the p-prims are very fluid in their ability to be cued. The bridging analogies may have worked more in their cueing ability rather than in their ability to provide a mental model of mechanism. This seems to have produced a very short term success, i.e. during
the bridging analogy approach but poor longer term success, i.e. going from post-test to retention test.

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**Chart 13 Change in sense of scientific and misconception answers for LIGHT 2**

![Graph showing change in sense of scientific and misconception answers for LIGHT 2.](image)

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Cueing p-prims is not expected to be successful in permanently changing a pupil's conceptions. There would need to be many occasions where the correct p-prim is cued for it to strengthen sufficiently to become a strong enough p-prim to reliably be automatically cued in the relevant situation. However, it is important to consider whether analogies work mainly by changing pupils' models or by cueing p-prims. If it is the former then it might be expected that pupils will be able to answer questions correctly given at a later time without the relevant analogy being given again. This may extend to questions set in a slightly different context. If it is the latter, then one might expect that questions given later, especially those posed in a different context might not elicit any more correct answers than those posed before the intervention. In other words, cueing p-prims has a very short life expectancy unless repeated very frequently. This appears to be what is happening in this topic.
This topic of colour probed the children’s understanding of what filters do to white light; do filters remove or add colour? For both the single and double bridging analogy approach, there was a substantial increase in the sense of the science conception compared with the misconception. This could indicate an increase in understanding the model of colour separation or it could indicate repeated cueing of the filtration idea through the approach. (It should be noted that the colour filters were referred to as ‘coloured see-through’ pieces of plastic rather than colour filters.) The drop in going from post-test to retention test suggests the latter. If there were an increase in understanding, one would expect the retention test results to not have dropped by so large a margin. In fact, it also explains why there was little increase from pre-test to post-test. The post-test was carried out one week after the intervention and this is probably too long for any p-prim cueing to be effective. Any increase was probably due to the explanation given after the bridging analogy approach. This may have acted as a partial model change but the control group’s model change was better. This may be because the control group’s practice with questions gave them a deeper understanding as these questions were given in a diagrammatic form. This is reinforced by the results for the last part of the research that tested the pupils’ response to low-key cueing of p-prims, which was extremely successful for this topic.

Changing ideas in this topic probably does not undermine any of the pupil’s fundamental concepts and the p-prims of ‘adding’ and ‘filtering’ are probably both easily cued. The fact that the majority of pupils made more sense of the misconception to begin with is probably because the p-prim of ‘adding’ is being cued because the colour filter has been added. It may not mean that that there is a strong idea that this is how a filter works. A small shift in the way the problem is viewed seems to have easily caused the correct p-prim to be cued. This is very much in keeping with the theory of p-prims.
7.5 Forces 1

There was an increase for the experimental group from pre-test to post-test but there was a larger increase for the control group (see Chart 6). This may be due to the practice questions that the control group had being very similar to the test questions.

However, the fact that this topic provided the largest increase of all the topics for going from the pre-test to post-test for the experimental group is indicative that the bridging analogy approach was being successful.

There was the same increase for the control group and the experimental group when going from post-test to retention test. Previous research has shown improvement for bridging analogies (e.g. Clement, 1998).

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Chart 6 To show average test marks for experimental and control groups for the three tests (forces 1)

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The single bridging analogy approach showed an increase in sense rating at each step whereas the extended bridging analogies used in the pilot research had caused
a dip in the sense ratings that was not recovered until after the explanation (see Charts 24 and 1).
It was suggested (see page 146) that this dip could be due to the fact that it was integral to the research that the pupils were not told that the experiments were analogies but were free to compare and contrast at will. This was the same for all the topics but it was only with this one that there was such a drop during the process. Another suggestion was that there was a state of confusion while misconceptions were being changed to a more scientific view. This could be so but it is strange that it was not repeated in the single bridging analogy approach. Another possibility is that the pupils regarded the springs as being totally different from the table and therefore assumed that they were definitely not meant to be analogous. It is possible that in the single bridging approach there was more discussion as to the similarities as well as the differences between the two situations. In addition, in the pilot research, only the sense that the scientific conception made was asked for but, if this analysis is repeated with the single bridging analogy approach, the shape of the graph (see Chart 25) is similar to Chart 24 where the ‘sense of the ‘misconception’ statement is subtracted from the sense of the ‘scientific’ statement’.

Chart 25 To show change in understanding (of scientific explanation) during course of single bridging analogy for FORCES 1

Stage of approach

<table>
<thead>
<tr>
<th>Stage of approach</th>
<th>Sense 'Scientific Explanation'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>2</td>
</tr>
<tr>
<td>After anchor</td>
<td>2.5</td>
</tr>
<tr>
<td>After bridge</td>
<td>3</td>
</tr>
<tr>
<td>After explanation</td>
<td>4.5</td>
</tr>
</tbody>
</table>
The overall changes between tests in the pilot research are too small to be significant. More important are the changes affecting individual questions and these have been more thoroughly discussed on pages 138-145.

This topic tests whether pupils thought that there was a reaction force to the weight of a book on a table. However, it actually asked about the forces on the book, whether there is one force on the book due to gravity with the table just in the way or whether there are two forces on the book, one being due to gravity and one being due to the table pushing up on the book. For the single bridging analogy approach, there was an increase in the sense ratings for the scientific conception compared with the misconception for each stage of the process. This could show an increased understanding of the ‘springiness’ model of the table or it could be due to the springiness p-prim being repeatedly cued.

The substantial increase between the pre- and the post-test for the single bridging analogy approach is suggestive that a better mental model is being produced by the pupils. It is unlikely that p-prims being cued would have this much effect although it could be the explanation given at the end of the approach that was successful. Supportive evidence for the lack of effectiveness of cueing p-prims in this topic comes from the low-key cueing of p-prims that did not work positively for this topic. The low-key analogies used for this topic had a detrimental effect in both the sense ratings and the percentage giving the correct answer (see Chart 14 reproduced below).
The idea that forces cannot be produced by an inanimate object has already been mentioned. The Earth is seen as the agency of gravity because objects generally fall towards the Earth when dropped, even though the Earth is inanimate. There may emerge from this some idea of the Earth as being somehow living which may be an acceptable viewpoint for children as all life as we know it is on Earth so it is not much of a leap to think of the Earth as being somehow living; a Mother Earth or Gaia picture. The idea that inanimate objects do not usually produce forces may be such a strong idea that the springiness p-prim cannot come into play and it may be that a full bridging analogy approach is needed where the links are made explicitly and the whole model of forces as interactions is explained together with some notion of Newton's third law.

A physicist would maintain there are two pairs of action-reaction forces to consider (see, for example, Pople, 1987). There is the gravity pair that comprises the force of the Earth pulling on the book and the equal and opposite force of the book pulling on the Earth. There is also the contact pair comprising the force of the book on the table and the force of the table on the book. Of course, when we consider the book itself, there are just two forces to consider; the force of gravity
on the book causing its weight and the force of the table on the book. These are
not an action-reaction pair as they are acting on one object. However, it still needs
a consideration of Newton's third law, as one of the forces considered is the
normal or reaction force. Viewed like this it is not surprising that most pupils
regard the table as just `being in the way'.

For the single bridging analogy approach and the low key analogies, the two sense
statements the pupils had to choose from were as follows:

a. There is gravity acting downwards on the book and the table is just in the
way to stop the book falling.

b. There is gravity acting downwards on the book and the table pushes
upwards on the book by the same amount.

If the scientific statement to the pupils had stated that the table applied some
upwards force on the book, using the low-key spring analogy may have had more
success. However, the statement refers to the table pushing up on the book by the
same amount as the book pushes down on the table. Not only is the blocking p-
prim available but also the overcoming p-prim (diSessa, 1993) where gravity
could be viewed as being stronger than any upward force due to the table. Thus, if
a pupil thinks that the table does push up on the book but not as much as gravity is
pulling down, they would still choose the misconception statement even though
they are well on the way to accepting the balanced force situation.
7.6 Forces 2

There was not much difference between the control group and the experimental group for the tests for this topic (see Chart 7 reproduced below). Both groups showed an improvement from pre-test to post-test and from post-test to retention test.

The single bridging analogy approach did not seem successful during the approach (see Chart 26). There was not much improvement in the sense ratings given between initial thoughts and those after the bridge and the results were not significant at the 0.05 level. The dip was discussed on page 173.
There was no extended bridging analogy carried out for this topic as there were no clear extra analogies that could be built in.

When the low-key analogies were used, although neither of the results was significant at a 0.05 level, there was a large improvement in the percentage giving the correct answer for the experimental group (21%) and a substantial drop for the control group (12%). This indicates that the particular analogies used for this topic worked well at cueing the correct p-prim. A different set of bridging analogies had been chosen for this part of the research to the more overt bridging analogies part of the research since it was felt that the previous ones could not be used in a low-key manner as they referred to the topic in question. It was necessary for the low-key analogies to be from another area to be surer that the pupils would not consciously see them as analogies.

The cue used was visual and this may be the reason for its effectiveness. This view is supported by the work of Kokinov and Yoveva (1996) and Kokinov et al (1997)
who found that diagrams could help as unconscious contextual clues (see pages 102-103).

It is likely that it was p-prims that were being cued as, for the experimental group in this part of the research, of the seven pupils who changed their minds between pre-test and post-test from the misconception to the scientific conception; none could explain why they had written that particular answer. There were no references to the analogy in any of the comments made.
8.1 Conclusions

1. The first research problem was:

To investigate whether scientific misconceptions can be overcome by the use of bridging analogies

Bridging analogies might help with concept understanding. This is shown by the change from post to retention test in the single bridging analogy approach for the topics. In two out of the six topics there was a rise for the experimental group going from the post to the retention test coupled with a drop for the control group (Heat 2 and Light 1). In the Heat 1 topic there was no increase for the experimental group but there was a drop for the control group. In the Forces 2 topic there was a greater increase for the experimental group than for the control group. In the Forces 1 topic there was the same increase for both groups. Only in the Light 2 topic was there a greater drop for the experimental group compared with the control group. Thus, for all but one topic, going from the post-test to the retention test proved better for the experimental group than for the control group.

Although this conclusion seems positive, the findings should not be misinterpreted. In all the topics the control group showed a bigger increase in going from the pre-test to the post-test. This may be a case of ‘teaching to the test’
since some of the questions in the pre-test and post-test were very similar to questions the control group had to answer as part of their lesson. This may (and should) have had positive effects on their post-test and possibly their retention test results. It is obvious that using the bridging analogies did not have such a positive effect in going from pre-test to post-test. It is possible that there would have been a better improvement if the analogous nature of the experiments etc. had been fully explained to the experimental group. This was not possible during this research as has previously been indicated (see page 151).

It is not always advantageous to increase the number of bridges in the bridging analogy approach. Some of the topics worked better with one rather than two bridges (Heat 2, Light 1 and Forces 1).

Bridging analogies do seem to have success during the actual teaching sequence as shown by the results to both the single and extended bridging analogies.

2. The second research problem was:

**To analyse the bridging analogy process using phenomenological primitives (p-prims)**

It was possible to analyse the bridging analogy approach using postulated p-prims as was shown in chapter six. Both the misconception and the scientific conception were analysed in this way and, in fact, this was one way that the particular bridging analogies were chosen. The other main feature in the choice of bridging analogies was that they started with a concrete anchor with which most of the pupils agreed and which could lead step by step to the target.
3. A research question that was posed was:

Do *p*-prims account for any success in this bridging analogy method or does the introduction of analogy cause more conscious thought processes?

Bridging analogies may work by cueing *p*-prims if the analogous nature of the anchor, bridge and target is not specifically pointed out. The research suggests that, if it is *p*-prims which are being cued, then this does not help longer term test results. This is as expected since the theory of *p*-prims is that they need to be cued many times before becoming strong enough to reliably be cued on each relevant occasion.

For some topics cueing *p*-prims on a low-key level can bring short-term success. However, this is not true of all topics. In all but the Forces 1 topic there was a greater improvement going from pre-test to post test for the experimental group compared with the control group. In the Forces 1 topic there was a decrease going from pre-test to post test for the experimental group.

There appears to be two extremes in the topics. At one extreme is the Light 2 topic. In this topic it was easy to cue *p*-prims but the long-term success of the bridging analogy approach was poor. This may link in with the idea that pupils do not have any very strong notions about how colour filters work. Given a choice of them working by adding or subtracting colours, many pupils would choose the adding model but can easily be persuaded to use the subtracting model by low-key use of analogy. The change does not last for long and they quickly revert to the adding model.

At the other extreme is the Forces 1 topic. This had good long term success with the bridging analogy approach (comparing the experimental group’s pre, post and retention tests for the different topics) but there was no success at all cueing *p*-prims in a low-key manner. It seems likely that the analogies need to be explained...
in order to build up a model of what is happening. The idea of the table just being 'in the way' is too strong to be changed by the use of low-key analogies.

This study was not designed to allow research into the use of analogy where pupils knew that analogy was specifically being used since part of the investigation was to see what happened at different stages of the bridging analogy approach. Being told an analogy was being used would be like telling the pupils what the correct answer should be. Knowing the correct answer might sway their perception of how much sense the correct answer and the misconception made. In the majority of cases, the pupils did not figure out that bridging analogies were being used even in the more overt bridging analogy approaches (main research, parts one and two). Less than one-third of the pupils, who changed their mind from the misconception to the scientific conception or at least increased their sense rating of the scientific conception relative to the misconception, specifically pointed out the analogies when asked why they had written what they had (see pages 199-201).
8.2 Usefulness of the research

One of the reasons the author embarked on this research was to improve her own teaching and in the process provide information which would be useful to other practitioners. Chapters 4 and 5 indicate ways in which bridging analogies could be used in the classroom as well as a guide to their likely success. The analogies used in Chapter 4 are shown in detail in Appendix IIa and those used in chapter 5 are given in Appendix IIIa.

This research has extended the scope of bridging analogies. It has shown that they are potentially useful in various topics as a way of retaining conceptions. They were found to be successful in this respect in the Heat 1 topic (thermal equilibrium), the Heat 2 topic (radiation and absorption), the Light 1 topic (reflection of light), the Forces 1 topic ('book on the table' problem) and the Forces 2 topic (extension being dependent on original length). Previous research had concentrated on forces topics.

It would be sensible to rewrite these so that they could be used in a more open way with the pupils knowing that analogies were being used. It should be noted that, if they were to be used in this way, it would be vital to explain the limitations of any analogies used as cautioned by, for example, Glynn (1991).

It is felt that using low-key analogy to cue p-prims has a place in the curriculum. Advantages of using analogy to cue p-prims are:

- P-prims are quick to cue. Long discussions as to the appropriateness and extent of the analogy are not required as the analogy is not being used to promote a mental model but merely as a cue.
• Cueing p-prims can be used to lead pupils to produce the right answer without being told what the answer is. This gives pupils encouragement and confidence in their scientific abilities.

• Cueing p-prims can help as a reminder as to the answer to a problem. It is obviously not feasible to always give clues, for example, in examinations but it is often useful to be able to point a pupil in the right direction.

• It may be beneficial to cue p-prims if a problem in a slightly different context is given. It seems unfair to penalise pupils who know the right answer but do not realise it is the right answer in a particular context. It may be that the judicial use of a little Vigotskian scaffolding could prove very beneficial.

Chapter 6 includes scripts that could be used as unconscious contextual clues where low-key reminders are required. The topics which proved successful in the short-term were the Heat 1 topic (thermal equilibrium), the Heat 2 topic (radiation and absorption), the Light 1 topic (reflection of light), the Light 2 topic (colour) and the Forces 2 topic (extension being dependent on original length). Previous research by such as Kokinov on unconscious contextual clues appears not to have included these topics. He and his co-researchers concentrated more on novel problem solving rather than recall of concepts.

If they were to be used in written questions rather than in a teaching situation, then they could be given as pictures or diagrams accompanying the text of the question. Some comment would have to be made that the pictures or diagrams were to be ignored as having nothing to do with the question. This was found to be a successful approach by Kokinov and Yoveva (1996). For example, in the colour topic (light 2) which worked particularly well, a diagram of a liquid with a solid settled at the bottom being filtered (anchor) could be shown together with a diagram of a solid dispersed in a liquid being filtered (bridging analogy). These
could be part of another question on the same page which the pupils would be told to ignore. The diagrams would be placed so it would be difficult to miss them.
8.3 Locating the research in its literature base

This research has utilised and extended the work of other researchers as follows.

**Clement, Brown, Thijs and Bosch**

As has been previously mentioned, previous researchers in the field of bridging analogies have concentrated on forces topics where they have found them to be useful. The present research has extended this to examine the efficacy of using bridging analogies in different topics utilising the idea that anchor analogies should be concrete when the particular bridging analogies were devised (Clement *et al*, 1989). The research has found varying levels of success for the different topics.

**diSessa**

diSessa’s work on p-prims has been used to analyse the misconceptions and scientific conceptions in this research and thus help to identify possible bridging analogy approaches for the different topics. This has extended the usefulness of the notion of p-prims being small knowledge structures which are capable of being cued. This research agrees in part with diSessa’s view (1994) that deep conceptual learning is unlikely to occur unless there is extended, cumulative experience with a concept (see page 77 of this research). An example of this is in the topic of colour. It was relatively easy to cue the right answer but this did not mean there was any deep conceptual learning. On the contrary, it appeared that there had been little or no long-term learning if the post-test and retention test in part one of the main research were valid measures of deep conceptual learning in this topic. However, other topics showed a more positive outcome. Although the post-test results for the experimental group were generally not as good as post-test results for the control grouping (compared with the pre-test results), in four topics there was an increase to the retention test results for the experimental group.
Kokinov

Although explicit hints may be useful in problem solving, Kokinov and Yoveva (1996) and Kokinov et al (1997) carried out research which showed that remote or unconscious contextual clues could be used to aid problem solving (see page 102). It was argued by Kokinov et al (ibid) that three mechanisms play a part in the problem context. These are reasoning, perception and memory. When an explicit hint is given but it is difficult to use reasoning to understand the analogous nature between the hint and the problem, then the hint becomes useless and an obstacle to solving the problem. However, if the hint is remote but in the visual field, perceptual mechanisms will begin to process it. There will be interactions with the memory mechanisms and its links to other memory elements will cue these and bring them to the fore. This will happen unconsciously.

The present research (main research – part 3) used non-explicit analogies as cues. In this case, the analogies would have been straightforward to understand if they had been used explicitly. However, it was decided to use them at a low-key level to see if the correct answer could be cued. This was found to be successful in some topics and it was argued that correct p-prims had been cued as the pupils did not seem to have made use of the analogies directly as they made no reference to them when asked about the reasons for their answers. Thus, there seems to be a connection between cueing p-prims and Kokinov’s remote hints. This research has extended that of Kokinov and his colleagues in that he used analogies which were difficult to use as analogies whereas this research has used analogies which were easy to understand but still seemed to be processed as visual (perceptual) clues rather than as analogical (reasoning) clues.
8.4 Reflections on methodology

It has already been stated that the background of the author is in the physical sciences and a decision was taken to use a quasi-experimental design. It is of importance to discuss the advantages and disadvantages of this and how the research could be furthered using different methodologies.

Advantages

- This type of design was more familiar to the author than other methodologies.
- The design used provides a substantial amount of data from class sets of pupils and it is classes with which the teacher is dealing.
- The data can be analysed using the statistical t-test to give an idea of the probability with which the null hypothesis can be rejected.

Disadvantages

- In order to control variables as much as possible, it was necessary that the pupils could not discuss ideas among themselves. It was pointed out on page 40 how this goes against the ideology of social constructivism.
- No feedback could be given to the pupils where tests were going to be repeated. This is an ethical issue and is further discussed on page 283.
- Although there is breadth of data, there is less depth of data.

Other design and methodological approaches

Other approaches were considered for this research and could be used in future research topics in the area. These included the following.

Interview

Semi-structured interviews could be given which introduce the bridging analogies during the interview. An advantage of this type of design is the chance of a greater depth of understanding of individual thought processes. This should be weighed
against several disadvantages. There are not as many pupils involved so the breadth of data is lacking and pupils may be unwilling to give up their own time for these interviews. Analysis of the interviews may be problematic as in that pupils often use words in a different meaning to how teachers use them. For example the word ‘force’ can mean something entirely different to a pupil and a teacher.

Semi-structured interviews were used to a small extent in this research in the Light 2 topic to elicit whether pupils knew why they had changed their minds between the pre-test and the post-test. However, they were not used as a means of introducing the bridging analogies.

Semi-structured interviews have been successfully used by Bryce and MacMillan (2005) to investigate the use of bridging analogies in teaching about action-reaction forces.

**Longitudinal study**

A longitudinal study was considered using either a quasi-experimental or interview design. An advantage of this approach is that the development of pupils over several years can be investigated. However, it was felt to be inappropriate for this research as cueing p-prims was not aimed to be long-term and even the retention tests for the first part of the main research were designed to be completed within two months. Future research could make use of a longitudinal study if it were investigating, for example, how bridging analogies could be used to link together topics studied in different years.
8.5 Possibilities for further research

- A severe limitation of this work is the fact that it was carried out in an independent selective all girls' school which is obviously not representative of the whole population of 12-13 year olds. More work needs to be done on the whole ability range of boys and girls in order to see whether similar conclusions are reached. One factor that could be further investigated is whether practical demonstrations are the best way to introduce the analogy for boys. Thijs and Bosch (1995) found that demonstration practicals are, for girls, more successful than small group practicals.

- The pupils were not told that analogies were being used as the research sought to analyse results within the approach. Further research should include allowing the pupils to know analogies are being made during the approach together with pre-, post- and retention tests to investigate the efficacy of bridging analogies in different topics. This was beyond the scope of this research. It is likely that better mental models would be built up than in the type of approach used in the present research.

- The topics were limited in this research to the areas covered by the year group and more research should cover different topics, e.g. electricity. This is an area well-known for misconceptions (see, for example, Shipstone, 1988).
8.6 Reflections on ethical issues

Permission for the research to be conducted was granted from the headteacher. The pupils were assured that individual pupils would not be identified in the write-up of the research and permission was sought from both parents and pupils where interviews were carried out.

One of the main ethical issues in this research was the fact that the two classes were having different teaching experiences from each other. This was overcome to a certain extent during revision (for the summer examination) lessons at the end of the year where approaches which had worked particularly well during the research were used with the class which had not already benefited from that approach. This was not ideal but was the only way both classes could benefit.

Another ethical issue was the lack of social interaction during the bridging analogy approach and the allied problem of lack of feedback to the pupils where tests were going to be repeated. The pupils were used to discussing problems unless they were doing a test at the end of a topic. They were not used to being given questions under test conditions at the beginning of a topic or even after a topic without having had the opportunity of revision. The pupils were clearly worried about not knowing the answer to the questions even though they were constantly reassured that their answers would not be used as part of their assessment for reports, etc. and that (at the beginning of the topic) they were not supposed to know the right answers – it was their ideas that the author was interested in. In future, it may be better to prepare pupils beforehand for similar research by introducing questions to be completed under test conditions at the beginning of all topics. The pupils would see this as a normal part of their physics lessons and it would also provide valuable information on their conceptions prior to being taught the topic.
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Appendix Ia  Pilot study bridging analogies used for experimental group (1999-2000)

A book resting on a table.

What force or forces are acting on the book?

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5
(where 5 is very sure, 3 is fairly sure and 1 is very unsure)? _______
Your friend says that the table is pushing up on the book as well as gravity pulling down on the book? How much sense does that make on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

**Experiment 1** Push down on the spring with your hand. Does the spring feel as though it is pushing up on your hand?

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

**Experiment 2**

How much sense does it make to say that the spring pushes up on the book as well as gravity pulling down on the book - on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?
When the book is balanced on the spring, the spring compresses. The further down the spring is pushed, the more it pushes back. The spring is compressed by the book to the point where it pushes back with a force equal to the book’s weight. For example, if the book weighs 5N then the spring will compress until it is pushing up with a force of 5N. Similarly, if the book weighs 10N then the spring will compress until it is pushing up with a force of 10N.

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

Many people say that the book on the spring is different from the book on the table. They say that the spring compresses but the table is rigid. Is the table rigid?

**Experiment three** Balance the plastic ruler on the blocks. Put a book on the ruler.

What happens to the ruler?

Now try the wooden ruler with the same book. Is there any difference?
The rulers both bend but the wooden one is less bendy. They both bend until they push up with a force equal to the book’s weight. The wooden ruler does not have to bend as far as the plastic ruler.

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

You can think of the ruler as being like the table. It is just that the table is not as bendy as the rulers - even the wooden one. The table bends a tiny little bit because of the weight of the book.

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

The table is made of particles which are joined to other particles by bonds which are ‘springy’. If you could look at the table under the book using a microscope you would see that the table bends very slightly. The table, just like the spring and the rulers is compressed and pushes upwards against the book. It pushes upwards with a force that is just equal to the book’s weight.

Now how much sense does it make to say that the table pushes up on the book on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

To summarise, everything is springy, even a table. Gravity pulls down on the book and the table pushes up on the book with a force equal to the book’s weight.

How much sense does this explanation make on a scale of 1 - 5 (where 5 is ‘it makes a lot of sense’, 3 is ‘it makes some sense’ and 1 is ‘it makes no sense’)?

_____
Appendix Ib  

Pilot study control group work (1999-2000)

If forces on an object are balanced then there is no change in speed in that direction.

If the object is still, it will not start moving. If it is moving to begin with, it carries on in a straight line at the same speed until the forces become unbalanced. This is Newton’s 1st law.

Some examples of balanced forces are:
1.

![Diagram of block being pulled with equal friction force](image)

The block is being pulled but the force due to friction is equal to the pull but in the opposite direction and so the forces are balanced and the block does not move.

2.

A book on a table

![Diagram of book on table](image)

The book on the table has the force due to gravity acting on it which is exactly balanced by the force of the table pushing up on the book.

3.

![Diagram of tug-of-war](image)

In the tug-of-war, the rope has two pulling forces acting on it - one from each person. If the forces are balanced then the rope will not move.
4. The floating block has its weight pulling it down and the force of the water pushing it up (this is called the upthrust). The two forces are balanced and so the block stays still.

5. The object has its weight pulling it down and the stretched spring pulling it up. The two forces are balanced and so the object stays still.

6. The force of gravity pulling the boy down is balanced by the force of the chair pushing up on him. The boy does not move.
Some practical examples of forces in balance

1. 

Push the block gently against the wall with the springs in position. See how much the springs are squashed. Are they squashed by the same amount or is one squashed more than the other?

Push the block gently against the wall with the push-meters in place. Note the readings on the push-meters. What are they?

Now push a bit harder. What can you say about the readings now?

2. 

Attach a piece of string to two newton-meters and pull gently. Note the readings on the newton-meters. What are they?

Now pull a bit harder. What are the readings?
Some questions on balanced forces

1. (QCA, 1997)

(a) Megan's dog is pulling on his lead. Which arrow, A, B, C or D, shows the direction of this force? Give the letter. ______

(b) Megan has to pull to keep the dog still. Which arrow shows the direction of this force? Give the letter. ______

(c) Suddenly the dog's collar breaks.

(QCA, 1997)

(i) When the collar breaks, the lead moves. Draw an arrow on the diagram to show which way the lead starts to move.

(ii) Why does the lead move when the collar breaks?
2. In a storm, a small ship was blown onto a beach. Now it is calm and there is no wind. A tugboat is trying to pull the ship off the beach.

![Diagram of a tugboat pulling a ship off the beach](image)

(QCA, 1996)

The tugboat pulls the ship with a force of 25 000 N. The ship does not move because of the force of friction acting on it.

(i) Tick one statement to show the size of the frictional force acting on the ship.

- Zero _____
- more than zero but less than 25 000 N _____
- 25 000 N _____
- more than 25 000 N _____

(ii) Add an arrow to the drawing to show the direction of the frictional force acting on the ship.

3. (QCA, 1997)

A railway engine is being used to try to pull a wagon along a level track. The wagon's brakes are on, and the wagon does not move.

(i) Draw one arrow on the diagram to show the direction of the force which prevents the wagon from moving.

(ii) Is the force which prevents the wagon from moving greater than, equal to or less than the pull of the engine?
Appendix Ic  Pilot study questions including (in italics) how each was marked (1999-2000)

SOME QUESTIONS ON FORCES

In each of the questions, I want you to think carefully about any forces which could be acting on or influencing the object. Sometimes you are asked to carefully draw on the diagram any force or forces which are acting on the object. Remember to use an arrow to show the direction of any force and also remember that the length of the line gives an idea of the size of the force. After each question you will be asked about how sure you were about the answer to the question. Try to be truthful.

1. An apple hanging on a tree

What force or forces are acting on the apple (forget about wind blowing or air pressure).

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure). _______

(Counted as correct if two forces in opposite directions are drawn).


What force or forces are acting on the book?

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)? _______

(Counted as correct if two forces in opposite directions are drawn).
3. Jenny is holding a dictionary on her outstretched hand. Gravity is pulling down on the dictionary. When she holds it perfectly still, does her hand push up on the dictionary?

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(Counted as correct if two forces in opposite directions are drawn).

4. You push down on a bedspring with your hand. After you push the spring down by 10cm, you hold the spring down, keeping your hand still. While you are holding your hand still, does the spring push against your hand?

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(Counted as correct if two forces in opposite directions are drawn).

5. Alice and Ben are pulling on a rope. The rope is not moving.

What force or forces are acting on the rope?

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(Counted as correct if two forces in opposite directions are drawn).
6. Alice goes home and Ben ties the rope to a sturdy tree. He pulls on the rope and he, the rope and the tree do not move.

What force or forces are acting on the rope?

![Diagram of a tree and a person pulling a rope]

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)? ______

(Counted as correct if two forces in opposite directions are drawn).

7. A large box on wheels stands on the ground. Sara tries to push it along the floor but it does not move.

What horizontal (not up and down) force(s) are acting on the crate as Sara tries to push it along?

![Diagram of a person pushing a box]

Draw the force or forces on the diagram making sure that you label them.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)? ______

(Counted as correct if two forces in opposite directions are drawn).
8. Sam is pushing a block against a wall. Sam, the block and the wall do not move. 

What force or forces are acting on the block?

Draw the force or forces on the diagram making sure that you label them. 

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(Counted as correct if two forces in opposite directions are drawn).

9. The lift is between floors and not moving. Draw any forces acting on the lift on the diagram. Remember to put arrow(s) on to show the direction. Label any forces with their name(s). If you have drawn one force, what can you say about its size? If you have drawn more than one force, what can you say about their sizes?

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(Counted as correct if two forces in opposite directions are drawn).
10. The man is floating as he is swimming forwards. Draw any forces acting on the man on the diagram. Remember to put arrow(s) on to show the direction. Label any forces with their name(s). If you have drawn one force, what can you say about its size? If you have drawn more than one force, what can you say about their sizes?

(QCA, 1992)

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(10i Counted as correct if two forces in opposite directions are drawn, 10ii Counted as correct if the two forces are indicated to be the same size).

11. The boat is floating and not moving forwards or backwards (the outboard motor is off). Draw any forces acting on the boat on the diagram Remember to put arrow(s) on to show the direction. Label any forces with their name(s). If you have drawn one force, what can you say about its size? If you have drawn more than one force, what can you say about their sizes?

(QCA, 1992)

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(11i Counted as correct if two forces in opposite directions are drawn, 11ii Counted as correct if the two forces are indicated to be the same size).
(QCA, 1993)

The drawing shows a woman sitting in a chair. The springs in the chair are similar to each other.

(a) Which spring has the greatest force acting on it? ________

(b) Explain your answer.

(c) In which direction do the springs push the woman? _______________

(d) When the woman gets up what happens to the springs? _______________

How sure are you that your answers are right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)? ________

(12c counted as correct if right direction is given).
13. A space rocket is on the launch pad. The engines start and an upward force is produced on the rocket.

(a) If the upward force of the engines is less than the weight of the rocket, what will happen to the motion of the rocket?

(b) If the upward force equals the weight of the rocket, what will happen to the motion of the rocket?

(c) If the upward force is greater than the weight of the rocket, what will happen to the motion of the rocket?

How sure are you that your answers are right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(13b counted as correct if a 'no motion' answer is given).
Forces act on the submarine when it is at rest on the sea bed. The water is still and the propellers are not turning.

Carefully draw arrows from the central dot to show two of these forces.

How sure are you that your answer is right on a scale of 1 - 5 (where 5 is very sure, 3 is fairly sure and 1 is very unsure)?

(14i Counted as correct if two forces in opposite directions are drawn, 14ii Counted as correct if the two forces are indicated to be the same size).
### Pilot study test results (1999-2000)

| question | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 i | 9 ii | 10 i | 10 ii | 11 i | 11 ii | 12 c | 13 b | 14 i | 14 ii |
|-----------|---|---|---|---|---|---|---|---|----|-----|------|------|------|-----|-----|-----|-----|
| pupil     |   |   |   |   |   |   |   |   |    |     |      |      |      |     |     |     |     |
| 1         | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 2         | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 3         | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 4         | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 5         | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 6         | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 7         | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 8         | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 9         | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 10        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 11        | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
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| control group | | | | | | | | | | | | | | | | | | |
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| 17        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
| 18        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1   | 1    | 1     | 1     | 1     | 1    | 1   | 1   | 1   | 1   |
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I = initial answers  P = post  R = retention  0 = wrong answer and 1 = correct answer
Appendix Ie  Sense ratings for the bridging analogy approach (Forces 1 – pilot study, 1999-2000)

The numbers refer to the sense rating (1-5) of how much sense the scientific statement makes at the various stages of the bridging analogy approach.

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Appendix If

End of year seven physics results for cohorts in research

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Appendix Ig

Key stage 2 results for end of year six

English results – key stage 2

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Nat. = national results (rows do not add up to 100% because of absent and disapplied pupils.  RS = research school results
# Mathematics results – key stage 2

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Nat. = national results (rows do not add up to 100% because of absent and disapplied pupils. RS = research school results

# Science results – key stage 2

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Nat. = national results (rows do not add up to 100% because of absent and disapplied pupils. RS = research school results
Appendix IIa Bridging analogies used for experimental and control group work (2000-2001)

HEAT 1 THERMAL EQUILIBRIUM - experimental group work

Page 1

WHY DO METALS FEEL COLD?

Experiment: Touch a piece of metal and a cork mat. Which one feels warmer?

Question: Why does metal feel colder than the cork?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. __

b. The metal feels colder because it is naturally at a lower temperature than the cork. __

Which do you think is the more likely explanation? __
Experiment:

Which pea would drop off first? ___________________________

Why? ____________________________________________________________________________________________

Watch the experiment. What happens?

_______________________________________________________________________________________________

Discussion:

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___
Experiment:

Which cools quicker - a beaker of hot water on a cork mat or one on a metal mat (both beakers have lids).

Watch the experiment. What happens?

Discussion:

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork ___

Which do you think is the more likely explanation? ___
Explanation: Metal is a good conductor of heat but cork is a poor conductor of heat. The metal rapidly conducts the heat away from the hot water so it cools down quickly. Cork does not conduct the heat away very quickly and so the water stays hotter longer in this beaker. Our hands are similar to hot water in that they are warmer than room temperature. Heat is quickly removed from our hands by metal but not by cork.

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___

Experiment: Take the temperature of a block of metal and a large cork. What are the temperatures?
WHY DO METALS FEEL COLD? - control group work

Experiment: Touch a piece of metal and a cork mat. Which one feels warmer?

Experiment: Take the temperature of a block of metal and a large cork. What can you say about the temperatures?

Explanation: Metal is a good conductor of heat but cork is a poor conductor of heat. The metal rapidly conducts the heat away from our hands so it feels cool. Cork does not conduct the heat away very quickly and so it feels hotter. If anything is left for long enough at room temperature, it will end up at room temperature. Heat is quickly removed from our hands by metal but not by cork.

Write up these experiments and answer the following questions.

Questions:

1. Why does a garden spade’s wooden handle feel warmer than the metal spade part?

2. Why does a concrete floor feel colder than a carpet?

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ARE GOOD ABSORBERS OF HEAT ALSO GOOD RADIATORS OF HEAT?

When objects are hotter than their surroundings, they give out (radiate) more heat than they take in (absorb), e.g. a cup of hot water cools down. When objects are cooler than their surroundings, they absorb more heat than they radiate, e.g. food warms up in a cooker.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Good absorbers must be poor radiators. ___

b. Good absorbers must be good radiators. ___

Which do you think is more likely to be true? ___
Think about this. In general, do you think that people who are good at throwing balls are good at catching them?

____________________

Discussion:

Sense: How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Good absorbers must be poor radiators. ___

b. Good absorbers must be good radiators. ___

Which do you think is more likely to be true? ___
Think of the balls as packets of energy that can be thrown and caught.

Discussion:

Sense: How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Good absorbers must be poor radiators. ___

b. Good absorbers must be good radiators. ___

Which do you think is more likely to be true? ___
Explanation:

When heat is radiated, it can be thought of as being thrown out in little packets. Objects that can throw out well (radiate well) can also catch heat well (absorb well).

Sense: How much sense do the following statements now make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Good absorbers must be poor radiators. ___

b. Good absorbers must be good radiators. ___

Which do you think is more likely to be true? ___

Experiment:

Watch the radiation and absorption experiments. Are good radiators also good absorbers? _________

What type of surface is a good absorber? _____________

What type of surface is a poor absorber? _____________

What type of surface is a good radiator? _____________

What type of surface is a poor radiator? _____________
ARE GOOD ABSORBERS OF HEAT ALSO GOOD RADIATORS OF HEAT? - control group work

When objects are hotter than their surroundings, they give out (radiate) more heat than they take in (absorb), e.g. a cup of hot water cools down. When objects are cooler than their surroundings, they absorb more heat than they radiate, e.g. food warms up in a cooker.

Experiments: Watch the radiation and absorption experiments.

The conclusion is that


Questions:

1. Why are fire-fighters suits made of shiny material?

2. Why is the back of a refrigerator painted black?

3. What colour car do you think feels hottest inside on a hot, sunny day?
Question: We can see this piece of paper. How can we see it?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place. ___

b. The light shines on the paper and stays there and that is how we see the sheet of paper. ___

Which do you think is the more likely explanation? ___
**Experiment:**
1. Mark a line on the paper along the front of the board.
2. Place the ball on the X.
3. Roll the ball towards A and make sure it bounces off.
4. When the ball stops, mark its position with an X.
5. Join the crosses to A.
6. Repeat the experiment using spot B making sure that the ball starts from the same place.
7. Remove the board and carry on the bounced-off lines backwards. If this was a mirror, where the lines meet would be the position of the image.

**Discussion:**

_Sense:_ Think about the first question again - we can see this piece of paper. How can we see it? How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place.

b. The light shines on the paper and stays there and that is how we see the sheet of paper.

Which do you think is the more likely explanation?
Experiment: In this experiment do the same as in the last experiment.

1. Mark a line on the paper along the front of the board.
2. Place the ball on the X.
3. Roll the ball towards A and make sure it bounces off.
4. When the ball stops, mark its position with an X.
5. Join the crosses to A.
6. Repeat the experiment using spot B making sure that the ball starts from the same place.
7. Remove the board and carry on the bounced-off lines backwards. Now you can see that the lines do not meet. There is no image but the ball has bounced off the surfaces according to the laws of reflection.

Discussion:

Sense: Think about the first question again - we can see this piece of paper. How can we see it?

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go in all over the place.
b. The light shines on the paper and stays there and that is how we see the sheet of paper.

Which do you think is the more likely explanation? __
Explaination: Look at the magnified picture of paper. See how rough it is. Look at the magnified picture of a mirror. See how smooth that is. Each little bit of paper reflects like a mirror but each bit is at an angle to the others because of its roughness so no image is seen.

Sense: Think about the first question again - we can see this piece of paper. How can we see it?

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place.

b. The light shines on the paper and stays there and that is how we see the sheet of paper.

Which do you think is the more likely explanation? ___
Question: We can see this piece of paper. How can we see it?

Explanation: A mirror's surface is very smooth and the light is reflected so we can see an image (remember last year's work?). A piece of paper is actually very rough - look at the difference between the mirror and paper using the flexcam. Although each ray of light follows the rules of reflection and some of the rays bounce off the paper into your eyes, the roughness means that you cannot see an image of yourself in the paper. Carefully draw the diagram, making sure that each ray follows the law of reflection.

Questions:

1. How can we see the Moon when it does not give out any light of its own?

   __________________________
   __________________________
   __________________________

2. Why can we not see this piece of paper in the dark?

   __________________________
   __________________________
   __________________________
Experiment: Look at a white screen through the red piece of plastic. What colour does the screen look?

Question: Why does the screen look red?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The red colour has been added to the white light by the piece of plastic. ___

b. The other colours have been taken away by the piece of plastic leaving only red. ___

Which do you think is the more likely explanation? ___
Experiment: Use the piece of plastic paper and funnel to separate the sand and water. See how the filter paper holds the sand while the water goes through.

Discussion

Sense: Think about the first question again - why does the screen look red? How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The red colour has been added to the white light by the piece of plastic. ____
b. The other colours have been taken away by the piece of plastic leaving only red. ____

Which do you think is the more likely explanation? ____
Experiment: Make a good spectrum of colour using the prism, lens and ray box. Place a red piece of plastic between the prism and screen. Look at the screen. What colours can you see?

Discussion

Sense: Think about the first question again - why does the screen look red?

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The red colour has been added to the white light by the piece of plastic. ___

b. The other colours have been taken away by the piece of plastic leaving only red. ___

Which do you think is the more likely explanation? ___
Explanation: Red pieces of plastic allow only red light to go through them and they absorb all the other colours. White light is made of several colours, most of which are absorbed by the red piece of plastic. Just the red goes through.

Sense: Think about the first question again - why does the screen look red?
How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The red colour has been added to the white light by the piece of plastic. ___
b. The other colours have been taken away by the piece of plastic leaving only red. ___
Which do you think is the more likely explanation? ___
COLOUR FILTERS - control group work

Colour filters can be made from pieces of coloured but see-through plastic. They allow some colours of light through but absorb and do not let through other colours of light. White light from a lamp is made up of several colours and sunlight can be separated into its 'rainbow' colours.

If we shine white light at a blue filter, the filter will let the blue light through and absorb all the other colours.

\[
\text{WHITE} \quad \begin{cases} 
\text{Red} \\
\text{Orange} \\
\text{Yellow} \\
\text{Green} \\
\text{Blue} \\
\text{Indigo} \\
\text{Violet} \\
\end{cases} \rightarrow \quad \rightarrow \quad \text{blue} \\
\text{Blue filter absorbs} \\
\text{red, orange, yellow,} \\
\text{green, indigo and violet}
\]

What will happen with a green filter? Complete the diagram.

\[
\text{WHITE} \quad \begin{cases} 
\text{Red} \\
\text{Orange} \\
\text{Yellow} \\
\text{Green} \\
\text{Blue} \\
\text{Indigo} \\
\text{Violet} \\
\end{cases} \rightarrow \quad \rightarrow \quad \text{Green filter absorbs} \\
\]

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What will happen with a red filter? Complete the diagram.

If a blue filter lets through only blue light, then what happens if I look at a red object through a blue filter? The object normally looks red because it reflects only red light and absorbs any other colours of light. Some of the red light that is reflected off the red object goes to the blue filter and is absorbed so no light gets through the filter. The object looks black.
What will happen with a red filter and a blue object? Complete the diagram.

White light
(R, O, Y, G, B, I+V)

red filter

blue object

What will happen with a red filter and a red object? Complete the diagram.

White light
(R, O, Y, G, B, I+V)

red filter

red object
A book resting on a table.

Question: What force or forces are acting on the book?

__________

Draw the force or forces on the diagram making sure that you label them.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. There is gravity acting downwards on the book and the table is just in the way to stop the book falling. ____

b. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount. ____

Which do you think is the more likely explanation? ____
**Experiment 1**  Push down on the spring with your hand. Does the spring feel as though it is pushing up on your hand?

Discussion

Sense: Think about the first question again about the book on the table. How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. There is gravity acting downwards on the book and the table is just in the way to stop the book falling. ____

b. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount. ____

Which do you think is the more likely explanation? ____
Experiment two  Balance a heavy book on the spring.

What happens to the spring?  

Discussion

Sense: Think about the first question again about the book on the table.
How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. There is gravity acting downwards on the book and the table is just in the way to stop the book falling. __________

b. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount. __________

Which do you think is the more likely explanation? ____
The table is made of particles which are joined to other particles by bonds which are ‘springy’. If you could look at the table under the book using a microscope you would see that the table bends very slightly. The table, just like the spring is compressed and pushes upwards against the book. It pushes upwards with a force that is just equal to the book’s weight.

To summarise, everything is springy, even a table. Gravity pulls down on the book and the table pushes up on the book with a force equal to the book’s weight.

Sense: Think about the first question again about the book on the table.

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. There is gravity acting downwards on the book and the table is just in the way to stop the book falling. ____

b. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount. ____

Which do you think is the more likely explanation? ____
If forces on an object are balanced then there is no change in speed in that direction.

If the object is still, it will not start moving. If it is moving to begin with, it carries on in a straight line at the same speed until the forces become unbalanced. This is Newton's 1st law.

Some examples of balanced forces are:

1. The block is being pulled but the force due to friction is equal to the pull but in the opposite direction and so the forces are balanced and the block does not move.

2. A book on a table

The book on the table has the force due to gravity acting on it which is exactly balanced by the force of the table pushing up on the book.
3. In the tug-of-war, the rope has two pulling forces acting on it - one from each person. If the forces are balanced then the rope will not move.

4. The floating block has its weight pulling it down and the force of the water pushing it up (this is called the upthrust). The two forces are balanced and so the block stays still.

5. The object has its weight pulling it down and the stretched spring pulling it up. The two forces are balanced and so the object stays still.
The force of gravity pulling the boy down is balanced by the force of the chair pushing up on him. The boy does not move.
Some practical examples of forces in balance

1. Push the block gently against the wall with the springs in position. See how much the springs are squashed. Are they squashed by the same amount or is one squashed more than the other?

Now push a bit harder. What can you say about the readings now?

2. Attach a piece of string to two newton-meters and pull gently. Note the readings on the newton-meters. What are they?

Now pull a bit harder. What are the readings?
Question: A 10cm spring has a 2N weight hung on it and it stretches by 3cm to 13cm. A 20cm spring, identical to the 10cm spring except for its length, needs to be stretched by 6cm to 26cm.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. 2N needs to be hung on the 20cm spring to stretch it by 6cm because the 2N weight stretched the 10cm spring by 3cm. Each 10cm of the spring is stretched by 3cm. ___

b. 4N needs to be hung on the 20cm spring to stretch it by 6cm because it needs to be stretched twice as far as the 10cm spring and that will need twice the weight. ___

Which do you think is the more likely explanation? ___
Experiment: Pull a short piece of elastic as hard as you can. How much does it stretch?

Starting length _____ Final length _____ Amount stretched _____

Now imagine that you had a longer length of elastic and you pulled it as hard as you could. Do you think that the stretch would be more or the same as for the shorter length? Remember that it is the amount of stretch that we are thinking about.

__________________________

Try it and see.

Starting length _____ Final length _____ Amount stretched _____

Is the stretch more or the same as for the shorter length? _________

Discussion

Sense: Think about the first question again - a 10cm spring has a 2N weight hung on it and it stretches by 3cm to 13cm. A 20cm spring, identical to the 10cm spring except for its length, needs to be stretched by 6cm to 26cm.

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. 2N needs to be hung on the 20cm spring to stretch it by 6cm because the 2N weight stretched the 10cm spring by 3cm. Each 10cm of the spring is stretched by 3cm. ___

b. 4N needs to be hung on the 20cm spring to stretch it by 6cm because it needs to be stretched twice as far as the 10cm spring and that will need twice the weight. ___

Which do you think is the more likely explanation? ___
Experiment:

Use a newtonmeter to pull a 10cm length of elastic with a force of 4N.

<table>
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<tr>
<th>Starting length</th>
<th>Final length</th>
<th>Amount stretched</th>
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</table>

Now use a newtonmeter to pull a 20cm piece of elastic using a 4N force.

<table>
<thead>
<tr>
<th>Starting length</th>
<th>Final length</th>
<th>Amount stretched</th>
</tr>
</thead>
</table>

Look at the dot half way along the 20cm piece of elastic (at 10cm). How far has the dot moved from the starting position?

Discussion

Sense: Think about the first question again - a 10cm spring has a 2N weight hung on it and it stretches by 3cm to 13cm. A 20cm spring, identical to the 10cm spring except for its length, needs to be stretched by 6cm to 26cm.

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. 2N needs to be hung on the 20cm spring to stretch it by 6cm because the 2N weight stretched the 10cm spring by 3cm. Each 10cm of the spring is stretched by 3cm.

b. 4N needs to be hung on the 20cm spring to stretch it by 6cm because it needs to be stretched twice as far as the 10cm spring and that will need twice the weight.

Which do you think is the more likely explanation?
Explanation: Substances are made up of particles held together by bonds. When these bonds feel a force pulling on them, they stretch and the particles move apart a little. Whatever the length of the substance, each bond feels the same pulling force (as long as the thickness of the substance has not changed). So, if we hang a weight on a piece of elastic, each part of the elastic will stretch a certain amount whatever the length of the elastic. A 20cm piece of elastic will stretch twice as much as a 10 cm length because each 10cm part of the length will stretch by the same amount.

The stretching of a spring works in a similar way.

Sense: Think about the first question again - a 10cm spring has a 2N weight hung on it and it stretches by 3cm to 13cm. A 20cm spring, identical to the 10cm spring except for its length, needs to be stretched by 6cm to 26cm.

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. 2N needs to be hung on the 20cm spring to stretch it by 6cm because the 2N weight stretched the 10cm spring by 3cm. Each 10cm of the spring is stretched by 3cm. ___

b. 4N needs to be hung on the 20cm spring to stretch it by 6cm because it needs to be stretched twice as far as the 10cm spring and that will need twice the weight. ___

Which do you think is the more likely explanation? ___
Experiment: Hang a 4N weight on the spring. How much does it stretch?

Now hang a 4N weight on a spring of twice the length. How much does it stretch?

What can you say about the stretch for both springs?

Does this work when the weight is 2N?

A spring will stretch by a certain amount when we hang a weight on it. It will stretch more if it is longer to start with because each part of the spring feels the same stretching force. A longer spring will stretch more when the same weight is hung on it.

Examples

1. A 12cm spring stretches by 3cm when a weight is hung on it. How much will a 24cm spring stretch by if it has the same weight hung on it?

2. A 20cm spring stretches by 10cm when 5N is hung on it. How much does each 1cm stretch by?
### Appendix IIb  Table showing progress during single bridging analogies (2000-2001) (m is misconception, s is scientific conception)

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SOME QUESTIONS - (THERMAL EQUILIBRIUM) HEAT 1

1. Sonia touched a metal clamp stand in the lab. and noticed that it felt colder than the bench it was on. She wondered why as she had not started doing any experiments and neither had anyone else. She decided to try other objects and she found that all the metal objects felt colder than all the wooden objects. Why do you think this was?

________________________________________________________________________

How sure are you about your answer on a scale of 1-5, where ‘1’ is ‘not at all sure’, ‘3’ is ‘fairly sure’ and ‘5’ is ‘very sure’? _____

2. Vicky was investigating how quickly ice cubes melt. She decided to put identical ice cubes on different surfaces. She put one on a metal surface and one on a polystyrene surface. Which do you think will melt first?

Why do you think this?

________________________________________________________________________

________________________________________________________________________

How sure are you about your answer on a scale of 1-5, where ‘1’ is ‘not at all sure’, ‘3’ is ‘fairly sure’ and ‘5’ is ‘very sure’? _____

3. Simon was doing an experiment to see how quickly objects cooled. He left equal sized and shaped hot pieces of copper metal and cork on a bench and took their temperatures as they cooled. When he came to the lesson the following week, he again took their temperatures. What do you think he found?

________________________________________________________________________

________________________________________________________________________

How sure are you about your answer on a scale of 1-5, where ‘1’ is ‘not at all sure’, ‘3’ is ‘fairly sure’ and ‘5’ is ‘very sure’? _____
SOME QUESTIONS - (RADIATION/ABSORPTION) HEAT 2

1. Why does wearing pale colours in hot, sunny weather help to keep us cool?


2. Why does it help to keep tea warm if the teapot is shiny on the outside?


3. A house is in a country where it is very hot and sunny in the day and very cold at night. It is painted white on the outside. How does this help:

i. in the hot, sunny day?


ii. at night-time?


1. Sara asked Jenny why she could see a book when the book does not shine. Can you help Jenny with her answer?

2. Look at this diagram. The torch is shining on the white wall-papered wall and none of the light from the torch can directly reach the white object in the corner. There is no other light source at all. Can we see the object? Explain your answer.

3. My wooden door looked rather dull so I painted it. The painted door was a similar-coloured brown but now it looked shiny and I could see a fuzzy reflection of the light bulb in it. Can you explain why the door looked different before and after painting?
1. Alex was looking at a white sheet of paper while she was wearing sunglasses which had blue lenses. The sheet of paper looked blue. Can you explain why?

2. Emma was using a see-through green piece of plastic to look at a blue circle. What colour do you think the circle appeared to be? Why is it this colour?

3. A mixture of blue and red light are shone at a see-through blue piece of plastic. What does the blue plastic do to these colours of light?
SOME QUESTIONS ON FORCES

In each of the questions, I want you to think carefully about any forces which could act on or influence the object. Sometimes you are asked to carefully draw on the diagram any force or forces which act on the object. Remember to use an arrow to show the direction of any force and also remember that the length of the line gives an idea of the size of the force.

1. An apple hanging on a tree

What force or forces are acting on the apple (forget about wind blowing or air pressure).

Draw the force or forces on the diagram making sure that you label them.


What force or forces are acting on the book?

Draw the force or forces on the diagram making sure that you label them.
3. Ben ties the rope to a sturdy tree. He pulls on the rope and he, the rope and the tree do not move.

What force or forces are acting on the rope?

Draw the force or forces on the diagram making sure that you label them.
SOME QUESTIONS ON STRETCHING

1. Sarah found that a 5cm spring stretched to 7cm when she hung a weight on it. She took a 10cm spring (identical to the first one except for the length) and hung the same weight on it. What do you think the new length was?

2. The graph shows the length (not the extension) of a spring with different weights on it.

Graph of length of spring against weight

Sketch on the graph what you would find if your spring was only 2cm long to begin with. The first dot is shown.
3. Alex has a box with a lid which she wants to hold secure with a rubber band. She finds that a 20cm rubber band is just the right tightness when stretched round the box. It has to stretch to 30cm.

She then takes another box and finds that the rubber band has to stretch to 60cm. She wants the same tightness of rubber band as for the first box. All the rubber bands she has are exactly the same except for their original length. Should she choose:

a. a 50cm rubber band because to be the right tightness, the band will need to stretch 10cm so a 50cm band will stretch to 60cm.

b. a 40cm band because to be the right tightness, the band will stretch by 10cm for each 20cm of band so a 40cm band will stretch to 60cm.
### Appendix IIId

**Test marks for pre-, post- and retention tests (2000-2001)** (shaded areas are the control group)

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Appendix IIIa  Bridging analogies used (2002-2003)

WHY DO METALS FEEL COLD? HEAT I

Experiment: Touch a piece of metal and a cork mat. Which one feels warmer?

Question: Why does metal feel colder than the cork?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___
Experiment:

Which pea would drop off first? ____________________

Why? __________________________________________

Watch the experiment. What happens?

________________________________________________

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Experiment:

Which will warm up quicker – the cork mat or the metal mat?

Watch the experiment. What happens?

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Experiment:

Which will cool quicker - a beaker of hot water on a cork mat or one on a metal mat?

Watch the experiment. What happens?

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Explanation: Metal is a good conductor of heat but glass is a poorer conductor of heat. The metal rapidly conducts the heat away from the Bunsen flame so the metal near the pea soon becomes hot which melts the Vaseline and that pea drops off. The glass does not conduct the heat very well and so the pea on the glass does not quickly fall off. The situation is similar for the beakers of hot water. The metal conducts the heat away quickly and so the temperature of the mat a little way from the beaker rises. The temperature of the cork, a very poor conductor of heat, stays about the same. The hot water on the metal mat cools down quickly because the heat is being conducted away quickly. Cork does not conduct the heat away very quickly and so the water stays hotter for longer in this beaker. Our hands are similar to hot water in that they are warmer than room temperature. Heat is quickly removed from our hands by metal but not by cork.

Sense: Think about the first question again - why does metal feel colder than the cork? How much sense do the following statements now make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. ___

b. The metal feels colder because it is naturally at a lower temperature than the cork. ___

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.

________________________________________

________________________________________

Experiment: Take the temperature of a block of metal and a large cork. What are the temperatures?
Are good absorbers of heat also good radiators of heat? *HEAT 2*

When objects are hotter than their surroundings, they give out (radiate) more heat than they take in (absorb), e.g. a cup of hot water cools down. When objects are cooler than their surroundings, they absorb more heat than they radiate, e.g. food warms up in a cooker.

People have different ideas about radiation and absorption. Some people think that things which are good at radiating heat must be poor at absorbing heat and others think that things which are good at radiating heat must be good at absorbing it.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Good absorbers must be poor radiators.

b. Good absorbers must be good radiators.

Which do you think is more likely to be true?

Why do you think that this one is more likely to be true?
Think about this. In general, do you think that people who are good at throwing balls are good at catching them?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Good absorbers must be poor radiators. □

b. Good absorbers must be good radiators. □

Which do you think is more likely to be true? □

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this page help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Think about this. Imagine an object being able to throw and catch little balls like we can.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Good absorbers must be poor radiators.

b. Good absorbers must be good radiators.

Which do you think is more likely to be true?

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this page help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Think about this. Imagine the object throwing and catching little packets of energy or waves.

**Sense**: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Good absorbers must be poor radiators. □

b. Good absorbers must be good radiators. □

Which do you think is more likely to be true? □

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this page help to change your mind or was it something else? If you have not changed your mind, please explain why not.

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

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Explanation: When heat is radiated, it can be thought of as being thrown out in little packets. Objects that can throw out well (radiate well) can also catch heat well (absorb well).

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Good absorbers must be poor radiators. □

b. Good absorbers must be good radiators. □

Which do you think is more likely to be true? □

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this page help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Question: We can see this piece of paper. How can we see it?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place. ____

b. The light shines on the paper and stays there and that is how we see the sheet of paper. ____

Which do you think is the more likely explanation (a or b)? ____
It is very important that you write down the ideas you have now. Do not worry about what you wrote on the last page. You may have changed your mind or you might not have changed your mind. Either way, it is fine. Please do not go back and change what you have written on previous pages.

**Experiment 1** Put two mirrors on the lines below.

![Diagram showing two mirrors and a cross](image)

Put a coin on the cross. Can you see more than one reflection? __________

Sense: Think about the first question again - we can see this piece of paper. How can we see it?)

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place. __

b. The light shines on the paper and stays there and that is how we see the sheet of paper. __

Which do you think is the more likely explanation (a or b)? __

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Take a piece of foil and look in its shiny side. Can you see your reflection? 

Now make a fold so your foil looks like this:

Look in the foil. Can you see more than one reflection? 

Sense: Think about the first question again - we can see this piece of paper. How can we see it?
How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’). 

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place. 

b. The light shines on the paper and stays there and that is how we see the sheet of paper.

Which do you think is the more likely explanation? 

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Crumple up your foil and then partly flatten it out so it looks like this:

Now look in the foil. Can you see your reflection (not your shadow)? ______. We know that it is still reflecting because we can still see the reflection of the lights.

Sense: Think about the first question again - we can see this piece of paper. How can we see it? How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place. ______

b. The light shines on the paper and stays there and that is how we see the sheet of paper. ______

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Explanation: Look at the magnified picture of paper. See how rough it is. Look at the magnified picture of a mirror. See how smooth that is. Each little bit of paper reflects like a mirror but each bit is at an angle to the others because of its roughness so no image is seen.

Sense: Think about the first question again - we can see this piece of paper. How can we see it? How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. The light reflects off the paper but we do not see an image because the roughness of the paper makes the light rays go all over the place.

b. The light shines on the paper and stays there and that is how we see the sheet of paper.

Which do you think is the more likely explanation? ___

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Question: We can see this piece of paper. How can we see it?
People have different ideas about how we can see things that do not give out their own light, e.g. paper.

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place.

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper.

**Sense:** How much sense do these ideas make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place.  

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper.  

Which do you think is the more likely explanation (a or b)?
It is very important that you write down the ideas you have now. Do not worry about what you wrote on the last page. You may have changed your mind or you might not have changed your mind. Either way, it is fine. Please do not go back and change what you have written on previous pages.

Experiment 1  Put two mirrors on the lines below.

\[
\begin{array}{c}
X \\
\end{array}
\]

Can you see more than one reflection of the X? ______

Sense: Think about the first question again - we can see this piece of paper. How can we see it?

How much sense do these ideas make now (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place.

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper

Which do you think is the more likely explanation (a or b)?

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Experiment 2  Take a piece of foil and look in its shiny side. Can you see your reflection? _____

Now make a fold so your foil looks like this:

[diagram]

Look in the foil. Can you see more than one reflection of yourself? _____

Sense: Think about the first question again - we can see this piece of paper. How can we see it?

How much sense do these ideas make now (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place. [ ]

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper. [ ]

Which do you think is the more likely explanation? [ ]

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Experiment 3  Crumple up your foil and then partly flatten it out so it looks like this:

Now look in the foil. Can you see your reflection (not your shadow)? _______. We know that it is still reflecting because we can still see the reflection of the lights.

Sense: Think about the first question again - we can see this piece of paper. How can we see it? How much sense do these ideas make now (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place. □

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper □

Which do you think is the more likely explanation?

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Explanation: Look at the magnified picture of paper. See how rough it is. Look at the magnified picture of a mirror. See how smooth that is. Each little bit of paper reflects like a mirror but each bit is at an angle to the others because of its roughness so you cannot see your own reflection.

Sense: Think about the first question again - we can see this piece of paper. How can we see it? How much sense do these ideas make now (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Some people think that light reflects off the paper a bit like a mirror but that we do not see our own reflection in the paper because it is rough which makes the rays go all over the place.

   [ ]

b. Some people think that light shines onto the paper and stays there rather than being reflected and that is how we see the paper

   [ ]

Which do you think is the more likely explanation?

   [ ]

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this experiment help to change your mind or was it something else? If you have not changed your mind, please explain why not.
Experiment: Look at a white screen through the green piece of plastic. What colour does the screen look?

Question: Why does the screen look this colour?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Green colour has been added to the white light by the piece of plastic.

b. The other colours have been taken away by the piece of plastic leaving only green.

Which do you think is more likely to be true?

Why do you think that this one is more likely to be true?
Experiment: Watch the piece of paper and funnel being used to separate the sand and water. See how the filter paper holds the sand while the water goes through.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Green colour has been added to the white light by the piece of plastic. □

b. The other colours have been taken away by the piece of plastic leaving only green. □

Which do you think is more likely to be true? □

Why do you think that this one is more likely to be true?

__________________________________________________________

__________________________________________________________

__________________________________________________________
Experiment: Watch the piece of paper and funnel being used to separate the cloudy mixture. See how the filter paper holds the solid while the water goes through.

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

a. Green colour has been added to the white light by the piece of plastic. [ ]

b. The other colours have been taken away by the piece of plastic leaving only green. [ ]

Which do you think is more likely to be true? [ ]

Why do you think that this one is more likely to be true?

___________________________________________________________________________________________

___________________________________________________________________________________________

___________________________________________________________________________________________
Experiment: Look at the spectrum of colours made from white light. A piece of coloured plastic is put between the prism and screen. Look at the screen. What colour(s) can you see?

Notice carefully exactly where the colour is on the screen compared with where the spectrum of colours was before the coloured plastic was put in position. What do you notice?

Sense: How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Green colour has been added to the white light by the piece of plastic.  

b. The other colours have been taken away by the piece of plastic leaving a. only green.

Which do you think is more likely to be true?

Why do you think that this one is more likely to be true?
Explanation: Green pieces of plastic allow only green light to go through them and they absorb all the other colours. White light is made of several colours, most of which are absorbed by the green piece of plastic. Just the green goes through.

Sense: Think about that first question again – why does the screen look green? How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

a. Green colour has been added to the white light by the piece of plastic. 

☐

b. The other colours have been taken away by the piece of plastic leaving only green.

☐

Which do you think is more likely to be true? ☐

If you have changed your mind about how much sense the statements make and/or about which is the more likely explanation, please explain why. Did this page help to change your mind or was it something else? If you have not changed your mind, please explain why not.
### Appendix IIIb  Table showing progress during extended bridging analogies (2002-2003)

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Appendix IVa  Questions given before and after analogy intervention (2003-2004)

Heat 1

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense').

When I touch a piece of metal, it often feels colder than, say, a piece of cork. Do you think that this is because:

a. The metal feels colder because it removes heat from your hand and takes it away and cork does not do this as much. [ ]

b. The metal feels colder because it is naturally at a lower temperature than the cork. [ ]

Which do you think is the more likely explanation? [ ]

Heat 2

Objects can radiate and absorb heat. Think about sitting in front of a warm fire; the fire is radiating heat and you are absorbing it. However, you are radiating heat all the time as well as absorbing it. Thermal cameras sense the amount of heat given off by different objects and human bodies give off quite a lot.

How much sense do the following statements make (on a scale of 1-5, where 1 is 'hardly any sense at all', 3 is 'quite good sense' and 5 is 'very good sense')?

An object that is better at absorbing heat than another object is:

a. Better at radiating heat [ ]

b. Worse at radiating heat [ ]

than the other object (both at same temperature).

Which do you think is the more likely explanation? [ ]

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Light 1

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’). We can see objects because light from a light source (e.g. a lamp or the Sun):

a. Hits the object and stays there, lighting the object up.  

b. Hits the object and is reflected

Which do you think is the more likely explanation?

Light 2

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

When white light is shone through a piece of red see-through plastic, red light is seen on the screen. This is because:

a. The red colour has been added to the white light by the piece of plastic.

b. The other colours have been taken away by the piece of plastic leaving only red.

Which do you think is the more likely explanation?
Forces 1

Gravity is a force that causes objects to fall down. If a book is on a table, then gravity is pulling on it so why does it stay where it is and not fall down.

How much sense do the following statements make (on a scale of 1-5, where 1 is ‘hardly any sense at all’, 3 is ‘quite good sense’ and 5 is ‘very good sense’).

c. There is gravity acting downwards on the book and the table is just in the way to stop the book falling. □

d. There is gravity acting downwards on the book and the table pushes upwards on the book by the same amount. □

Which do you think is the more likely explanation? □

Forces 2

A 2N weight is hung on a piece of elastic that extends by 5cm. The 2N weight is then hung on a similar piece of elastic that is twice as long to begin with. How much will this piece extend? Circle the correct answer.

a. 5cm b. 10cm
### Appendix IVb continued

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Appendix IVd  What did you learn today?

NAME __________________________________ FORM ____ DATE ______

I would like you to think about today’s lesson and about your own ideas about the topic we were doing. Sometimes lessons help you to change your mind about things; sometimes they support your ideas and help you see things more clearly. Either way, you should keep track of what you are thinking. Have a go at answering these questions (honestly) and you will be thinking about thinking.

What did you learn in today’s lesson? ____________________________________________

_____________________________________________________________________________

Did today’s lesson make you change your ideas about anything? If so, how did your ideas change?

_____________________________________________________________________________

_____________________________________________________________________________

What happened to make you change your ideas? ______________________________________

_____________________________________________________________________________

Are you still confused about which ideas are right? ______

Was the way in which the lesson was taught helpful? ________ Which parts were helpful or unhelpful?

_____________________________________________________________________________

_____________________________________________________________________________

If there are any more comments you would like to make, please do so. _________________

_____________________________________________________________________________
Appendix V Interview transcripts (2004-2005)

Colour 19.01.05 Pupils A and B (I is interviewer)

I ....... Now, last week we were looking at colour and the little sheet is what you wrote last week and I asked you to say how much sense certain statements made and which you thought was the right statement. Now, you had already done the same thing right at the beginning of term and I picked you two to interview because you’d actually changed your mind between the two occasions and that’s absolutely fine but the question is, “why did you change your mind?” So, if you want to remind yourself what you wrote the first time which is number four (see Light 2 in Appendix IVd), why, in fact, you both chose a on number four; this time you chose b (laughter from A and B). now that’s absolutely fine but do you know why you changed your mind. And again, it’s OK to say no, you do not know why you changed your mind but was there anything you had done in between times which made you change your mind from choosing a to choosing b? So, in fact b, it’s the correct answer, b is. These colour filters, these coloured pieces of plastic are actually acting as filters and the other colours are being taken away by them, leaving only red. Now, I just wondered whether you’d got any idea why you’d changed your mind.

A Because the week we, er, did this we used the filters.

I Yes, and?

A And, em, and it had shown that using different filters er like it says here, with the red

I Hm hm

A Being seen, em, because it had taken the others away and it makes sense to me.
I Right, (turning to B) do you have why you

B I think I chose that one because I didn’t know, em, because when you put the red light through you couldn’t see any white; it was just red.

I Right

B And the red light just looked the same as the red plastic.

I Right, OK, so that

B And I didn’t see where, how the white couldn’t be there.

I Right, so that’s why you chose b that time?

B Yes

I Any idea why you chose a the last time? I know it’s going back a long way to the beginning of term and you hadn’t done any experiments on colour then so you might not know why you chose that but at the time it made more sense to you, any

A Er, I think because we hadn’t done much of this before. In art, sort of, white is nothing and adding to me seemed simpler than taking things away.

I Right, that’s absolutely fine and B, have you any?

B Erm, can I say the same?
I Now last week we looked at colour. To remind you what you said last week, I asked you how much sense certain statements made and which you thought was the right statement. Now you’d already done that, the same thing, a few weeks ago and the reason I wanted to interview you two and the other two especially was because you’d actually changed your mind between these two occasions. That’s absolutely fine but what I want to know really, is why you changed your mind. You might not know and that’s absolutely fine but you might have some ideas about it. So, just to remind you what you wrote the first time, it’s number four (see Light 2 in Appendix IVd) so if you just want to see what you wrote, once at the beginning of the year and once last week. Erm and, in fact, last week you chose the right answer whereas the first time you’d chosen the wrong answer. now, we hadn’t done the topic at all before the beginning of the year and we’d only done a little bit about it by last week but any reasons why you’d changed your mind? Can you remember why you chose b last week rather than a?

C Isn’t white light meant to be made of all the colours of the rainbow?

I It certainly is. Now, did you know that at the beginning of the year?

C No.

I Because we had done it, sort of, a couple of weeks ago, hadn’t we? So that might be a reason why you had changed you mind. Em, any other reasons why you might have changed your mind? D?

D Well I knew that before, that I didn’t know that white light was just, was made up of all the colours but I knew that when, like light from the Sun shone through
water made a rainbow so I just thought about that and thought it’s probably not been added ‘cos because red would have been there before.

I Right, so, OK, erm but the first time when you did it you actually thought that a was the right answer. any idea why you might have chosen that, as I say, it’s a long time since you did it but any ideas why you might have chosen that there?

D Well, it sounds a bit funny for things to be taken away.

I Right, yes, OK, that’s absolutely fine.