A STUDY OF ALTERNATIVE FRAMEWORKS IN SCHOOL SCIENCE

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SUMMARY

This study makes use of a constructivist epistemological stance (in particular that of George Kelly) to explore the many conceptions young people develop for four concepts in school science - energy, force, heat and light. The work is placed within a growing area of research into students' alternative conceptual frameworks and by adopting a broad, actionable, notion of a concept it is possible to explore the beliefs and contingencies that pervade these youngsters' personal theories. The central methodology involved is an individual interview approach framed around a set of line drawings depicting various situations which the students are asked to discuss in terms of their own conceptions. The interview sessions are conducted in schools and are audio-recorded. The four concepts are treated separately across three age bands and the resulting four-by-three, twelve cell, matrix lays the pattern for the analysis and discussion of data. Three levels of analysis are discussed which are conceptions, categories of response and frameworks, and these are used as a means of examining the transcript data for some 134 interviews. The relationships between the frameworks are considered and some emphasis is given to the degree of overlap that occurs in the students' use of the four main concepts. The responses of four particular students are explored across all four concepts and the resulting four-by-four, sixteen cell, matrix allows a study of their personalised approach to these ideas in further detail. The methodological checks employed are evaluated and, finally, summaries of the outcomes
of the study are made, implications for current practices in science education are drawn and future trends for research are indicated.
DEDICATED WITH LOVE TO GAYNOR, SIÂN AND RHIAN
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CHAPTER 1

The study is placed in context within areas of research into alternative conceptual frameworks, personal meanings, and science education.

1.0 Introduction
1.1 A Discussion of Concepts
1.2 Misconceptions and Alternative Frameworks
1.3 Developing a Conceptual Framework

CHAPTER 2: METHODS OF INQUIRY

The particular methodologies and underlying assumptions of the study are examined as they are used to generate the data involved

2.0 An Introduction to the Chapter
2.1 First and Second Orders of Perspective
2.2 The I.A.I. Approach
2.3 The Research Design
2.4 Methodological Checks
2.5 A Summary

CHAPTER 3: PUBLIC KNOWLEDGE: PERSONAL SCIENCE

The four main concepts are introduced in terms of classical physics and current research into students' perceptions of them.

3.0 An Introduction to the Chapter
3.1 Classical Concepts
3.2 The Four Concepts
3.3 Organisation and Fragmentation of Constructions
CHAPTER 4: ALTERNATIVE FRAMEWORKS  Pages 4.0 - 4.87
The notion of alternative frameworks is outlined and the major ones for each of the four main concepts are described.

4.0 An Introduction to the Chapter
4.1 A Discussion of Alternative Frameworks
4.2 Some Proposed Outlines for Frameworks
4.3 Frameworks for the Main Concepts
4.4 A Summary

CHAPTER 5: FRAMEWORKS, FOCI AND BOUNDARIES  Pages 5.0 - 5.109
The intra- and inter- concept frameworks are discussed for similarities, differences and overlaps in meanings.

5.0 An Introduction to the Chapter
5.1 Frameworks Within the Concept Areas
5.2 Inter-Framework Relationships
5.3 Overlaps in Meanings
5.4 The Incidence of Frameworks
5.5 A Summary

CHAPTER 6: SIXTEEN CONCEPTIONS IN MORE DETAIL  Pages 6.0 - 6.87
The interviews of four students for each of the four concepts are considered at length.

6.0 Introduction to the Chapter
6.1 Colin's Interviews
6.2 Cushla's Interviews
6.3 Petina's Interviews
6.4 Susie's Interviews
6.5 A Summary
Some of the many implications for science education and science education research are drawn for both the research outcomes and the methodologies used.

7.0 An Introduction to the Chapter
7.1 Methodological Considerations
7.2 A Consideration of the Research Outcomes
7.3 Some Implications for Classroom Practice
7.4 Some Directions for Future Research
7.5 Expectations

REFERENCES

Appendix II: The Interviewees and the Extracts Used
Appendix III: A Sample Transcript (Cl,4L)
Appendix IV: A List of the Schools
Appendix V: The 'Energy' Authentication Questionaire
INTRODUCTION

Nothing is more characteristic of everyday school life than the innumerable ordinary answers that students give as they record impressions, give reasons and provide explanations of their world at large. Within a context of school science the answers may be so innumerable and ordinary as to be overlooked. This study represents a closer view. Its central claim is that, whilst commonplace, youngsters' explanations are far from being ordinary in the sense of drab or repetetive: they are genuinely creative attempts to explain their own experiences. Many answers to questions are not entirely for a questioner's benefit; youngsters have a real and material stake in securing for themselves viable answers as to how things work in the world. The search for answers stands both at the very centre of cognition and the heart of science. It provides the impetus from which knowledge of the world is arrived at.

The purpose of this work is to explore students' responses concerned with particular concepts and situations in science. In doing so, it attempts to describe the patterns of belief, both naive and sophisticated; that students bring to bear on their explanations of common phenomena. Behind it lies the premise that it is important to the venture of science education that school students find science both meaningful and relevant. To describe students' perspectives is to grant teachers the insights to allow them to facilitate that meaning and relevance. A second premise is that people, in general, do not settle for any

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answer as explanatory. They seek viable and tenable answers that are compatible with their experiences and are ampliative. That is, they enhance understanding - if only in a small way. Quick, intuitive ascriptions and deliberate, sophisticated explanations are parts of a single system of practice and belief within each individual.

In recent years, there has been an important change of direction in research in science education. The responses students provide in the course of learning science have enjoyed two extremes of treatment. In the psychological arena they have commonly been treated as problems; treated in broad terms and have often been subsumed within general developmental theories of cognition. This approach may be attributed to the fact that research in all areas of children's cognitive development has been greatly influenced by the work of Jean Piaget.

In contrast, within the area of science instruction, the 'deviant' is often dispatched rapidly and has little or no status. Mistakes are commonly associated with individuals, not groups, and are categorically rejected as 'wrong' with respect to (supposedly) correct science.

For researchers, the prospect has been between assuming a common pool of experience and then seeking universal, developmental changes of conceptual structures on the one hand - or valuing individual idiosyncratic conceptions on the other. The latter is to recognise the wide diversities of conceptual development (dependant upon the context and content of specific experiences), and is a choice to explore localised changes related to particular areas of knowledge.
This study follows the second path. The eventual argument is that it may be untenable to look for universal, invariant cognitive structures across broad age-related groups. Thus, it is part of a small, but now expanding, body of idiographic research into children's understandings of parts of science. Some previous attempts have focused on conceptual development as though this was in some way separate from language. However, it seems likely that a major aspect of the problem is the way in which everyday terms are used in a specialised context. Many concept labels in science are typically multi-meaning (polysemic) and exist at varying levels of explicitness. Explicit concepts are defined eventually by implicit ones whether they are the precise concepts of a public knowledge domain like physics, or the imprecise personal conceptions of a young physicist. The interactions between implicit and explicit; personal and public are a continuing theme throughout.

A number of decisions and judgements formative in shaping this work have been made on pragmatic educational grounds. Foremost of these has been the selection of the four concepts under consideration: force, energy, heat and light. They were selected not as concepts basic to modern physics - although arguably they fit that description too - but for their prevalence within school science curricula as made manifest by syllabi and text books.

Whilst this work is not bound by a single theory and is informed by several distinct principles, it must be said that it leans heavily upon the writings of George Kelly and his theory of personal constructs. In part, this is taken to mean
that learning, as a general process of change within childhood, adolescence and thereafter, continues remorselessly. It is not restricted to classrooms, to what a teacher intends should take place, or even to what she thinks is taking place. It recognises that a person achieves a large part of his education 'in the world' and that people are active meaning-bestowing agents.

Making this assumption places considerable stress upon each individual's past experience and prior knowledge - when a person bestows meaning they do so in a way that relates to a meaning structure they already have. Here recorded interviews are used to explore individual meanings and to establish common belief patterns. The language youngsters use is scrutinised for evidence of such common 'conceptual frameworks'. This process in turn allows for an exploration of the complex issues concerning the status and interrelatedness of distinctive frameworks and both the functional and logical boundaries that may exist between them.

This study is reflexive in that it is itself an example of what it hopes to discuss. The construction of world views as a part of their imaginative efforts to explain phenomena is not solely a feature of young people. Rather than follow the customary practice of engaging in a general review of pertinent literature, each of the major sections is introduced with regard to its own origins and perspectives. Thus at two levels the emphasis is upon drawing together some of the distinctive strands of argument in order to explore their continuity and coherence.
After some theoretical and methodological discussions, answers to the following main questions will be sought:

(a) What are the major alternative (conceptual) frameworks commonly held for each of the four concepts of energy, force, heat and light?

(b) How do these conceptual frameworks vary in samples of secondary school students of different ages?

(c) What is the relationship between individual conceptions of phenomena and the commonly held frameworks?

(d) In what ways are the frameworks related and what distinctions mark the limits to each one?

(e) To what extent are the conceptions and common frameworks context bound?

(f) What are some of the consequences for both student and teacher of each idea?
CHAPTER 1

Section 1.0: Introduction

Section 1.1: A discussion of concepts

The process-product dimension

The formal-informal dimension

The hypothesis-testing-abstraction dimension

The semantic-logico-mathematical dimension

Section 1.2: Misconceptions and alternative frameworks

(i) Studies of misconceptions

(ii) Some factors influencing a change to alternative frameworks

(iii) A review of some 'newer investigations'

Section 1.3: Developing a conceptual framework
1.0: Introduction

This thesis is about the responses made by young people to questions concerning some specific concepts in school science. They are asked to respond in terms of their understandings of these concepts as they apply them to a range of common situations. What results is an interweaving of many meanings. A single youngster as (s)he talks uses the concepts in such ways as to signal a variety of meanings which can shade into one another, and which, in turn, interconnect with the meanings given by other youngsters. The task of the thesis is to impose some order on this web of interrelations.

There are four major themes that run through all of the chapters to follow. First, any imposition of order on these varied discussions is not to subvert the ideas and opinions proffered by the youngsters involved. Instead, the intention is to highlight the texture, the richness and quality of the 'weft and warp' of their pronouncements. That is, their discussions are treated seriously as indicating their own personal theories for parts of science.

A second theme is that of constructivism: the view that these youngsters - as the leading actors in this activity - construct their own knowledge through interactions with the world around them. They come to know things about their environs only in so far as they can make interpretations of it, and approach a greater awareness of events by constructing successive approximations and hypotheses.

Third, an allied theme is the tension between partial or piecemeal views of the world and a notion of underlying
integration. There is a sense in which the many systems of ideas operated by an individual person are always held in unity by that individual. The constructive integrating ability of each person enables explanations to retain a unity - which leads, in this study, to exploring the interrelated interpretations of the world that youngsters use as they bring coherence to it.

Fourthly, a major strand is the interplay between individual and collective accounts of the same, or similar events. It revolves around the attempts to make comparisons between individuals in their constructions of experience. In the context of this study, some youngsters can be seen to provide very similar accounts which lead them to draw very different conclusions. Conversely, they can use very different explanations which converge to an almost identical result. The problem is a methodological one: how to construct interpretations of similarities in meaning and yet express essential differences.

In the field of science education research, the central thrust of this thesis can be neatly pinpointed by reference to a figure used by Driver (1982). It is shown below in figure 1:

Figure 1

Development of logical operations

Development of causal frameworks
In that paper, sandwiched as it is amongst critiques of Jean Piaget's work, Driver surveys the implications of Piaget's writings for science education. Her conclusion is that his theories are a useful but only partially apt description of young people's development in science. Separate from, and of equal importance to, their development of logical operations (as described by Piaget) is the development of their causal frameworks.

It is not that Piaget's work is the only one to have a bearing on science education. In that same volume, for example, Novak (1982) discusses a number of theoretical approaches to describing student conceptualising in science. However, as Driver points out, Piaget's ideas have been highly influential in this curriculum area. He can be credited in his early work (Piaget 1929, 1930, for example) with initiating exploration of children's causal frameworks only to ignore this aspect of conceptual development and emphasis in his later work, the structure of logical operations. In comparison to the large amount of research conducted in that field, conceptual frameworks have been barely touched. The purpose of this study is to assist in a small way in some redress of this situation.

Bringing Piaget's name to the fore in this introduction is not to place this study in opposition to the direction of his work - rather to use it as a reference point and (as Driver (1982) suggests might be the case) to augment it. It shares a number of the metaphysical assumptions with his work - namely in terms of his views on the participants in the research, the methodologies appropriate to that
activity and an underlying epistemological stance. Piaget's constructivism (Piattelli-Palmarin, 1980; Furth, 1980) maintains that the development of 'knowing' is something each one must construct for themself. It is not that Piaget ignores social influences, it is that knowing is an active process; knowledge is not passively received.

However, to move along the 'causal framework' axis of Driver's figure is to depart from the mainstream of Piagetian enquiry. In doing so it moves away from considerations of strict logic and towards a more diffuse area of language and meaning, of personalised constructions of events as elaborated in linguistic terms. As Elliot and Donaldson (1982) point out, this is an issue which Piaget does not widely address - the active use of language to explore issues, to give answers and justifications, and to find things out. In this case other reference points are sought where similar metaphysical assumptions are in force. Foremost of these is the work of George Kelly (1955) which offers a number of insights into the personalised constructions of individuals. Others have drawn parallels between Piaget and Kelly (for example, Bannister and Fransella, 1980) which are not pursued in detail here. Rather, it is their general underlying notions of the constructive development of knowledge that is of interest.

This study, then, centres on the responses that school students provide as they discuss some fairly common situations, and the meanings that they have for some common words in school science. Many linguists (for example, Smith, 1982) make a distinction between two aspects of language,
its surface structure and deep structure. The former can be regarded as its physical properties - the sounds of speech, the written marks on a page. The latter, on the other hand, is meaning. Meaning, as Smith points out, defies measurement. It:

'exists in our minds - in the nonverbal, inaccessible theory of the world in our head - underlying the language we produce and making sense of the language we understand.'

Surface structure and deep structure are not reflections of each other, there is no one-to-one correspondence between spoken (or written) words and meanings that are singly, or collectively held. That is, meanings can be expressed by more than one set of expressions and any one expression can have more than one meaning.

Smith's notion of 'worlds in our head' epitomises those important strands throughout all of the chapters to follow. Constructivism, as seen by Kelly, is an active construction of meaning that is not independent of the person doing the construing. As Novak (1981) suggests:

'ignoring or negating the internal world of people misses the essence of their personhood, flattens human reality and leads to educational practices which are mechanistic and lacking in respect for the basic integrity of the person.'

In this study, a serious attempt is made to explore with students the ways in which they use words like force, energy, heat, light (and so on) in order to explain phenomena. It is a central tenet that it is important to come to an understanding of the view of the world held by youngsters as they attempt to make sense of, and personally reconstruct, the science they meet at school. In this way it is part of a growing shift in focus of educational research towards the
study of individual and collective views around particular issues (Pope, Watts and Gilbert, 1983).

The expression 'causal framework' is itself an example of the gulf between surface and deep structure in that it has a multiplicity of meanings. The notion of causation is itself not unproblematic and, as is discussed in chapter 4, the use of the word framework varies even within a small research area. Elsewhere Driver (in Driver and Easley, 1978) refers to alternative frameworks and describes them by saying:

'In learning about the physical world, alternative interpretations seem to be the products of pupils' imaginative efforts to explain events and abstract commonalities they see between them.'

In similar lines of research they are known as 'misconceptions' (Helm, 1980), 'preconceptions' (Novak, 1977) and 'children's science' (Gilbert, Osborne and Fensham, 1982). This study concentrates upon pupils' responses to questions on specific science concepts and, as such, makes use of the expression in the form alternative conceptual frameworks.

In mapping the field of relevant research, in order to locate this study within a broader research tradition it is useful to talk in terms of a movement. In general this is a movement away from the notion of misconceptions towards one of alternative conceptual frameworks. This is illustrated in figure 2.

MISCONCEPTIONS  ALTERNATIVE CONCEPTUAL FRAMEWORKS

Figure 2
This representation gives some substance to what Gilbert and Swift (1981) and Sutton (1982) refer to as the 'alternative frameworks movement', in that it indicates what the movement might be moving away from, and the direction it is moving in. It would be misleading to suggest that all of the work to be considered here has a common basis by which to plot its progress along such an arrow as is shown in figure 2. However, a general trend is detectable in some senses — often as a change of emphasis within programmes of work, or in the citing of kinds of literature by which to contextualise a single study. In a survey of recent alternative frameworks research, Driver and Erickson (1982) suggest that there are three widely held assumptions:

i) Some form of 'cognitive structure' in people is presupposed. It is perhaps a structure of content-independent processing skills, but for most of the more recent studies, (they suggest) it is a structure of content-dependent elements such as particular concepts or propositions;

ii) A constructivist epistemology is assumed;

iii) It is taken on trust that understanding pupils' ideas is important for the classroom.

These are useful pointers to the 'state of the art' as it is at present. There is a need, however, to characterise the origins of the movement up to this point and to project forward from it. Whereas this study can be seen to fit comfortably within the three assumptions above, it is also an attempt to make progress forward along the line of research.

One way to map the research movement is to examine the notion of a concept which has arisen in the course of
the various studies. There is often an assumption that everyone knows, in a general sort of way at least, what a concept is and how it is used. In actuality this assumption is far from being as innocent as might appear at first sight, and it cloaks an essential ambiguity in the use of the word. To plot the shift in meanings of this term is to give some indication to the trend of development towards the 'newer investigations' (as Driver and Erickson call them) of students' alternative frameworks. In this way 'concept' is used as a shibboleth for marking studies along this line of research.

The remainder of this chapter is split into three main sections. The first details this discussion of concepts as a way of shedding light on the field of work already completed. The second section continues by exploring the movement depicted in figure 2; and the third develops from this a rationale for a more explicit view of conceptualisation to shape the empirical work in following chapters.

1.1: A Discussion of Concepts

The tide of curriculum innovation in science education, began some twenty years ago and well described by Bruner (1977) and Novak (1977), was motivated largely by scientists' dissatisfaction with the backwardness of the teaching material of the time. The response from curriculum designers was to adopt the policy of first isolating the 'main' concepts of the discipline. These concepts were then dissected into portions of 'digestible' size, ordered into a logical
sequence and delivered to an awaiting student (see Gagne 1970; Gowin, 1970; for examples).

Optimism concerning the efficiency of such a process has now waned, with the realisation that the interactions between the roles of learner, teacher and course material are of vital importance (Laurillard, 1979; Marton and Säljo, 1976; Säljo, 1982). Nevertheless, concepts are increasingly to be seen as integral parts of curriculum statements of many kinds - syllabi, school texts, teacher training material and a variety of articles on how and what to teach. As a mark of their importance Stones (1979) for example, argues that:

'the skill of teaching for concept learning is probably one of the most important skills a teacher should acquire.'

In only a few references to concepts is there any acknowledgement that the term itself may be ambiguous, or have many referents. Nearly two decades ago, Wallace (1965) rued the lack of a generally accepted definition of 'concept' or 'conceptual activity' by which he might arrange the wide variety of concept studies he reviewed. Freyberg (1980) notes the current diversity of meanings the term has for many educationalists. Claxton (1980) makes the same point for psychologists when he says:

'The most glaring example of... isolationism is seen at the very heart of cognitive psychology, in the study of conceptualisation: what are concepts? How are they represented? How are they formed and used? We have the Cell-Assemblians (headed by D.O. Hebb), the Stored-Contingencies of-Reinforcements (led by Skinner), the Cambridge Logo-Geneticists (under Chief John Morton), the Semantic Networkers (like Collins and Quillan), the extinct but revered Old Schematicians (Piaget), New Schematicians (Neisser) and a thousand others - all grappling with the same central problems.'

1.9
From the multitude of distinctions that can be made between the major schools of thought, this section concentrates on four. The intention is not to undergo an exhaustive review of all concept studies, so much has been accomplished by others like Bourne, Dominowski and Loftus (1979) or Bolton (1977). Nor are all studies pertinent. Rather by choosing the four dimensions enumerated below it is possible to explore some of the antecedents of this work:

i) Process ———— Product

ii) Informal ———— Formal

iii) Hypothesis testing ——— Abstraction

iv) Semantic ———— Logico-mathematical

Such a treatment of concepts is, of necessity, selective. The aim is not so much a 'compleat' treatment of concepts, more a critical appreciation of the term in use as a guide to pinpointing its limitations.

These four dimensions emphasise the inherent ambiguity of the word concept. It can apply with equal authority to describe both the individual personal knowledge structures of the human mind and to the general categories of public disciplines. It is the way in which the interaction of these two meanings is discussed that indicates the orientation of a particular study. Largely, the bulk of research work into concepts and concept development sees the concept itself as fairly immutable and focuses instead upon how people perform as they fail (or manage) to 'acquire' it.

In Marton's (1981) terms, this is a first-order perspective. This study, however, adopts a second-order perspective (a point discussed more fully in chapter 2) and considers the interaction between personal conceptions and public concepts.
as far as possible through the eyes of the actors involved.

(i) The process—product dimension

A process/product dichotomy is an oft used separation, and here it is brought to bear on the nature of concepts. There are those who regard a concept as a verb, a guiding action, a dynamic process of organising occurrences in the light of one's past experiences (for example, Markova, 1982); and those for whom a concept is a noun, a product of conceptualisation or, as Wallace (1965) parodies it, 'a piece of mental furniture'. Russell (1960), for example, talks of concepts as 'one type of the material of thought as distinct from the processes.' In contrast, Vinacke (1952) describes them as 'cognitive organisation systems which bring past experience to bear on a present object or situation.'

It is a dimension which highlights two distinctive approaches. Firstly, treating concepts as products tends to the view that they are fixed, referential, independent components of cognition. Secondly, it provides for the notion that, once attained, they are relatively static. White (1979), for example, considers concepts to be units of cognition in a cognitive structure that is 'more static than fluid'. This tendency to nominalise concepts has been criticised by many for example, Putnam (1979) suggests that it is a fallacy to ascribe to the mind what is only an abstract property of its operations. Lenneberg (1967) also argues that:

'Concepts . . . are not so much the product of man's cognition, but conceptualisation is the cognitive process itself'. (emphasis in the original).
A second distinction is between informal and formal concepts. Essentially, this is a distinction between concepts that are seemingly found ready-made in the world outside the person, and concepts generated by the person himself. Johnson-Laird and Wason (1977) make a similar separation:

'Conceptual classification, like many other cognitive functions, seems to exist at two distinct levels: one level consists of the intuitive, implicit categories of daily life, many of which are reflected in ordinary language, and the other consists of the more self-conscious and cold-blooded categories of an explicit classification system such as one finds in a science.'

The implication here is not that there are two, or more, different kinds of concepts so much as the two levels represent opposite ends of a continuum. By an 'informal' concept is meant a tacit, perhaps partially explicit conceptualisation in contrast to a fully explicit, societally accepted form which Ziman (1979) calls:

'A concept within an academic subject.'

There is a second aspect to the informal-formal distinction which might have been better served by being treated as a separate dimension. Instead it is included here because at least one of the two parts remains the same. A very large number of concept studies have been conducted using 'experimental' concepts rather than 'everyday' ones. In this case they are not the formal rigorously precise concepts of, say, physics but are what Dodd and White (1980) call 'logical concepts'. They are formal in the sense that they are defined by a strict rule and a set of pre-determined attributes, or are defined by single arbitrary artificial value. This 'common element' — or monothetic
approach relies on sorting or matching tasks of geometric designs or nonsense syllables. It is typified by the work of Bruner, Goodnow and Austin (1956). On the other hand, Rosch (1977) has argued that everyday, natural (informal) concepts are not logically bound entities. They are seldom unified by a single common property - are polythetic - and are, in Rosch's view, 'fuzzy'.

The 'formal' view of concepts - as it is used here - is one Markova (1982) relegates to a Cartesian tradition. One consequence of this is that studies of conceptual development are often concerned with straightforward 'object' concepts (like 'ball') which have direct referable meanings, and so (by extrapolation to all concepts) that the acquisition of knowledge is a 'yes-no affair'. It is a trend in psychological studies that treats people as containing special compartments dealing with reasoning, one with emotions, one with beliefs, one with language and so on (Salmon, 1980).

(iii) Hypothesis-testing Abstraction dimension

This third distinction has a long history: it is a long-standing discussion between schools of concept formation, the abstractionists being what Bolton (1977) calls the 'traditional' school. He describes them this way:

"The traditional theory, known as the theory of abstraction, or as the 'copy-theory', is that concepts are formed by the subject abstracting (i.e., 'drawing away') certain resemblances among otherwise dissimilar stimuli. On this view, a concept is a representation of the generalities we have observed to occur among our many particular perceptions. The opposing point of view is that a concept is formed not by the subject merely attending to such general features but by having a particular hypothesis about certain features of his environment."
The abstractionists have been roundly criticised (see Nelson, 1974; Johnson-Laird and Wason, 1977; Markova, 1982, for example), primarily for the model of human learning that underlies this stance. Essentially it implies that individuals are passive recipients of sensations, merely attending to general features amongst stimuli. It belies the notion that consciousness is intentional. Piaget (1979) for example, has long been an adversary of such abstractionism and has maintained a constructivist and interactionist approach. His work has prompted Kessen and Nelson (1978) to say:

'Of course, it would be a moment of memorial grandeur to assert that Piaget's critique had at last and forever chased abstraction theory - in its classical and in its modern modes - off the psychological field, but the dragon still limps around, still breathing out obfuscating smoke.'

One aspect of the 'modern mode' of abstractionism alluded to here concerns the primacy and sequencing of operations during concept formation. Clark (1973) for example argues that when young children categorise objects, it is perceptual similarity that is of fundamental importance. Nelson (1974), however, contradicts this by saying that it is the functionality of the object that is paramount. She presents a strong argument that any theory visualising children as simply attending to perceptual 'features' again overlooks the child's own independent organisation of experience.

(iv) Semantic ——— Logico-mathematical dimension

The last distinction is between those who study semantic concepts, and those who have explored logico-mathematical ones. Studies within linguistics and cognition are often
seen as separate and distinct, to the point that a recent
debate between leading exponents in each field (Chomsky
and Piaget) was heralded by the organisers as 'historically
important' (Piattelli-Palmarini, 1980). Many studies of
logico-mathematical concepts are associated with Piaget's
work. In essence, the crux of his theory of mental devel-
opment is that a child's intellectual growth is not due to
sensory perception or anything else passively impressed on
her from outside, but by her own actions. These actions
are internalised through the child's acquisition of language
and her growing use of imagination and representation.
These in turn are organised into mental operations governed
by rules of mobile equilibrium, basically rules of logic
and mathematics.

On the other side, some of Piaget's critics oppose
his relegation of language to the periphery of cognitive
processes (Brown and Desforges, 1979; Donaldson, 1978).
Moreover he seeks cognitive 'universals' (unlike Chomsky's
linguistic ones) and concentrates upon logical 'schema'
rather than natural language concepts. Both Moore (1973)
and Nelson (1977) see Piaget's theory as being more easily
reconciled with semantic development at early stages of
infancy. It loses its applicability as the child ages.
As Sinclair-deZwart (1973) says:

'Piaget sees the construction of cognitive operations
as following structurally defined stages and as a universal
phenomenon... No such necessary and universal character is
attached to the morpho-syntactical rules of specific lang-
 uages and therefore we cannot expect either universality or
clearly defined stages: in fact we expect them less and
less as language learning proceeds.'
Semantic development is possibly the least understood aspect of language development. Much of the oldest lines of research have concerned vocabulary counts, used as indications of vocabulary growth. Some latterday examples of this approach are Evans (1974) and Cassels and Johnstone (1979). A decline in interest has come with the realisation that the presence of a word in a person's vocabulary does not by itself tell an observer much about the meaning of that word to the person. Moreover vocabulary counts ignore important relations amongst word meanings - relations that make vocabulary more than just a list of words.

A distinctive approach has been that of the 'semantic networkers'; Collins and Quillian (1972); Smith, Shoben and Rips (1974) and Rumelhart, Lindsay and Norman (1972). Semantic networks are very complex and have been criticised as being difficult to test empirically (Claxton, 1980). Moreover, they favour validation by computer simulation (Baddeley, 1976) rather than personal meaning systems in natural situations.

In general terms the semantic system of a language is the knowledge a language speaker must have to understand groups of words and relate them to his knowledge of the world. Unlike phonetics or syntactical grammar, the semantic development of a person is the aspect of language development most directly linked to his broader cognitive development. As Dale (1976) says:

'The question of how do children express their ideas? cannot be neatly separated from the question what kinds of ideas do children have to express? Therefore understanding of semantic development requires a deeper understanding of cognitive development.'
To summarise this discussion of concepts a number of points can be made. The ends of the dimensions that have been used characterise two different paradigms of inquiry. Gilbert and Watts (1983) refer to these as paradigms 1 and 2. The first embodies an 'erklären' tradition. Here, explanation is the goal, it is strongly realist in outlook, it shows allegiance to an empirical - inductivist view of knowledge, has a firm belief in the value of a reductionist approach to phenomena and the use of replicable experimental methods in the search for causal mechanisms. It is what Markova (1982) calls the Cartesian tradition. Paradigm 2, shares a 'verstehen' tradition. This is more relativist in outlook, shares the influence of post-inductivist views of knowledge, holds a belief in the value of an holistic approach to phenomena, seeks to perceive understanding as shown by individual actors in human situations without - necessarily - the open pursuit of generalisation. For Markova (1982) this is the Hegelian tradition.

Transferred to the area of science education research, these two sets of assumptions characterise the two parts of the movement depicted in figure 2. Needless to say, it is often difficult to establish quite what the philosophical assumptions are that underlie a single study. Moreover, few of the studies viewed in the next section can be slotted simply at either end of what is a continuum. As Gilbert and Watts (1983) suggest, when research is in a Kuhnian pre-paradigmatic state (Kuhn, 1970) it might be expected that underlying assumptions and modes of research conduct are not always specified explicitly or completely. Many
1.2: Misconceptions and Alternative Frameworks

In their seminal paper delineating the field and coining the phrase alternative frameworks, Driver and Easley (1978) review a range of research reports. They divide these into studies of misconceptions and 'naturalistic studies of alternative frameworks'. They dismiss the former as 'lacking interpretive power'. From what has been said, such a straight division of research is perhaps unwarranted - it is more the case that any discernible movement from paradigm 1 to paradigm 2 will show only with time. Since Driver and Easley's paper many more studies have been completed which indicate both these end poles and various points in between. Moreover, some researchers, and groups of co-workers, have migrated from studies of misconceptions to alternative frameworks.

This section looks first at some studies of misconceptions, then considers some factors that favour a change of emphasis. Finally, current work within the 'frameworks' movement (and the topics they investigate) are discussed.

i) Studies of Misconceptions

Having considered concepts along four dimensions, the general picture to emerge is that concepts and conceptual development are not clear cut issues, but are unsystematic and messy. To talk of misconceptions is to attempt to minimise this lack of order. Essentially it is a gross over-
simplification, treating concepts as having a binary mode. Either one 'has' or one does not 'have' a concept. For example, it is often where concepts are seen as 'products' that it becomes possible to talk of 'having' concepts. It is what Pines and Leith (1981) call the 'all-or-none' view of concepts. In contrast, they describe alternative frameworks as:

'a complex network within a child's cognitive structure'.

Another example is Gagne's (1970) theory, where any 'piece' of knowledge can be acquired only if the learner possesses pre-requisite pieces of knowledge in full. These in turn are founded upon other pre-requisite knowledge items. In this sense misconceptions are attributed to the 'absence' of a required concept. Little or no credit is given for partial, unorthodox or variant understandings - concepts are seen as integral units. This approach is an example of what Kelly (1963) rejects as 'accumulative fragmentation.'

Similar attitudes are adopted by others who begin from another point of view. Shayer (1978), for example, concludes that certain elements of school science cannot be mastered by the majority of youngsters who are asked to tackle them. He links non-mastery to failure in Piaget's formal-thinking tasks: large proportions of the student population fail to master basic concepts. He says:

'A series of excursions half-way up the cliffs surrounding what would be interesting territory, if it were ever reached, is no use to anyone.'

Anything less than a whole (or proper) concept is denigrated as useless.
In some cases 'misconceptions' are seen as the causes of students failing to think 'formally'. Aiello-Nicosia and Sperandeo-Mineo (1980), for example, say:

'The familiarity with a problem's content can indeed play an important role to pull-out these formal strategies... but it can also have a negative effect if preconceptions or misconceptions are present.'

The normative implications of this statement (of formal operational 'norms' with deviant fluctuations) raises an allied point. Cawthron and Rowell (1978) argue that much of current science education is governed by an 'empiricist-inductivist', or 'positivist' view of science. Consequently, in many studies a students' failure to conceptualise the 'objectively' true concepts of science is to be misconceived. Failure to be correct is to labour under a misconception, or to have developed a 'wrong' concept.

In this vein, Za'rour (1975) talks of students' 'erroneous notions about some scientific facts and concepts... referred to as misconceptions.' Ferbar (1980) equates misconceptions with mistakes in mechanics. Helm's work (1978, 1980), which at the time attracted popular attention (Maddox, 1978), shows that not only do students 'fail' conceptual physics questions, but so do their teachers. That they are seen to be as bad (or worse) than their students gave rise to Maddox's title, 'The blind leading the blind up a blind alley.'

Other studies to follow a similar outlook have been Linke and Ventz (1979) and Harris (1978). Goldsmith's (1978) survey was to measure the continued popularity of some old misconceptions.
Some Factors Influencing a Change to Alternative Frameworks

The shift from paradigm 1 towards paradigm 2 can be summarised by reference to a changing climate of research in terms of psychological orientation, methodological innovation and philosophical assumptions. Though hinted at in Gilbert and Watts (1983), these factors are described more fully in Pope, Watts and Gilbert (1983). Here it is argued that paradigm 1 traditions have resulted in a tendency to undervalue human learning in order to discover fundamental general principles. In this sense much of educational research conducted in this mode has been of little direct help to practitioners who have to deal with awkward and complex learning issues in natural settings. Paradigm 2, or New Paradigm research (Rowan and Reason, 1981) shows regard for the dignity and autonomy of research subjects and focuses on an holistic examination of individual behaviour - and the personal reasons for actions and decisions.

For example, Salmon (1980) advocates the acknowledgement of the 'particular reality of the learner' and thus of a more phenomenological perspective to be adopted. This is a disruption of the usual 'scientist-subject' distinction of traditional psychological research. This, like Kelly's (1955) work, is within the traditions of the verstehen approach. Important, too, are research methodologies that are compatible with, and serve to enhance, such understandings (Swift, Watts and Pope, 1983) - a point to be developed in chapter 2. In that paper the authors argue that any
methodology must be compatible with the philosophical assumptions that are part of the research design. As new and different methodologies become available so the shift to a new paradigm of research becomes visible.

Changes in philosophy, too, have borne on the conduct of research. The rapid developments in the philosophies of science due to Popper (1963), Kuhn (1970), Lakatos (1970) and Feyerabend (1979) have emphasised a continuous reconstruction of scientific explanation. This has, in turn, had a profound effect upon the human sciences so that what Abell (1982) calls the Kuhn-Barnes thesis can be seen to be having an increasing effect. Central to this is Barnes' (1982) Kuhnian view of concepts. He suggests that people map their environment conceptually through a subtle mixture of ostensive definitions and 'conceptual fabrics'. Barnes calls this 'finitism', and one major consequence is that concepts are always open. He contrasts this with what he calls 'extensional semantics' where a concept is defined once and for all so that it is seen as covering a decided and agreed content. There is a strong similarity here with the poles of the four dimensions already discussed. In this case Barnes (via Kuhn) blurs any distinctions between personal and public concepts. He blurs, too, distinctions between 'natural' and 'social' science so that there is no way of drawing any other than a conventional boundary between science and non-science. Whatever is the case, progress is not made through closed concepts; every concept has a moving history and meaning is never fixed. Concept formation is selective, not absolute. Some explorations of
the influences of philosophy upon science education have recently been undertaken, for example by Swift et. al., (1982), Watts and Pope (1982) and Zylbersztajn (1983).

Intermediate between the poles of paradigm 1 and 2, between the Cartesian and constructivist traditions, lie a range of concept studies. These can be seen as transitional between the two. Markle and Tieman (1970) for example, question a behaviouristic approach yet settle for a typical syllogistic definition of a concept. Herron, Cantu, Ward and Scrivenssen (1977), similarly, attempt a taxonomy of school science concepts. Here they question the perceptibility of the instance of the concepts. Osborne and Gilbert (1979) follow Klausmeir's (1974) model of a concept which, whilst being developmental takes an abstractionist viewpoint. In each of these cases the nature of concepts is being queried and reformulated. However, concepts are analysed primarily as 'concepts in an academic subject' (Ziman, 1979) and scant attention is given to the individual's perspective: the disposition to construct conceptions on a wide range of bases.

Albert (1978) rejects the 'subject' approach, as do Freyberg and Osborne (1981). For them, a concept is displayed by a person's response to instances, rather than her ability to recite a definition or a list of criterial attributes. As Kelly (1963) pithily points out, people are inventive. Consequently, there will not be unique solutions but alternative ways of representing events and experiences. Pines (1980), too, has sought to challenge traditional aspects of concepts, particularly in the failure to represent everyday, natural conceptions. He points (Pines, 1982) to
his own work on a 'conic model' of a concept. Whilst, he suggests, it is elegant, has appeal and would provide a large number of research questions, it fails to represent human concept development. He sees a schism between precise theoretical (formal) models of concepts and the outcomes of classroom practice: the former are too removed from everyday experience to be of value.

An important adjunct position to the constructivism in paradigm 2 are studies which place an emphasis on cognitive structure and prior knowledge. Whereas concepts are not isolated discrete entities but are ways of organising experience on the basis of what is already known, they are often discussed as being 'transmitted to' students rather than constructed by them. Novak's (1977, 1982) popularisation of Ausubel's (1968) work has prompted much revision in work on concepts. Some, for example, are reported by Kempa (1982). A number of difficulties and criticisms have been levelled at Novak-Ausubel studies (for instance, West and Fensham, 1974; Barnes and Clawson, 1975; Mayer, 1979; Driver, 1982). In the context of this discussion, it is the 'transmission model' of concept acquisition that marks the divide between these studies and those in paradigm 2. Novak's (1982) approach is strongly nomothetic, so that when he describes concepts as 'regularities in events or objects', he then classifies student responses as misconceptions or incomplete conceptions. The conflict here revolves around what an 'incomplete' regularity might be. Clearly, for Novak, it is not the student's regularities that are important, only their irregularities when compared to 'correct' concepts.
iii) A Review of 'Newer Investigations'

The majority of the studies considered here are what Driver and Erickson (1982) would call 'newer investigations'. In Erickson's (1979) terms they attend to the substance of actual beliefs and concepts held rather than to reasoning and logical skills. In considering a very disparate range of studies, it seems convenient to group them roughly in two ways: by approach and by topic. In a short review of papers, West (1982) chose four headings - 'intentions', 'methods', 'types of representation' and 'theories of learning'. The two latter issues are dealt with in other sections, here, intentions and methods are considered briefly together under 'approach'.

It is possible to identify a small number of important pieces of work that have fostered and generated many more replications and modifications. They have been influential as the starting point for a wide range of studies. Driver and Easley's (1978) review has already been mentioned, with it can be considered Viennot's (1979) work on force, Nussbaum's (1979) questions on gravity, and Osborne and Gilbert's (1979) methodology in looking at work and electric current.

In that brief review by Driver and Erickson (1982) the authors fastened upon a unity of approach that contained elements of cognitive structure, constructivism and classroom importance. It is that type of similarity in approach that is noticeable even in a wider spread of studies. The 'context' of such work - and the outcomes reported, are dealt with more fully in the sections relating to particular
concepts, that follows. Nor are all studies reviewed here - the approach used by different groups can best be exemplified rather than enumerated. The majority of the work has been accomplished within physics, particularly in pre-relativistic mechanics, although some inroads have been made into the 'chemical' and 'biological' sciences.

By far the most wide ranging series of studies has been those within the Learning in Science Project, Waikato, New Zealand. Based upon the IAI approach (Osborne and Gilbert, 1979; Gilbert, Watts and Osborne, 1981, and described fully in the next chapter), the topics have embraced much of mechanics and related issues. For example, Stead, K; and Osborne (1980 a) have looked at gravity and friction (1980 b); Stead, B. and Osborne (1980) at light; Stead (1980 a) has explored living and (1980 b) energy. Osborne has reported on children's ideas of force and electric current (Osborne, 1980, 1981). Their work has commonly encompassed the secondary school age range and has used both interview and paper-and-pencil methods. The results are generally described in terms of students' 'views', answers to questions are combined to be presented as percentages for certain categories of response.

Other studies have been less cohesive, tackling a more restricted set of topics with a more diverse range of methods. Duit's (1981) study, for example, centres upon a word-association questionnaire with a request for students' own definitions and examples for energy, force, work and power. It also includes multiple-choice elements and, concentrating primarily upon energy, considers gymnasien students' notions of energy before and after course instruction. Part of the
same study compares variations in notions between students in Germany, Switzerland and Philippines.

Driver (1981), Engel (1982) and Engel and Driver (1981) have looked at youngsters' alternative frameworks of weight, heat, pressure and evolution. Their methods have used both written test questions and interviews, sometimes in combination. In a similar vein Erickson has looked at children's 'conceptual inventories' of heat and temperature (1979), heat (1980) and vectors (1982). He has used an interview approach, followed by a survey of popular answers, with children of 6-13 years in Canadian schools.

Force and gravity have been the two most widely researched concepts. The seminal work by Viennot (1979) looks at the persistence of reasoning patterns by Belgium physics undergraduates concerning forces in springs. Osborne (1980), Gilbert and Osborne (1980) and Watts (1983) report the use of the IAI approach with force with secondary pupils across a range of common situations. A paper- and-pencil variation on this method (Watts and Zylbersztajn, 1981) asks for an explanation along with a particular choice of response. Used by others too, (Wright, 1982; Thomaz, 1983) it shows that students' frameworks are clearly at variance with orthodox scientific viewpoints. Sjoberg and Lie (1981) in Norway have reached similar results; as have McCloskey, Carmazza and Green (1980) and Minstrell (1982) in America. The outcomes of these studies will be considered more fully when discussing the concept of force.

Gravity, too, has received special attention. As Sneider and Pulos (1981) suggest, students are generally required to recognise the part-to-whole relationship between
visible ground and the whole earth. They must accept such apparently absurd ideas as the existence of people who live under our feet on the other side of the earth. That they are reluctant to do so is reported by Nussbaum (1979); Vincentini-Missioni (1981) argues that this is true of adults too. In Australia, Gunstone and White (1981) employ a set of questions first used by Champagne and Klopfer (1980) to look at the views of first year undergraduate students. They also comment on the diversity and tenacity of students' views, along with their reluctance to accept disconfirming evidence.

A growing emphasis has been upon the overlap between concepts; in particular, force and energy. Duit (1981) points to a considerable overlap between youngsters conceptions for both concepts, both before and after school instruction. The interchangeability of the two terms has been noted by Clement (1978), Viennot (1979), Jung (1981a) and Watts and Gilbert (1983). An interesting aspect of Duit's work is the even greater overlap between energy and electricity - noted too by von Rhoneck (1981).

Outside of mechanics and thermodynamics Guesne (1980), Stead and Osborne (1980), Jung (1981b) and Andersson and Kärrquist (1982) have chosen to look at light. This is a remarkably small number considering the major role that light plays within the study of physics. Fewer still have ventured into the traditional areas of chemistry. A notable exception is Pfundt (1981) with a study of children's conceptions of 'substance' and chemical and physical change.

Many of these studies are considered in detail in
chapter 3 - in relation to the specific concepts in this study: energy, force, heat and light. Before moving on to the next section it is useful to recap for a moment the arguments suggested so far.

Firstly, this thesis deals with the complexities of youngsters' discussions around four concepts in science. Seen against the backdrop of previous research it is primarily concerned with understanding students' own conceptions, the substance of their ideas, rather than grading their concept 'acquisition' in terms of correctness, completeness, formality, syllogistic logicality and so on.

Secondly, such an approach to students' own ideas is distinctive and can be seen as part of a verstehen tradition. This is at variance with an erklaren tradition, and both approaches have been labelled paradigm 1 (erklaren) and paradigm 2 (verstehen). In this sense it is possible to see similar studies of students' alternative frameworks as falling in paradigm 2.

Thirdly, previous research has been described as a movement away from 'misconceptions' towards 'alternative frameworks' and some reasons for this movement have been outlined. Research studies have been characterised as falling on the continuum between these two poles. Research at each end has been discussed along with some that has been designated to intermediate or transitional points.

What remains to be done is for a more detailed picture to be developed, both for the notion of concept and conceptualisation being used here, and for the ensuing research design. These issues are taken up in the next section.
1.3: Developing a Conceptual Framework

The studies of 'misconceptions' already discussed can be seen as researchers' attempts to reduce the highly complex aspects of concept development towards clear and distinguishable issues. The unfolding oversimplification results in an inappropriate model - when applied to the intricate subtleties of human actions during the generation and exploration of explanations. In this study, the theoretical assumptions are that the students are taking an active role and are learning whenever they experience something, which includes the interview - the data gathering method itself. This reflects, then, upon the very task at hand, how the task should be presented to the student, what kind of instructions are to be given, what kind of analysis to be used and what kind of methodological checks to employ. That is, the very notion of the students' conceptualising of situations (both the exemplar focus situations within the interview and the interview itself) determines the shape and design of the study.

So far, much that has been said about concepts (and concept development) has been negative. Natural (everyday) conceptualisations are not necessarily logically bound, are not simply abstracted regularities, are not distinct entities clinically derived and unaffected by other human considerations. The purpose of this section is to detail the proposed view of conceptualisation and the intended course of exploration. These are discussed as six distinctive but related points.

First, although this study has been identified within science education research via Driver's (1982) summary
diagram on page 1.6, it is necessary to relate it, too, to its broader realms of interest. Here use is made of another figure, by Harré (1982), who calls it 'two-dimensional space of anti-Cartesian psychology'. This is shown below in figure 3. The first quadrant (I) is intended to represent the domain of social meanings of which science is a highly specific example. Items in science have significance because they are both located within networks of relations in a semantic system and they are public: they are conventionally bound (within the conventions of science) entities. The second quadrant (II) represents the personal interpretation of the social domain - privatised versions of the public. The third quadrant (III) represents items of personal thought that have no meaning in the public-collective domain at all. These might be daydreams, private fantasies or inner (inexplicable) doubts or fears (for example). The final quadrant can be seen as part of the individual meanings of a person that can be, and are, displayed in public - by means of their behaviour and speech in a public arena. This study fits into no one quadrant but use can be made of the axes described in this way.

Figure 3

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<td>III</td>
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<tr>
<td>Personal</td>
<td>PRIVATE</td>
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It can be said that the meanings of individual students that fall within quadrant III are inaccessible. If they are displayed in public then, unless they have some recognisable counterpart in the social domain, they will be unintelligible. If a personal meaning is truly private and individual then the items concerned cannot interact directly with the public network of meanings, to other people or the social milieu. However, a second-order exploration of conceptual frameworks can be made by examining the interface between the other three quadrants, as depicted in figure 4.

Figure 4

The interface between quadrants I and II Harré calls 'appropriation'. Personalised ideas of the social domain are those meanings that are privatised versions of the public ones. Harré quotes Vygotsky (1962) as describing learning as appropriating for personal use practices which are essentially public. It is a description of meaning that holds that it is not inherent in things, but within people who are actively engaged in interpreting the events (words,
acts, speeches, situations) confronting them. It is an active imposition of meanings or interpretations upon public features. In the context of school science it is the active imposition of meanings by students on the words, drawings, apparatus, experiments, charts, etcetera that comprise the realm of science as they encounter it in school.

The interface between quadrants IV and I Harré calls 'catachresis'. This is the making public of an individuals' personally derived meanings, their own language in action. Rather than, as in the other interface, being a personalisation of the concepts of science this is the expression of words as they are used by students, their own language in action as they are coordinating their accounts, and forging explanations. Put crudely, these two interfaces might be sensed in two questions: how would you (the student) describe this situation (using, for example, the word 'force')? This is a very different question from what do you (personally) mean by the word force in science? And yet, in order to explore youngster's meanings-in-use, their conceptual envelope for the word, both questions are necessary. They are complementary facets of personal meanings for parts of science.

The second major issue in this section is a development of the first. In identifying this study as a (science orientated) subset of the interaction between the individual, personal and the public domains of meaning, it needs to be noted quite which metaphysical assumptions are being made. Clearly, if persons are actively engaged in interpreting the events confronting them, they can be seen to impose different interpretations on these events and so disagree
about their 'true' nature. This is a relativistic stance akin to the philosophies of Kuhn (1970), Lakatos (1970) and Feyerabend (1975) already mentioned. In particular it is within the spirit of Kelly's (1963) philosophy of constructive alternativism which states that 'all of our present interpretations of the universe are subject to revision and replacement.' This underlies Kelly's whole theory, his model of the person and of psychological change. In these terms people (to a large extent) base present actions on past constructions of similar events. In this way predictions are made and hypotheses decided which can then be tested. Rather than adopt the analogies current at the time of his writing, of 'man-the-machine' or 'man-as-impulse-driven', Kelly opted instead for the metaphor 'man-the-scientist'. He invites exploration of the metaphor: to see the way that persons go about making sense of their world as if they are scientists. This way, he says (1969) the:

'ultimate explanation of human behaviour lies in examining man's undertakings, the questions he asks, the lines of inquiry he initiates, the strategies he employs rather than analysing the logical pattern and impact of the event with which he collides.'

The overall consequence of this for what follows is that, as is argued in Swift, Watts and Pope (1983), a pupil's expressed view which is at variance with the curricular 'orthodoxy' of school science can not be construed as a 'mistake' in any simple or discreet sense.

'School science' is itself a broad framework (as Zylbersztajn (1983) suggests) of conventional text-book and teacher meanings to be found in school curricula and classrooms. Here it is used as a reference framework by
which to consider the responses students make as they discuss the various situations and concepts. However, it is not intended as a normative basis by which to categorise the 'correctness' of student answers. Rather, as indicated earlier, this is a study of the interaction between the 'public' and the 'personal', the oxymorons of science which are tethered by conjunction in the confection of school science.

Before moving on to the next point, an additional comment is necessary here. The process of conceptualisation portrayed so far has been discussed in rather inductive terms whereby new events are organised in relation to prior knowledge. This undoubtedly is the case - it is a procedure through which expectations of future events are dictated by the results of past experience. Critiques of induction - from 'Popper and after' (Stove, 1982) - are levelled at logical induction, for the 'rules of induction' as a basis for the acceptance of scientific statements. As Piattelli-Palmarini (1980) says:

'Hume's critique of induction did not impede the practice of induction which, logicians notwithstanding, goes successfully on today as it always has, but rather the rules of induction.'

The practice of induction only becomes a problem when it is cited as both a process of conceptualisation that is psychologically guided and stimulated by antecedant knowledge, and the way in which scientific theories and hypotheses are logically determined. In this case, induction can be seen to be sandwiched between methodological 'rules' of scientific acceptance and the psychology of hypothesis formation.
This is not intended as a neat and dichotomous separation between philosophy and psychology - there are few resolutions to the tensions between the two, and this study is not an attempt to provide one. Constructive alternativism is a philosophy of pluralism (Swift, Watts, and Pope, 1983) so that no one explanation or interpretation of concept formation in either the public or individual sphere can be sufficient.

The third major point to be made here is allied to this. Despite the general use of the term so far, not all forms of constructivism are identical. Commonly they differ in emphasis. Piaget's structural or 'systematic constructivism' (Piaget, 1979) relies heavily upon his theory of genetic epistemology. Keil (1981), on the other hand, argues that Piaget's 'groupments' - structures with certain formal properties - can be re-interpreted in terms of his own 'constrained constructivism'. He suggests that humans come equipped with strong constraints upon their knowledge systems - cognitive constraints that operate differently in different cognitive domains, making cognition domain-specific. This is an argument for cognitive subsystems, rather than widely generaliseable rules for cognitive development like Piaget's. Marton's (1981) constructivism is more phenomenologically based: descriptions of people's world views he calls 'phenomenographs'. Sigel (1978) and Sigel and Holmgren (1981) posit a 'constructivist dialectic' view, one that attempts to vie between a number of theorists to produce a fuller account of constructivism. They described constructivism as follows:
'Constructivism refers to that process of constructing in effect, creating, a concept which serves as a guideline against which objects or people can be gauged. During the course of interactions with objects, people, or events, the individual constructs a reality for them. The object, for example, is defined mentally. This mental construction then guides subsequent actions with the object or event.' (in Sigel, 1978).

The notion of 'creating concepts' is an important one. From the discussion of concepts earlier, it can be seen that a constructivist perspective sees the individual as constructing the form and content of his own experience.

'Constructive theory holds that the form and the contents of all experience are constructed... This proposition represents a complete break with the theory of knowledge long dominant in psychology' (Cofer, 1977; in Disibio 1982).

It has already been noted that constructive alternativism is a philosophy of pluralism. It supports the premise that an individual does not have a personal theory about the world— but has many. Each 'mini-theory' (Claxton, 1982) derives from the need to make sense of, and act effectively within, new types of situations. Kelly (1970) says:

'Like other theories, the psychology of personal constructs is the implementation of a philosophical assumption. In this case, the assumption is that whatever nature may be, or howsoever the quest for truth will turn out in the end, the events we face today are subject to as great a variety of constructions as our wits will enable us to contrive.'

In Claxton's (1982) terms, the implementation of constructivistic alternativism can be described as follows: people construct theories around life events and once a successful way of construing is found then the same construction or conception in this case) can be applied to other novel but similar events. The event and its immediate context form the 'focus of convenience' of the theory which, if successful with subsequent events, readjusts and alters its 'range of convenience' to include each new occurrence. In this way
a mini-theory gradually, through learning, broadens and refines its range. That is, the boundaries beyond which it fails to explain and predict events are open to exploration. The failure to explain gives rise to fresh, alternative, theories which are tested for their applicability.

Each construction is defined and delineated by the domain of experience to which it is generated to apply. The success or failure of a theory (its viability) is not an instant measure; immature or imperfectly located theories might be refined or replaced only over a period of time. It follows that there will be domains of experience for which some people will have no theories, others for which they will have many.

Kelly's own theory is not without its critics (for example, Shotter, 1975; Holland, 1970) and it needs to be said that his own focus of convenience was psychotherapy rather than the general educational process. That said, Kelly saw his theory as reflexive; capable itself of having its range of convenience altered and refined, and the resulting constructions explored for their viability. In this way, the theory can provide a constructive and supportive context in which to explore the world views and conceptual frameworks of youngsters in school.

This discussion of constructivism bears directly on the fourth point to be made: some notion of 'concept' that is compatible with the description of personal meanings and constructive alternativism that has taken place so far. What Kelly's work can add to a view of a concept is both specific and general. At the time of his writing, Kelly (1963) rejected 'concepts' for reasons similar to the
arguments used here against the traditional use of the term: because they are part of the context of 'mentalistic psychology or of formal logic.' He sees constructs as including the notion of precepts, so that it carries with it the sense of being a personal act. However, the use of the word concept where it embraces this same personalised set of conditions is also acceptable:

'Some logicians take the view that a concept is a way in which certain things are naturally alike and that all other things are really different. For them the concept is a feature of the nature of the things with which it is connected and not an interpretative act of someone. We would agree that a concept is real, but its reality exists in its actual employment by its user and not in the things which it is supposed to explain.'

Within the compass of this study the term concept will be reserved for use in describing the public-collective meanings in science—particularly of energy, force, heat and light, and the associated concepts in the network of physics. The term conception will be used to denote individual, personal meanings as displayed to a listening audience, in much the way that Kelly refers to 'concepts' above. In this sense, conceptions will be seen as similar to Claxton's mini-theories and will be described in terms of their range of convenience and their focus of convenience. It is a use of conception that approaches Bolton's (1977) description of a person's concepts as 'constructive hypothesis testing', and as:

'a stable organisation in the experience of reality /.../ to which can be given a name.'

Given the 'warmth' of personal intention to this view of concept(ions) there is little difference between it and Kelly's notion of a construct. He (1963) puts it this way:
'Forming constructs may be considered as binding together sets of events into convenient bundles which are handy for the person who has to lug them. Events, when so bound, tend to become predictable, manageable and controlled.'

It needs to be noted, however, that for Kelly constructs are essentially bi-polar and dichotomous. This is not so of conceptions, which can be seen as polythetic nodes in the meaning networks of individuals.

The fifth major point is as follows. The view of concepts, conceptions and the philosophical assumptions of constructive alternativism lend to a particular model of people and their construction of knowledge. These can be shaped for the purposes of this study as follows:

a) People are active constructors of meaning. Kelly invited the use of the metaphor person-the-scientist. That is, people in their science-like behaviour hypothesise and test their personal conceptions of reality;

b) Peoples' conceptions help them choose between alternatives, by allowing them to test their expectations and elaborations of the conception;

c) Conceptions are contingent on past experience so that ones which do not work are eventually discarded;

d) The range of convenience and focus of convenience of the conceptions grows by restructuring from within and not by simple addition from outside;

e) Conceptions are contingent upon the intentions, purposes and anticipations of the individual.

As already suggested, it is a relativistic philosophy. Pope (1982) suggests that Kelly saw all theories - including his own - as created in order to fit known facts and ideas at any particular time. When found wanting, they are modified
or eventually replaced by a better one. Watts and Pope (1982) explore the similarities between constructive alternativism and Lakatos' (1970) philosophy of science. Lakatos advocates a 'revolutionary activist' approach to knowledge which he describes as follows:

"'Passivists' hold that true knowledge is nature's imprint on a perfectly inert mind: mental activity can only result in bias and distortion... 'Activists' hold that we cannot read the book of Nature without mental activity, without interpreting it in the light of our expectations or theories. Now conservative 'activists' hold that we are born with our basic expectations, with them we turn the world into 'our world' but must then live forever in the prison of our world... But revolutionary activists believe that conceptual frameworks can be developed and also replaced by new, better ones; it is we who create our 'prisons' and we can also, critically, demolish them."

The important point is that there are no objective markers or shibboleths to guarantee the truth or 'correctness' of any group of competing theories. The metaphor of person-the-scientist allows this description to be observed for individuals as they theorise, interpret and conceptualise situations in a variety of different ways. Needless to say, the same can be said of the fruits of analysis of this study. There is no attempt in later chapters to argue that the interpretations made of the responses students provide are the only ones that can be derived from the data. Interpretations are made and are evidenced as fully as possible from the data-base, in order to describe both individual conceptions and alternative frameworks.

Finally, the sixth point to be made concerns the means by which access can be gained to meanings. A number of methods are possible for accessing personal conceptions (Swift, Watts and Pope, 1983) and some of these are discussed in the next chapter. In this study, access is by means of
dyadic discourse. Following the tenets already described, of ascribing kudos and status to the responses made by the students in order to examine their personal conceptions from their own accounts, a fairly informal discussion is called for. Unlike other forms of discourse (speeches, texts, narratives etcetera) informal conversation lacks finish, is exploratory and tentative. It is the prototype out of which finish may eventually be produced - at this stage, however, it is progressive, mutual, alternating and sometimes incomplete. This being the case, in order to study such exploratory discourse, it is necessary to 'freeze' it in transcript form so that it can be inspected.

This kind of informal discourse is an attempt to identify with another's personal meanings in science - and it is well to recall that personal meaning is dynamic, a process not a thing. The semi-focused interviews described in following chapters are, in principle, social encounters which are improvisations around a concept theme. They are imprecise, and are ones in which participants interact using, and constructing creatively, the conventions of science and language. How well the documented analysis captures this process is a point of debate in the final chapter. It is an approach which Whitehurst (1979) neatly observes: 'is like catching rain in a bucket for later display. What you end up with is water, which is only a little like rain.'

Whilst similar to Piaget's clinical interviews they differ in that they focus on a set of drawings, rather than laboratory equipment. Although there are disadvantages to this, as discussed in the next chapter, it has a strength
over and above Piagetian methods in the possibility of escaping from the constraints of a concrete, demonstrable task. It has the ability to explore a wider range of incidents and to transcend them and so lessening the fear of contextual influences on inferences made from school science.

The interviews can be seen as a method developed to take account of conceptions in action as they are brought to bear upon the stylised situations depicted in the pictures. The interview as a whole can be understood as a time-line through a range of personal conceptions as held by an individual in relation to the topic under discussion. Harré's appropriation and catachresis are parallel processes in the explication of the meanings involved.

The interviews produce data for each individual student so that the discourse can be studied as a single case study in looking at the responses for the focal items and how they relate to the individual. However, a second purpose of this study is exploring similarities and differences in meanings within groups of students. It is an examination of the overlap of meanings as students both appropriate the language of science for their own purposes, and generate their own uses for familiar words in their vocabulary. Such overlaps can take place at various levels. Here, as Osborne and Gilbert (1979) suggest, it is the relationship between their use of words that is important. The point here is that, having come to consider similar and different sets of exemplar circumstances and having worked out their ideas about what the circumstances are all about, students come to account for their ideas in terms of the many polysemic words of science like force, pressure, power, stress,
strain and so on. For some, power (for example) will be synonymous with energy, or force, or pressure. For others, it will have some vague but unspecified connection, or perhaps a strong and developed relationship. Yet others will consider all of the words entirely separate and distinct within their own range of conceptions.

In short then, the following chapters are considerations of personal conceptions and discernible common conceptual frameworks that are alternative to—and yet related to—the system of public scientific meanings. Each level of meaning consists of a network of relations in which (mainly four) focal entities are embodied. Above all, the interpretations presented of the individual and his/her personal meanings are necessarily a reflection of the researcher's own philosophical assumptions and meaning matrix.
CHAPTER 2

METHODS OF ENQUIRY

2.0 An Introduction to the Chapter

2.1 First and Second Orders of Perspective

2.2 The I.A.I. Approach

(i) The exploration and curriculum analysis of target concepts

(ii) The generation and design of a deck of instance cards

(iii) The conduct of interviews in two phases

(iv) The transcription and editing of the audio-tapes

(v) The analysis of interview transcripts

(vi) The evaluation of the technique at various points

2.3 The Research Design

2.4 Methodological checks

2.5 Summary
2.0. Introduction

Traditionally, the first chapter in a thesis reflects the current state of the art and presents the opening arguments in favour of an adopted approach. Here, for instance, the trend towards research in alternative frameworks has been noted, along with a description of the pressures that have helped to shape it. Some arguments have been put forward for a constructive alternativist interpretation of individual explanatory dispositions. None of this is intended as a castigation of all previous enquiries or of other theoretical positions. Rather, a case is being made for a re-focus of emphasis upon students' responses to the questions they are asked. Their answers are to be used as evidence for the explanatory frameworks they adopt - and as indications of the level of commitment they hold for the arguments they put forward.

This second chapter is orientated towards matters methodological. Its agenda provides for a description of the specific methodology of this study, after a review of some of the methods used in similar studies. A third section describes the research design, and a final section enters into the much controverted problem of the justification of research.
2.1. **First and Second Orders of Perspective**

The phenomenon of imposing meaning on the outside world can be described from at least two perspectives: as it appears to an external observer and as it appears to the actor herself. Marton (1981) calls this a distinction between a 'first order' and a 'second order' perspective. As Säljö (1982) suggests, questions and problems belonging to the first order perspective have a matter-of-fact quality, and concern such issues as the performance of students, or the evaluation of one curriculum programme or another.

An example of a first-order enquiry is that by the Assessment of Performance Unit (D.E.S., 1981, 1982). This is an attempt to make an assessment of students' performances on a range of science questions. The performance on questions is then matched against a number of personal and school characteristics, like geographical location or class size. An example of a second-order enquiry is Pfundt's (1981) explorations of youngsters' (aged 8 to 13 years) conceptions of 'substance', and its transformations. She uses a loosely structured interview as she undertakes four demonstration experiments (for example, burning some alcohol). She records not only the students' accounts, but also notes her own reactions to their comments. This focuses, then, not on the performance side of learning, but on the experiential aspects as they appear to the participants.

The discussion of concepts in the first chapter can be seen in this light. Much of the traditional studies have emphasised a first-order perspective of concept
acquisition studies. Perhaps this has been a result of psychologists' distrust of the 'objectivity' of mental processes, as Shanks and Abelson (1977) suggest. The move away from purely behavioural indicators towards a regard for the introspective evidence of constructivism allows use of both orders description. Pope and Keen (1981) suggest that any methodology that allows a person to elaborate on his own personal meaning of events is opposite to large scale nomothetic studies. In contrast, Marton argues that the two orders are complementary, giving different kinds of information.

A point to make here is one that Marton hints at but does not make: the two perspectives may require differing methodologies. Novak (1980) has pointed out the need for research methods to be compatible with the underlying assumptions of the research approach. Pope and Keen's (1981) argument is similar: for a 'coherence' between theory and methodology. The central feature of this study is a second-order enquiry into students' own statements concerning common physical situations. At first sight, a pluralist epistemological position, like constructive alternativism might seem a recipe for eclecticism. Swift, Watts and Pope (1983) have argued that advocates of personal construct psychology have not been nearly wide ranging enough and have placed over reliance on a single methodology - the repertory grid technique. Plurality of methods is acceptable where this is based upon a compatible philosophy.

These issues shape the discussion in the sections to follow. The growth of research into students' alternative
frameworks can be seen as an attempt to 'compensate for the
traditional emphasis on behavioural data by building a body
of experiential data' (Colaizzi, 1971). The suggestion
here is that such an attempt is constrained by two main
factors. There is no single appropriate methodology; in
fact there is a need for a range of methods because 'there
are no guaranteed techniques which would work with all
students' (Novak, 1980). Secondly, the methods need to be
compatible with a second-order perspective or, in Novak's
words, do not entail 'ignoring or negating the internal
world of people'.

The first section surveys some of the methods employed
in other alternative frameworks research. This is followed
by a description of the details of the Interview-about-
Instances approach and then by some of the methodological
checks employed in justifying the research outcomes.

2.2. A Review of Methods

Kuhn (1970) suggests that when a research worker
adopts a paradigm, he accepts not only theoretical commit-
ments but also methodological commitments to that paradigm.
The primary methods within the alternative framework move-
ment have been based upon students' accounts in visual,
verbal, or written form. By visual is meant observation,
by a researcher in situ, or by remote camera videotaping.
The most common verbal approach is through interviewing,
although there have been a variety of interview methods
used. By 'written form' is intended paper-and-pencil tests,
surveys, and graphical responses. Seldom is the division between methods a clear-cut one, many are used in combination even in a single study.

Observation on its own allows only a restricted opportunity to explore second-order perspectives. It has most commonly been used in combination with other methods. Zylbersztajn and Gilbert (1981), for example, use classroom observation coupled with an analysis of documents, in their case, the class worksheets that students were using. They also tape-recorded groups of students as they worked. A similar combination is used by Tasker (1980) and Tasker and Osborne (1980) to produce 'lesson portrayals'. In all these reports, observation techniques allow insight into the substance of the interactions between students' frameworks and teachers' requirements.

In contrast are the more commonly used classroom observation schedules like the Science Teaching Observation Schedule (S.T.O.S.) (Egglestone et al., 1975). The latter allows for types of questions and interactions within a classroom to be charted at three minute intervals, but cannot cope with the content of the interactions. S.T.O.S. has been criticised on this and other bases (Dunkerton and Guy, 1982).

By combining observation with other methods, the emphasis is moved from a first-order to a second-order perspective. Driver (1981) gives a good example of this. She reports observations and (presumably) recordings of teachers and pupils as they interact around classroom experiments in the laboratory. The emphasis here is not just on
the quality of the discussion taking place, but is primarily on the types of explanations being used in terms of the pupils' alternative frameworks of heat and force. In another form of observation, Gilbert and Pope (1982) use remote video-cameras to record discussions between small groups of students. The talk takes place around a set of Interview-about-Instances cards of 'energy'. The analysis of the video tapes explores both the interactions that take place between students and the content of their discussion in terms of their alternative frameworks of energy. The observation is combined with 'de-briefing' interviews and requests for students' own drawings of examples of energy. In this way Gilbert and Pope are able to comment about the actions of the participants in debate and to make inferences about their 'internal worlds'.

The majority of research into students' frameworks has used interviews in some form or another. These range from one-to-one 'case studies' over time, to group discussions with part or whole classes. Crookes (1982), for example, describes the changes in explanatory framework used by a single student in discussing heat transfer. The talks occur over a number of sessions using tape-recorded informal interviews, the pupils' own written accounts and recorded deliberations as both student and researcher conduct experiments to explore various explanations. Similarly, Clement (1978) uses protracted discussions with a single student, involving pieces of laboratory equipment, as they discuss force and energy. Nussbaum and Novick (1981), on the other hand, describe whole group debates and explanations for the nature of gases. Individuals within the class
articulate specific models, which are then used as the focus for a general debate. This, too, is an excercise that extends over several sessions, as laboratory equipment is introduced in order to crystalise some of the issues. Solomon (1980) also uses classroom debate to elicit students' perspectives on energy. Such methods are not unproblematic. Recording group-talk raises many difficulties in transcription and analysis. Rarely is it possible to identify individual speakers and therefore to attribute a particular line of argument to one person. As individuals talk over each other, finish sentences for one another, leap-frog comments and side-track each other, it is seldom possible to evidence coherent explanatory frameworks. Rather, as in Gilbert and Popes' (1982) work, it becomes more meaningful to talk of 'sequences' or trends in the movement of explanations. The facility to 'freeze' an argument at one point, in order to explore its implications in detail, depends upon the willingness, or ability, of the researcher to intervene in the group debate as it progresses. This is, of course, the difference between observing a group, and attempting to interview it.

Many studies rely on solitary one-to-one interviews around some focus. Much of the Interview-about-Instances work is of this nature (Osborne and Gilbert, 1979; Watts, 1982; Watts, 1983) as is described fully in the next sections. It is a variation of the 'clinical interview' - a name derived from the 'clinical' methods adopted by Piaget (1929). The focus of such interviews can differ between sample materials or laboratory demonstrations to
pictures or written questions. Osborne (1980) for example, describes interviews with students concerning events that were taking place at the time. Called the Interview-about-events approach, the focus of the interviews are such occurrences as water boiling, steam condensing on a cool surface, or ice standing in a beaker. Pupils are tape-recorded as they give explanations of the events and Osborne takes particular interest in the students' use of the word 'particle' to describe evaporation or condensation. Brumby (1981) uses photographs and samples to elicit responses in terms of evolution - as it might have occurred in birds or moths. Pfundt's (1981) interviews use short experiments like burning alcohol, adding water to anhydrous copper sulphate and heating lead oxide on charcoal to produce lead. Her goal is to generate discussion on the transformations of substance.

A number of interviews are used in conjunction with paper-and-pencil tests or other written responses. Engel (1982) uses questions in interviews based on items pupils had already completed in a written test. Questions on pressure, for instance, ask respondents to explain what happens when a person drinks orange juice through a straw, or why someone sinks into snow when wearing boots (but not when wearing skis). Interviewees are re-presented with the test questions and asked supplementary probe questions. The format also allows for new questions and practical tasks (like actually drinking orange juice through a straw) to be introduced during the discussion. Posner and Hoagland (1981) use a bank of written items concerning statements
about science and scientific beliefs. Its use is primarily as a survey questionnaire with American college students, however it is also used as the basis for a series of interviews. They comment that students are 'unfailingly creative' in what they respond to an item during interviews, and this leads them to place items in contrast with each other and then require students to make a choice. In another study, Von Rhoneck (1981) describes the use of questions and diagrams as the basis for interviews on electric circuits. The interviewees are asked to predict values for the current in the circuit, and for the 'voltage' across parts of it. A demonstration is then conducted to produce measured values and the students are asked to explain discrepancies between their predictions and the circuit measurements.

These kinds of methods lead easily into various written approaches - where no attempt is made to interview respondents, but to collect larger samples of written answers. An example of this is Watts and Zylberztajn's (1981) survey -about-instances approach where some 150 responses were generated from a multiple-choice-with-explanation format. The questions are adapted from other studies, like that of Viennot (1979), and require a choice to be made concerning the forces present in particular situations. Each choice is accompanied by a request for an explanation for the choice made. Viennot's work is similar, albeit with different situations, and in her case, aimed at undergraduates. Zylberztajn and Watts (1982) have used a variation of this, where explanations are sought to questions
about the operation of optical filters. Students are asked to write explanations after seeing a classroom demonstration of a torch shone through a red filter. Gunstone and White (1981) use parallel methods to explore undergraduate frameworks of gravity. Again, whole class demonstrations are conducted - this time with falling objects of different mass - requiring written answers from large groups.

Still with notions of gravity, Sneider and Pulos (1981) use a questionnaire with young children to explore gravity in relation to the earth's shape and size. The questions ask for both multiple-choice responses, as well as the completion of diagrams - by showing the trajectory of a stone dropped into a tunnel cut along a diameter through the earth.

Duit (1981), too, uses written responses. His work is conducted using word-association tests to explore students' meanings for terms like force and energy. The associations are supplemented with other test questions and with requests for free definitions for these and related concepts.

This last study raises some further points to round off this section. Firstly, no methodology is unproblematic. Word-association tests, for example, have been roundly criticised. Gilbert (1982) argues that they give no basis for inferring the relationships that students make between words. In this sense they are similar to vocabulary counts, or simple word lists, in that they cannot permit a high level of inference concerning the 'internal world' of the learner. This is a telling argument - essentially word association tests are indicators of performance in a first-
order perspective and, on their own, perhaps cannot be transferred to explore second-order ones. Certainly Duit's work is much enhanced by the additional tests and questions he uses, as he himself notes.

This is a criticism that could be aimed at other methodologies too. Observation alone, as in the S.T.O.S. schedule already mentioned, could fall into a similar trap. To explore second-order perspectives relies on the production of some account by the respondent - an account that must go beyond a simple 'tick response', a direct calculation, or a single-word answer. The request for an explanation, for examples, or for extended descriptions must play an integral part in the task for it to form a basis from which second-order inferences can be made.

Other methods run into different problems. Sutton (1980) argues that clinical interviews, word association tests and repertory grids are all problematic as research tools because of their doubtful reliability and validity, or through being time consuming, or both. Posner and Gertzog (1982) make similar comments about some specific studies using clinical interviews. Both critiques are aimed rather more at the outcomes of the interviews after analysis. However, as the outcomes bear directly upon the conduct of the interviews, the questions and the questioner's actions, then they also reflect upon the interview as a whole. Engel (1982) also argues that interview results have problems in terms of reliability and validity. In this thesis it is argued, that these criticisms are essentially misplaced. To use a Kuhnian expression, these two terms are the product
of another paradigm (in this case, paradigms) and are, in many senses, incommensurable when used in a different research movement. Care and attention does need to be placed on the authentication of research outcomes, however this issue is removed from traditional 'psychometric' definitions of validity and reliability as described in standard psychology texts (for example, Hilgard, Atkinson and Atkinson, 1979). The point to be made is that different research perspectives look to different methodological checks, and not to a re-dressing of the old ones. Such issues, already argued elsewhere (Watts, Harrison and Gilbert, 1982), are taken up again in the last sections of this chapter. First, the methodology and design of this study are to be described in detail.

2.2 The Interview-about-Instances (I.A.I.) Approach

The IAI approach is a development of Osborne and Gilbert's (1979) seminal work. Their own use of the method has been described in a number of reports (Osborne and Gilbert, 1980; Gilbert and Osborne, 1980; Gilbert, Watts, and Osborne, 1981).

In outline, the IAI method consists of tape-recorded dyadic discussions with individual pupils, using a series of pictures as a focus. These are drawings concerned with the central characteristics of a major concept, as seen by physicists. Each picture card depicts a line drawing of a situation which may, or may not, represent an example of a concept. The method elicits a wide range of responses
and, whatever the response, further probe questions are used to explore the response using, where possible, the language of the student.

The situations, or instances, as taken from syllabuses, texts and teachers, and some would lie on the borderline of a physicist's concept, being unusual or unorthodox. A number of the pictures contain a 'dynamic element' that requires the interviewee to make some predictions as to the possible outcomes.

The IAI approach can be subdivided into six distinctive stages, each of which is discussed separately. They are:

i) the 'exploration' and curriculum analysis of the target concept

ii) the generation and design of a deck of 'instance' cards.

iii) the conduct of the interviews in two phases

iv) the transcription and 'editing' of the audio-tape recordings

v) the analysis of the interview protocol

vi) the evaluation of the technique at various strategic points.

Before the discussion of each stage, there are several general points to be made. Firstly, there are two major intentions that underly the approach. It was a primary requirement of the methodology, from its first inception, that it should be readily useable and therefore open to use with a broad sample of interviewees. In reporting the method, Gilbert and Osborne (1980) suggest that it is applicable over
a wide range and is non-threatening to the interviewees involved. Another intention is that it should be sensitive to individual, idiosyncratic perspectives. What Posner and Hoagland (1981) see as a drawback to interviews - students 'unfailing creativity' - is here considered a virtue of the approach.

This second intention is part of a broader issue. From the outline sketch above, and from the arguments put forward before, it can be seen that the method complies with the requirements that might be made of any attempt to monitor second-order perspectives. That is, it allows for, and encourages, the participants to expand on their accounts of the focal situations. Although there are general probe questions available, the interviews have commonly followed lines directed by the lines of argument pursued by the interviewee. The questions are shaped as supplemental, non-evaluative and reflective although clearly the interviewee will construe the questions in personal, individual, ways and develop corresponding answer strategies throughout the session. The interviewer is not (nor is seen to be) a neutral eavesdropper to a dispassionate monologue. The conversation is probed and extended in ways which reflect the interviewer's interests as well as those of the interviewee.

In this sense, the interview operates broadly at two levels; in exploring youngster's hypotheses and conceptions of certain situations, the interviewer is of course, extending and developing his own hypothesis concerning the alternative conceptions the interviewee is adopting. The characteristics of a person's conception are inferred
from what is said, in this way, shaping the approach to subsequent questions and probes. So much is to accept Piaget's (1929) dictum that:

"at every moment he (the interviewer) must have some working hypothesis, some theory, true or false, which he is seeking to check'.

Thus, the methodology can be seen to be coherent with the underlying philosophical assumptions. Pope (1981) describes IAI as being within the 'spirit' of Kelly's theoretical framework; as an approach compatible with the explanation of personal constructions of knowledge.

i) The analysis of target concepts

The purpose behind the analysis of target concepts is to provide a rational basis for the design of the interview cards. At the early stages of the research, this took on an 'essentialist' view: that it was possible to complete an attributional analysis of scientific concepts in order to generate conjunctive or disjunctive sets of attributes. These sets could then be used as the ingredients of situations in the instance pictures. The suggestion was (Watts, 1980) that the conjunction of criterial (essential) attributes would form examples of the concept and that non-examples could be generated by omitting or negating one or more such attributes. This approach trades on the view of scientific concepts as idealised logical entities, and relates to the formal-informal dimension discussed in chapter one. Logical concepts are definitional in that they are defined by the presence of logical rules. The simplest logical concept is defined by the presence or absence of a single attribute:
a vertebrate is defined by its having a backbone, an invertebrate by not having one. By applying a similar analysis (albeit, more elaborated) to the concepts force, energy, heat and light, the intention was to produce similar classes of examples.

This approach has been rejected on three counts. Firstly, the purpose of the cards, and therefore the concept analysis, is to explore the interaction between the informal conceptions of youngsters and the formal concepts of physics. To view that interaction requires a model of concepts that can be applied to both, even at the opposite poles of a continuum. Whereas an 'essentialist' view of category formation is applicable to the (somewhat ideal) principles of a scientific (and formal) language; it is not a satisfying model for the communicative requirements of everyday language (Shweder, 1977). The analysis of the youngsters' transcripts in this study does not rely upon a conjunctive or disjunctive list of elements for their concepts, (in a similar way to Bruner, et. al., 1956) and so an essentialist view of scientific concepts would not provide a compatible theoretical base.

Secondly, whereas an attributional analysis is applicable to straightforward concepts like vertebrate/invertebrate, it is not clear that it applies with equal facility to more formal concepts like force. The process of negating or omitting single attributes becomes more cumbersome as concepts become more complex and less 'perceptible', as Herron et. al., (1980) suggest. The concept of force, for example, is both formal and logically bound in
a complex set of relationships with other concepts in physics. Its attributes lie in formal propositional statements, like those of Newton's first two laws of motion: attributes which are themselves complex concepts like mass, acceleration, inertia, vectors and so on. This opens a door to a morass of circular arguments that, in physics, is resolved by postulating 'fundamental' quantities. These are axiomatic entities, so that the logical structure of physics, in some areas particularly, is based upon a distinct hierarchy and the order for producing definitions becomes important. There is a sense in which it is meaningless to attempt to produce non-examples of force, for example, by 'negating' or omitting inertia. A full description of force would include a description of mass, and therefore inertia, but it is the relationships between the concepts that is the important issue here, not artificial, non-combinations of imperceptible attributes.

Thirdly, at a pragmatic level, the production of the instance cards is geared to an exploration of what Gilbert Osborne and Fensham (1981) call 'curriculum science', and not 'scientists science'. They suggest that 'scientists science' embodies the public concepts of orthodox consensus science. Whether or not such a consensus exists is a moot point. O'Sullivan (1979), for example, points to four distinct conceptualisations of force currently in use. Kuhn's (1970) central thesis allows for the incommensurability (non-consensus) of terms between competing paradigms. Harré (1972) argues that concept of force is 'inessential' to the science of mechanics, which could be reformulated
without it. None of this forbids an attributional analysis of a description of force at this level. It would be, however, removed from the purposes and the debate. Here, it is the characteristic features of the concepts as they are described and organised in common texts and syllabi that is at issue.

The task of concept analysis, then, can be seen as the compilation of a list of descriptors of the concept. Many texts include only the explicit definitions of concepts along with contrived (often numerical) examples, without a general discussion of their many relationships and implications. Here, a descriptor analysis of the concept attempts to make explicit the assumptions that are often tacit, and to recognise the intrinsic limitations placed upon it by its relationship with other concepts in a specified domain. It is by operating outside of these limitations that it is possible to generate non-examples of the concept.

The descriptors are expressed at two levels: a small number are higher level descriptors at a general, more encompassing level of specificity. On the other hand, low-level descriptors are more descriptive, particular and detailed, and often describe relationships between other descriptors. The low-level ones are more easily exemplified concretely and are therefore more easily expressed in pictures as instances of situations. This is similar, but not identical, to Reif and Heller's (1981) use of the term 'descriptor.'

It is an exercise that Lewis (1978) describes as the 'unpacking' of a curriculum area and, in doing so, of
delineating both the implicit and explicit characteristics of central concepts. Kilmister (1981) and Warren (1979) for example, both give useful discussions of the 'concealed implications' of the concept of force. In terms of producing illustrable situations for the instance cards it has been necessary to generate a list of some thirty descriptors of a concept. The difficulty in practical terms has not been in producing that number, but of limiting it.

In their original work, Osborne and Gilbert (1979) suggest that a key problem for the method is how to select a necessary and sufficient set of instances which will clearly explore the:

"theoretical structure of the concept, the attributes of the concept, the relationship between the concept and other concepts... For each component attribute of a concept at least one instance and one non-instance need to be included to specifically investigate student appreciation of that particular attribute.'

By relinquishing an attributional view, the problem becomes, instead, one of clearly exploring the dimensions and boundaries of the concept. A top limit of thirty cards is arrived at, purely from pragmatic considerations. Experience has shown that forty minutes is a convenient length of time for an interview, both in terms of the comfort of the participants and the expediency of class teachers. In that time, students vary in the number of cards they will discuss. Some may linger on no more than six, others will swiftly respond to all provided. This places an importance on the ordering of the cards - an issue that is discussed later.

The eight-step process listed below (a-h) is a summary of working practices (Watts, 1980; 1981):

a) The analysis begins with a derivation and determination
of a number (commonly, three) of different definitions of the concept. For example, force can be defined as 'a push or a pull'; as 'anything which can cause a body to start moving when it is at rest, or stop it when it is moving, or deflect it once it is moving' (Harrison, 1968). It is also 'proportional to rate of change of momentum' (Wehham, et al., 1972), and so on. The differences between the definitions are considered in detail - a process similar to that adopted by Sefton (1980) when examining 'formal' and 'operational' definitions of force.

b) Each of the terms of the definition is examined for notions that 'pervade' them. Seldom, for example, do definitions make explicit statements about inertia when discussing forces. These are supplemented by related concepts from texts and syllabi, in this sense, items that are generally accepted by curriculum planners as forming the basis of courses in physics. For example, force is interrelated with such concepts as distance, speed, velocity, average velocity, mass, etcetera. In practice, these have been schematised in the form of linked diagrams, in the manner described in Dow (1976).

c) Each of the terms and expressions are examined for their ambiguity and opacity. Often, for instance, no distinction is made between force and resultant force, so leaving the term with a duplicity of meaning. An allied concept to force is weight, again, an ambiguous term (Stead and Osborne, 1980). Opacity implies a vagueness of reference: forces are often discussed in terms of 'systems' without that term ever being clearly delineated.
d) Applications of the concept are now listed, how (and if) it can be experienced; detected; measured; in what units; in what usual and unusual situations.

e) The concept is explored in terms of the models and analogies by which it is seen. Schon (1963) for instance, describes the use of forces (of attraction and repulsion) as metaphors to describe interpersonal relationships in psychological theories. Harré (1972) argues that force in physics is itself an analogy. The concept force carries with it the implication of human effort which is transferred to inanimate objects as, in Harré's words, 'an aid to understanding, a device by which intuition is engaged in the business of understanding motion'. The authors of Nuffield Advanced Science (1971) draw an analogy between the tensional forces in a spring with the potential differences in a resistance-capacitor circuit.

f) The descriptors are framed in the light of other studies in alternative frameworks of that particular concept. To continue with the example of force; a number of studies have pointed to a range of alternative frameworks, work by Osborne (1980), Viennot (1979); Clement (1978) and Sjoberg and Lie (1981) for instance.

Because the concepts are all linked together; it becomes inevitable that some of the descriptors would be common to the lists of all the concepts. In this way, the descriptors of the relationships between force and energy would appear on the list for both concepts, for example.

g) The list is elaborated in terms of the applications of the concept in common textbook examples; in everyday
contexts and in unusual situations. Antonyms, synonyms and everyday usage are all examined to delineate and specify the boundaries of the concept.

h) The final part of the process is to order and limit the number of descriptors. The list eventually suggests an order from the higher level descriptors to the low level, often operational ones. As far as possible, the list reflects the emphasis on various aspects of the concept that occurs in syllabi and texts. The results have produced a coherent, unified set of propositional descriptors in terms of higher level generalised relational characteristics and low-level functional ancilliary characteristics.

ii) The generation and design of a deck of instance cards

There is a long history of using pictures in cognitive psychology studies. In this study, they play a central role: they embody some element or elements of the descriptors listed for each concept, and they are the focus of discussion for the respondent in terms of her own explanatory frameworks. In Sless' (1981) words, the cards have the dual functions of focusing the 'author/message' and the 'audience/message'. Both messages, he says, operate within a 'framework of assumptions and expectations.' Moreover, he argues that there is no logical basis for presuming that there is necessarily a nexus between the two:

"They represent two worlds in which the only unconditional similarities are the physical form of the message and the humanity of the participants."

There will be ample examples from the interviews to follow, to show that any link between the author's message ('curriculum
(science') and the students' framework is tenuous indeed. This is an important point. If this study had been conduced within an 'associationist' philosophical perspective, the 'associations' produced by interviewees would carry implications stemming from the assumptions and expectations of that stance: in some cases stimulus-response contingencies might be investigated, or whatever.

To adopt a constructive alternativist position is to emphasise the interpretation of events, where 'events' in this case mean the presentation of line drawings during an interview about physics concepts. It is this process of interpretation and reinterpretation - as a person tries to encompass his inner and outer worlds - that is of importance (Swift, Watts and Pope, 1983).

Bannister and Mair (1968) make the point that the essential reason for developing personal constructions in this way is anticipation: for 'the better understanding of future events.'

The design of interview cards, then, takes on a third role. Not only do they focus author and audience messages, they also allow for the expression of anticipation within a person's constructions.

From a 'repetory grid' point of view, the cards might be seen as 'provided elements' in order to gather information about an individuals views on a particular topic and to make comparisons between a number of people's viewpoints. Incidentally, here their grid-like qualities end - a point that is taken up at the end of this section. When
Pope and Keen (1981) discuss the use of provided elements for these two purposes, they make the point that the elements should represent a range of events which can be construed by such people.

In practice, and by its very nature, the design of the cards is a mixture of art and science. The examples are based upon the descriptors and use is made of contemporary studies, as suggested, as a source of possibly challenging situations and borderline cases.

Osborne and Gilbert's (1979) suggestion of producing at least one instance and one non-instance for each descriptor is almost impossible to accomplish. As an illustration, it is not possible in principle to have 'negative' energy and there are only some very specialised instances where there might possibly be zero energy. Therefore, in using instances that fall within the reference of the students to be interviewed, design is immediately limited to positive examples. In developing non-instances in this case, it has been more meaningful to extend the intrinsic limitations placed upon a concept by its relationship with other concepts. That is, to seek instances outside the orthodox curriculum science range-of-convenience for the concept. Some examples of the instance cards for force are shown in figure 2.24; the full range of cards is shown in appendix I.

The style of the drawings retains that initiated by Osborne and Gilbert's (1979) original study. 'Stick-People' are represented in various situations and objects.
A golfer hitting a golf ball. Are there any forces here?

Walking along with a balloon. Are there any forces here?

Two similar torches. Has one more force acting on it than the other?

The astronaut has tripped over a crater on the moon. Are there any forces here?

A book lying on a table. Are there any forces here?

Diving into a pool. Are there any forces here?

Figure 2.1: Some Examples of the Force Cards
are drawn in outline. Some small amounts of shading and highlighting are used to add perspective, to show substance and suggest motion. The choice of line drawings over, say, photographs or sample laboratory equipment has been a matter of pragmatism. Line drawings allow considerable control of content as in the representation of concepts for which there are no perceptible instances (Herron et. al., 1979), or in the presentation of a conceptual model (like a model of an atom). Further, they allow for the omission of any extraneous detail and context present in photographs and are both portable and less susceptible to the frailty of laboratory equipment. Spaulding (1956) and Paivio and Csapo, 1973) both suggest that illustrations that are intended to convey specific ideas appear to be more effective if they are simple: not making too large a demand on the interviewee's handling of information. Paivio and Csapo suggest that the number of specific features in a fixture are inversely related to the level of abstractness of responses.

A further consideration in the design of the cards has been the logistical ease of application. In contrast, a range and variety of practical laboratory equipment would require a high degree of involvement and investment of resources at school level - involvement that may have not been so readily available as the release of an individual student for a single-period interview.

Finally, the type of line drawings described here are seen to fit well within a broader educational setting.
Whether in books or on blackboards, pictures are used to inform, instruct, exemplify, motivate and stimulate.

Students are taught to draw and to recognise drawings as aids to comprehension (Lindstrom, 1980) and in order to be more skilled at expressing their ideas (Tough, 1976).

iii) The conduct of interviews in two phases

The interviews are commonly 35-40 minutes in duration, each conducted with a student taken from a science or physics lesson, in a nearby laboratory or preparation room. They are private and anonymous to the extent that no one in the school is present at the time, or hears the tape. Discussion with teachers about students is kept to a superficial minimum, and comments like 'she seemed very interested,' 'he was very pleasant and chatty' are the norm. The task is introduced conversationally as a request to 'find out how people use a particular word', along with the emphasis upon there being 'no right or wrong answers'. Permission is sought to record the discussion and some indication given of how the recording would be used. At the end of the session the interviewees are invited to ask questions about either the subject matter of the discussion or the conduct of the exercise. Some have taken the opportunity to listen to parts of the tape and add their own comments.

From this description, it can be seen that this type of interview lies somewhere between a 'rapport' and a 'depth' interview as suggested by Massarik (1981). There is an attempt to engage the students interest in an informal discussion where the focus of the interview can be altered
and rescheduled by the interviewee. This is not always successful because, whereas the interviewee is a volunteer, the constrained context and social milieu do not permit a fully informal debate on equal terms. On the other hand, it bears little resemblance to the highly structured survey interview of the type described by Brenner (1982). Some virtues and disadvantages of the IAI interview have been discussed by Bell and Osborne (1981) and Watts, Harrison and Gilbert (1982). As Powney (1982) points out, partially structured interviews offer the interviewer considerable flexibility so that the direction of the interview may be determined by the interviewee's responses.

In this study, the interviews are used in two stages. The first stage is the pilot stage for a particular deck of cards. It is at this point that feedback is used to make adjustments to the drawings, the selection and the order of the instance cards. This permits the use of youngsters' own examples and non-examples (where appropriate). More importantly, it allows for a selection of cards that 'work' - that is, promote lengthy and varied discussion. In their own use of a deck of IAI energy cards, Pope and Gilbert (1982) assess them in terms of the 'fruitfulness' and the 'level of interaction', the cards produce. The cards that produced extended discussions between youngsters (in the absence of an interviewer) tended to be multi-faceted: they had a number of aspects in them to be tackled. These were not always the cards that produced the greatest number of interactions (interpretations, challenges or argumentative strategies) during the same sessions.

In this study, the initial drawings were produced on A6 card. During trials work, it was suggested that some
students might like to amend or expand upon the theme of the drawings. This implied a 'consumeable' set of drawings, so that the final format has been on A5 paper. Some students have taken advantage of this, and have, for example, placed arrows on the drawings to indicate the forces present. An example is shown in figure 2.2.

A second purpose of the pilot phase has been to establish an order for the cards. Given that some interviews would make use of only a few cards, the first cards in the deck are required to be productive in terms of protracted and varied talk.

A contrasting requirement has followed a general criticism from co-researchers who suggested that many of the cards might not explore some of the more abstract boundaries of the target concept. Such discussions have led to a three stage ordering, as follows:

Card No.

| 1,2 | Obvious, stereotypical examples | S |
| 3  | an obvious non-example       | T |
| 4,5 | obvious examples             | A |
| 6  | a non-example                | G |
| 7,8 | two examples                 | E |
| 9  | non-example                  | 1 |

At the end of this stage, which for some might be the end of the interview, students are asked for their meaning of the word-label for the target concept: - force, energy, or whatever. Then: Cards 10 - 17 feature novel instances and borderline cases. Interviewees are also asked for their own examples of the concept. This is the second
In this example, the arrows were added during the interview by an 18 year old 'A' level student.
stage. The third stage, cards 18 - 24 are comprised of 'difficult' examples and non-examples suited to exploring the more abstract boundaries, as suggested. When confronted with these cards, the younger pupils in Pope and Gilberts' (1982) study found them problematic, both because they were unsure of the meaning of the drawings and of the written description. These instance cards clearly fell outside of the range of elements that the respondents were able to construe.

In designing cards it is sometimes possible to duplicate cards on the same descriptor, or for some cards, to be seen as duplicates from the respondents point of view. The initial phase of interviews allows for a selection process to take account of this. Examples of duplicated cards in the first draft are shown in figures 2.3 and 2.4.

The second phase of interviews has been less responsive than the first. A settled deck of cards becomes more common and changes less frequent. These interviews constitute the bulk of those conducted and follow the experimental procedures described in the next section.

iv) The transcription and editing of the audio-tapes

Methods of transcription are not uniform. Different research areas require varying degrees of completeness in the transcribing of taped interviews. In this case, it has been considered important to be as accurate as possible as far as the content of the speech is concerned. A representation of intonation or pitch has been relatively unimportant unlike, say, in the work of Wells (1981). The role of the transcriber has been to provide a faithful account

2.31
Figures 2.3 and 2.4.

Examples of cards in the early stages of the Pilot Study. These two cards were seen as duplicating similar ideas.

**Figure 2.3**

Two identical irons

This one is hot

This one is cold

Which iron has the most force acting on it?

**Figure 2.4**

Two torches. A is switched on

Which torch has the most force acting on it?
of the interviewee's speech and stress, in a manner that allows for subsequent annotation and addition of detail. In circumstances where talk is barely audible, or comes together and accuracy is difficult, a system of symbols are used to indicate partial words, 'best guesses' and transcriber's doubt (Watts, 1980).

The majority of tapes used in this study have been transcribed by someone other than the interviewer, but have then been 'edited' and annotated by the interviewer/analyst at a later stage. This two phase approach has been described elsewhere (Watts, Harrison and Gilbert, 1982). During the editing stage, the interviewer/analyst makes use of other material (interview notes, interviewee's drawings, supplementary comments) to annotate the transcript.

The transcripts are not punctuated in any normal way, and the speech not divided into sentences. The typescript occupies the centre of the page, leaving large margins for notes. Each separate utterance is numbered, and occasionally, numbers are included off the tape-recorder to allow swift reference back to the tape. An example interview transcript is included in appendix II.

Both the transcribing and editing of tapes is clearly an interpretational activity: it is virtually impossible to write down or annotate everything that is transmitted by speakers. What is written is inevitably selective.

v) The analysis of interview transcripts

Following on from above, the inevitable subjectivity
in transcription leads directly to the inevitable subjectivity of analysis. As constructive alternativism would suggest, the interpretation of data is open to a range of hypotheses and constructions. Clearly, when allied to a reflexive attitude, this approach implies that the very processes at issue - the use of explanatory frameworks by young people - applies equally well to the researcher as to the researched. The basis of this work assumes that the youngsters interviewed are guided and constrained by their own conceptions. In a similar way, the analyst's own conceptual frameworks play a similar role whilst preparing and interpreting the resulting data.

Seldom are the details of analysis made explicit in journal reports, often for editorial reasons. A review of methods of analysis might founder for that reason. Interesting exceptions are Konold and Well (1981) and Posner and Gertzog (1982). Both report broadly similar methods, of condensing reported talk to manageable units on a case-by-case basis. Posner and Gertzog report work by Pines (1977), who calls his system of analysis 'conceptual propositional analysis'. This essentially involves transforming all of an interviewee's responses into propositional statements that are independent of the questions that produced them. These are then analysed against a range of criteria like relevant/irrelevant, surface/deep and so on.

Two serious limitations to this propositional approach concern, firstly, the assertive nature of propositions and secondly, their supposed independence from questions. Frequently, the responses made by interviewees are made tentatively,
or are offered as hypotheses. This represents a lower level of communication in their statements than that produced by a 'disembodied' propositional statement drawn directly from the transcript and then attributed to the interviewee. In some cases, the interviewer will summarise a discussion and offer the summary for comment: 'I understand you as saying... was I right?' Again, agreement with the interviewer's summary cannot properly be made into a propositional statement attributed to the interviewee.

An important point Pines (1977) does make is that 'almost any child interviewed will exhibit responses characteristic of many categories irrespective of the category system used.' Here, such diversity of response is taken as being entirely consistent with a constructive alternativist view.

Elements of this analysis are based on Giorgi's (1975) protocol analysis (Watts, 1980). The goal is to develop descriptions of students' conceptual frameworks powerful enough to encapsulate individual differences and yet not so specific as to have as many models as there are students.

The first step begins with the 'editing' of the tape - a careful reading of the raw typescript. It is at this point that some decisions are taken as to what the interviewee is trying to say about the concept or the instance in question. Discussion of one instance, or of a particular idea might extend from one utterance to long protracted 'episodes' (Pines, 1977). An episode can thus be seen as dialogue that relates to some specific topic. The interview can be separated into a number of such episodes, commonly
where the discussions centre on, or returns to, a particular card. Possibly, within a single episode, a respondent might adopt or display a range of alternative frameworks.

The frameworks are first established as tentative, temporary statements: hypotheses concerning the perspectives of an individual. Taking a first transcript the hypotheses are posed as questions, which are then tested on the next transcript. Here, some will be confirmed, some are left open and yet more are formulated from the second transcript. This complex of hypotheses is now visited upon a third transcript with the same effect. The models that are being developed are now taken back to the first two transcripts and the procedure repeated - a process of redressing and reshaping that is a continuous cycle as more and more transcripts are drawn into the pool. This is similar to the procedure reported by Konold and Well (1981), and Piaget's (1929) concern for hypothesis testing. He also says that the researcher

'must in fact make up for the uncertainties of the method of interrogation by sharpening the subtleties of interpretation.'

The more tentative frameworks of early interviews grow or shrink in status as progressively more and more interviews are analysed.

Two further points need to be made. Firstly, it is necessary to treat each response in the transcript seriously, unless flippancy or humorous intent is signalled by either participant. Secondly, all responses have to be accounted for in some way. Some seem illogical or inconsistent when juxtaposed with other statements by the same person. However, as Sinclair and Coulthard (1975) suggest, it is unacceptable to ignore or discount some statements simply if they prove
awkward and fail to fit categories. These points are taken up later in the discussions of individuals' use of frameworks.

The suggestion here is that the most confusing or inconsistent responses may be the very ones to temper initially clear cut models. Moreover, the conjunctives used by the interviewee, their pauses and anacolutha, can be used alongside explicit statements to mark changes in the frameworks being adopted. In practice, the problem has not been in generating hypotheses, or more stable frameworks, but in limiting the number. This process is an attempt to draw a balance between generalising frameworks beyond the individual yet retaining specificity.

The analysis has been conducted with these main features in view. Firstly, of establishing frameworks pertinent to particular concepts across all of the interviews with a single set of IAI cards. That is, of developing a limited number of frameworks for each of the four main concepts. Secondly, patterns of frameworks are sought at each of the three age bands described in the next section. Thirdly, the coherence of frameworks is considered by using a small number of transcripts as case studies. These case studies are conducted using transcripts chosen from the main body of interviews, though primarily using transcripts from students who have been interviewed on more than one, or in some cases all four, of the major concepts. In this way some of the answers to the central research questions may be reached.

2.37
iv) The evaluation of the technique at certain points

During the course of the stages described so far, a series of checks are made on the procedures as they are being undertaken. Commonly these have been with co-researchers and colleagues, sometimes with teachers in schools, sometimes with students during interviews.

The eventual list of descriptors produced as part of the concept analysis has been assessed and criticised in this way. All four lists have been considered at some point by co-researchers, particularly Dr. Arden Zylbersztajn, whilst the energy and force descriptors have been commented upon by Dr. Ian Sefton (Department of Physics, Sydney University, Australia) and heat and light by Professor Will Graben (Department of Physics, Clemson University, U.S.A.). Some attempt, also, has been made to adopt a list of descriptors consistent with the 'list of concept areas' produced by the Assessment of Performance Unit (D.E.S., 19%).

Individual cards used during pilot interviews are evaluated along criteria similar to those adopted by Gilbert and Pope (1982). As has been suggested, these are based upon the fruitfulness of the card to produce varied and protracted discussion, as opposed to a cursory or summary dismissal. The order of difficulty of both the examples and non-examples was also decided at this stage. Again, colleagues were asked to comment about cards as the pilot stage ensued.

During the course of developing the methodology questions have been raised concerning the role, and effect, of the interviewer. Gilbert and Pope (1982) study has been
very illuminating in approaching these issues. In their study, groups of younger students (12 year olds) discussed IAI energy cards, some with and some without an interviewer present. They observed that in all of the groups there was an increase in the number of 'dialogue interactions' which occur when the interviewer is present. They suggest that this is due to the interviewer's use of direct questions; using non-directive, reflective techniques; the use of summary statements similar to the example in the analysis section above; and of directing the discussion towards individual students. The greater incidence of 'dialogue interactions', however, did not necessarily result in a greater number of explanatory frameworks being displayed.

Two more points need to be made in this section. Firstly, the evaluation of the analysis and the research outcomes is discussed in the final section in this chapter, and is not covered here. Secondly, the methodology as described is clearly unlike the 'repertory-grid' techniques commonly associated with constructive alternativism. The increased use of grids over recent years has not been unproblematic. As Pope (1981) suggests, some researchers have been unconcerned by the detachment of the technique from its theoretical base. Using Marton's (1981) terms, this could be seen as using a second-order method to gather first-order data. This lack of compatibility between theory and method, (for example, the use of grids as a 'definitive' measure of people) has perhaps marred their use (Watts and Pope, 1982). Whatever their misuse by others, however, bears only slightly on the decision not to use them in this
study. Primarily, this stems from the primacy of Osborne and Gilberts' (1979) methodology in the initial design of the study, and of the inappropriateness of a bipolar, dichotomous rating system for use on polythetically designated concepts. The disparity between concepts and constructs already discussed has pressed for a broader methodology.

2.3. The Research Design

In this study, twelve main groups of students have been interviewed. Each of the four IAI decks has been used with three major age-bands: 13-14 years; 15-16 years and 17-18 year students. These ages cluster around three secondary school year groups: third year, fourth year, and lower sixth. Each group has been labelled as shown in the table in figure 2.4.

<table>
<thead>
<tr>
<th>Concept Year group</th>
<th>Energy</th>
<th>Force</th>
<th>Heat</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd. yr. band</td>
<td>3E</td>
<td>3F</td>
<td>3H</td>
<td>3L</td>
</tr>
<tr>
<td>4th, yr. band</td>
<td>4E</td>
<td>4F</td>
<td>4H</td>
<td>4L</td>
</tr>
<tr>
<td>6th. yr. band</td>
<td>6E</td>
<td>6F</td>
<td>6H</td>
<td>6L</td>
</tr>
</tbody>
</table>

Figure 2.4

A small number of students have been interviewed on all four target concepts; some on two or three of them. The majority in each group have been interviewed only once with just one deck of IAI cards. The age range in each group is not exact. A strict record of age, in years and months, has
not been considered important: rather, it is the 'year' of schooling that has dictated groups. The conduct of the interviews has spanned a three year period and so, in following up some students for further interviews, they were to be found in different year groups. Those interviewed in the early part of the fifth year, for example, have been included in the fourth year band. Those in the early throes of fourth year work have been included in the third year band.

Such a school-year grouping is fairly arbitrary in many ways: obviously the age difference in any one year can span twelve months. Nor have all students followed identical syllabi to allow the suggestion that a year's schooling is somehow uniform or standard. Students have been interviewed from general science classes at third-year and physics classes at fourth year and sixth year. In many schools no formal distinction is made at fourth year level regarding the proposed examination entry of students. Students due for entry to both O-level and CSE-level examinations follow an identical course, and are entered for separate examinations after tests, some four months before the examination date. That is, over mid-way through the fifth year. This means that there is a wide variance in the levels of achievement of the students in both the third year and the fourth year band. The sixth year band is considerably more homogeneous in that all students are prospective A-level candidates.

The sample can best be described as an 'opportunity' sample based upon availability and ease of access within
the secondary school system. Commonly, schools and teachers are reluctant to release examination year students, even for short periods of time, and so the groups chosen represent those seen as most available for interview. During the early stages of research, some interviews were conducted with younger pupils at the end of primary schooling and in the first two years of secondary. In many ways the groups reported here are more interesting. During the third year of secondary school, students are required to opt for subject choices to follow in the fourth and fifth years. That is, they are in the process of moving from physics as a compulsory subject to it as a selective one. Many will not opt to do physics, some will choose to do no science at all. Arguably, the conceptions they hold to at this age will form the basis for those they will carry forward into adult life, with little or no influence from formal science teaching.

At fourth year, they are meeting formal instruction in physics concepts and are in the process of weighing newly introduced physics concepts against their own previous ones: of, possibly, giving up (or ammending) one conception for another. At sixth form level, they are seen as having been successful students, for whom this is their second time of choosing to study physics. That is, they might be more willing to identify with matters scientific, and may be aware of incompatibilities between their own frameworks and those of orthodox science as Posner and Gertzog (1982) suggest.

In all, some 210 interviews have been conducted.
Not all of those are reported here in detail, some were more to enhance the interviewing skills of the interviewer, others were part of the phase I of interviews. Here, only phase 2 interviews are discussed - those that have taken place with a settled deck of IAI cards. The division in each group is largely equal between males and females, to within one or two interviews in each case. This is not so at the sixth form level where the number of girls studying physics A-level is considerably less than the number of boys. Here, the ratio is roughly two-thirds male to one-third female. The numbers in each group are shown in figure 2.5.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Energy</th>
<th>Force</th>
<th>Heat</th>
<th>Light</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 3</td>
<td>10</td>
<td>15</td>
<td>9</td>
<td>9</td>
<td>43</td>
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<tr>
<td>Year 4</td>
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<td>14</td>
<td>11</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td>Year 6</td>
<td>10</td>
<td>14</td>
<td>9</td>
<td>8</td>
<td>41</td>
</tr>
<tr>
<td>TOTALS</td>
<td>34</td>
<td>43</td>
<td>29</td>
<td>28</td>
<td>134</td>
</tr>
</tbody>
</table>

**Figure 2.5**

The total number of interviews to be reported here is 134. Of these, four students have been interviewed with all four IAI card decks, three students using three of the decks and ten students on two decks. Initially, the intention was to interview more than four students with each deck, however, some of those interviewed on three decks were earmarked for four but were later unavailable for interview. This was either because they had subsequently moved from
the school, or were unavailable within the school due to exam work and so on. The spread of 'multiple' interviews of this sort are shown in the table in figure 2.6.

The large majority of interviews have been conducted in comprehensive schools in the Greater London area. A full list of schools is shown in appendix IV. Schools have been chosen for their willingness to cooperate with the venture, to release students for interviews, to provide a quiet space for recording and generally, to tolerate interruption to their working life. Some schools have been extremely generous in their time and, clearly, each of the 'multiple' interviews using several card decks have been conducted in a school where return visits are welcomed.

Interviews using:

<table>
<thead>
<tr>
<th>Decks</th>
<th>E.F.H.L.</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 decks of cards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 decks of cards</td>
<td>2 E.H.L.</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1 F.H.L.</td>
<td></td>
</tr>
<tr>
<td>2 decks of cards</td>
<td>4 E.L.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 E.H.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 E.F.</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1 F.H.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 F.L.</td>
<td></td>
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*Figure 2.6*

2.4. Methodological Checks

Simons (1981) suggests that research reports commonly fail to discuss interview practices on the grounds that interviewing is seen as an idiosyncratic, interpersonal process that is not susceptible to systematic analysis. She makes the point that

'We must begin to discuss the problems we experience in practice, however self evident, situation specific or limited when restricted to the written word they may seem.'
The type of interviews, and interviewees, described here present their own kind of problems. The interviews have been individual, informal, almost conversational and without a fixed question schedule. They have been structured by the expectations of the school environment, the perceived status of the participants, a list of guideline questions and the control exercised by the interviewer over the occasion. The majority of interviews represent a first time meeting between participants. None of the 'multiple' interview students expressed any reluctance to repeat the operation, or to be audio-taped. All of those who have participated in three or four interviews did so willingly, were eager volunteers.

As interviews progress, informal frameworks produced and derived from earlier interviews feature later as the interviewer's hypotheses. Konold and Well (1981) make the point that:

'It is this ability to revise and test hypotheses during the process of data collection which constitutes the greatest strength of the in-depth interview. However this fluid, ongoing exchange between hypotheses and data is the very characteristic of the in-depth interview which can make it difficult to evaluate the validity of the research.'

Traditionally, questions of validity and reliability have been concerned with the extent to which a test actually measures the entity which it was designed to measure, and the extent to which a test gives the same result when applied by different people or on different occasions.

Reason and Rowan (1981) argue that there are many different sorts of validity, that it is a relative measure and that:
'any notion of validity must concern itself with the knower and what is to be known: valid knowledge is a matter of relationship'.

Between these two positions, the traditional approach and Reason and Rowan's 'new paradigm', it is possible to find a variety of stances and opinions on the issue. Stenhouse (1978), for example, argues that validity is to be found in the relationship between interpretation and evidence, and the justification of research outcomes is characterised by appeals to the reasonableness of interpretation based upon publicly accessible forms of evidence. Kushner and Norris (1981) argue for a process of negotiation between the participants in the research, a position similar to that put forward by Terhart (1981).

For the purposes of this research, the essential aspects of the arguments would appear to be as follows: An appeal to the reason of evidence (as in Stenhouse's case) is clearly unsatisfactory given a constructive alternativist theoretical basis. Any data is open to a wide variety of interpretations, each of which is arguably as reasonable as the other, dependent upon the viewpoint of the interpretor. Nor is it simply sufficient to make public the interpretations alongside the 'evidence'. Whilst this is a necessary step, it fails to take into account the presence of audiences. The question of 'for whom is the research valid' needs to be addressed. Elliott (1980) has argued that such research can only be validated by the participants involved in the study. He maintains that it is necessary for the researchers and participants to reach agreement by a 'free and open dialogue' as to what a truthful description of the researched would be.
This seems to miss an essential point. Research results offered to a wide audience can expect to be evaluated against a wide variety of diverse criteria. In any ensuing debate, particular audiences ought to be able to base opinions on a reading of the methodologies, the circumstances, conclusions and implications. As Powney (1982) suggests, there should be no areas in which it is uncertain what was done. In this way, the possibility is open for interested people to generate alternative explanations of the data, with an exchange of views and the possibility of a richer understanding. This is not an argument for a consensus agreement between all involved. Rather, the point is that participants in the study, the users of the information and an audience of informed critics can relate to the description and analysis - a point that Patton (1980) makes.

In this context, these three audiences can be seen to be the students who have been interviewed, science teachers in schools, and research colleagues. The particular methods, and their evaluation, are discussed in chapter 7. In outline, their purpose is twofold. The first is to explore the popularity of, and generalisability of, some of the frameworks with different groups in different contexts. Secondly, to present thumb-nail sketches of the frameworks alongside sample quotations and example instance cards, for the critical scrutiny of each of the three audiences mentioned.
2.5. **Summary**

To summarise this chapter is to make the following points. The discussion has dwelt upon many methodological issues and has argued that the methods of this study are exploring a second-order perspective; one that explores the internal world of a person. Such a methodology, for generating and examining interview discourse, must be sensitive to individual, personal constructions of events and to a theory of conceptual-change processes in people.

The Interview-about-Instances approach has been detailed along with some 'ongoing' and 'final form' methodological checks. The preparation and presentation of a research report has audiences in mind for whom the outcome should be credible in the circumstances; sensible, in that they can be interpreted in a meaningful way, and functional in some sense, if only as a basis for debate.
CHAPTER 3

PUBLIC KNOWLEDGE, PERSONAL SCIENCE

Section 3.0: Introduction
Section 3.1: Classical concepts
Section 3.2: The four concepts
   a) The energy concept
   b) The force concept
   c) The heat concept
   d) The light concept
Section 3.3: Organisation and fragmentation of constructions
3.0: Introduction

This chapter enlarges on some of the issues raised in chapter 1. In that chapter, a traditional (paradigm 1) view of concepts was rejected in favour of a continuum that stretches between personal conceptions and public concepts. Moreover, the rigid 'logical' nature of concepts was rejected in favour of a looser definition in terms of a 'stable organisation'. The point of this chapter is to introduce in some detail the four public concepts of interest: energy, force, heat and light. They are important concepts in physics and between them encompass a web of interrelated ideas. They have been chosen because they are interrelated and, in the context of this study, the relationships bear scrutiny alongside the concepts themselves. As has already been argued, concepts are not to be seen as singular entities but take their meaning from their relationship with other concepts. School students meet physics concepts in a reified form - as being both incorrigible and inconvertible. It is (largely) in this form that they are presented here - as the 'public' concepts of physics. The point of interest is the intersection of the public and the personal: between the seemingly impervious physics concepts in a public knowledge system and the personally constructed conceptions of young people. It is a juxtaposition of agreements about 'what is the case' with a plural world of 'beliefs about what is the case.'

Clearly, when students conceptualise energy and force in individually different ways then they will conceptualise
the link between the two in different ways as well. It is entirely possible that a student will see no necessary overlap between the ranges of convenience for their conceptions of force and energy. Nor any overlap between heat and light, light and energy, force and light and so on.

It is an underlying theme of logical and psychological coherence that is discussed in this chapter. Having left the description in terms of conceptions and mini-theories in chapter 1, it is now useful to consider how these might be related. It has been argued that conceptions embody expectations and are therefore predictive. There are three points at issue, which are:

a) In what sense are 'conception' and 'theory' synonymous?
b) In what sorts of ways might personal conceptions be organised?
c) How are both of these issues to be seen from within the spirit of Kelly's (1955) work?

The first section discusses the four main concepts in general terms and the criteria for choosing these particular concepts. The second section deals with the four concepts separately and a selection of the most recent literature on students' conceptions is reviewed for each one. The final section takes up the issues just mentioned: about the order and structure of personal theories within a Kellyan perspective.
3.1: Classical Concepts

It has already been suggested that the four concepts energy, force, heat and light have been chosen because they are interrelated. Energy and force are most commonly related through the concept of work, heat is defined in thermodynamics as the energy that moves from one point to another because of a temperature difference; whilst light and energy are related through Planck's constant and, of course, the famous $E = mc^2$ expression.

These four concepts are 'classical' concepts in three separate ways. They are concepts at the very heart of the history of physics and so are classical in terms of their acknowledged importance and value. They are classical, too, in the sense that they are discussed here in their pre-relativity form; primarily as classical mechanics and optics. The reason for this emphasis is that this is the way they are presented in curriculum materials, with the exception of some (later) sections of some A-level courses.

They can possibly be seen as classical in a third sense, too. They are commonly placed at the 'formal', 'abstracted', logical ends of the dimensions described in chapter one and so would be, in Smith and Medin's (1981) terms, part of the classical view of concepts. This classical view suggests that every concept has a set of necessary and sufficient features. Warren (1982), for example, says of energy that it is a very 'abstract' idea, a very 'advanced' concept which can only be understood if the student has first mastered several difficult basic ideas (particularly force, work and conservation) and has extensive knowledge of elementary physics. He goes on to say that the only way...
to overcome difficulties in learning the concept is to teach it 'logically' to students who have been properly prepared. Leaving aside matters of instruction for a moment, and Warren's own view of matters, the classical view illustrated by this example is closely aligned with the positivistic philosophy of science (Newton-Smith, 1981). In this perspective, the theories and concepts of science are conceived of as being organised only according to the canons of deductive logic, the logic of mathematics and taxonomy. As Harré (1972) maintains, the most important consequence of the positivistic view is that concepts which appear only in theory are construed as having meaning only by virtue of their position in the theory - as logical devices. Moreover, these are separate and distinct from the observational entities commonly experienced. 'Classical' in this sense, then, is part of the paradigm 1 tradition.

The influence of the philosophy of science upon science education is tenuous: in schools a single paradigm (in a Kuhnian sense) is commonly accepted as being the case (Cawthron and Rowell, 1978; Gilbert and Swift, 1981). Not that this need be the situation, as has been argued by others (Pope and Keen, 1981; Watts and Pope, 1982). A philosophy of constructive alternativism underpins a relativistic stance as has already been argued. However, the 'curriculum science' (Zylbersztajn, 1983) described in the next section, and taken from current curriculum materials, is of the 'old school'. As Schofield (1982) remarks, school-science is:

'seen to have the answers... plurality is thought of as being untidy, unrewarding and epistemologically disreputable.'
Before moving on to discussing and reviewing the concepts themselves two further points can be made. Because of the dailience of positivistic thinking in curriculum materials (O'Sullivan, 1980) differences in interpretation of theories and concepts, or disputes about conceptual coherence or theoretical emphasis, are seldom raised. Very often textbook readers are not informed that alternative viewpoints are possible. That there are differences of opinion and emphasis is worth a passing note. O'Sullivan for example, notes that, upon a closer inspection of textbooks, it can be seen that the conceptual structure within which Newton's laws are interpreted varies considerably. He presents four different 'pictures' of Newton's laws which he concludes are equally valid in that no one picture can be a more 'correct' viewpoint than another. Kilmister (1981) also makes the strong point that the 'hidden' implicit assumptions underlying the concept of force are seldom made explicit in school texts. Within the science education journals, it can be seen that protracted debates have taken place around a number of terms, for example, weight, (McClelland, 1975; Iona, 1975; Brown, 1976, etcetera) and energy (Warren, 1982; Richmond, 1982) and so on. These serve to illustrate that the seeming consensus surrounding such curricular concepts is sometimes frayed.

The second point concerns the choice of concepts: around the concept of energy. There are two reasons for the choice as follows. Firstly, it is important for the concepts to have some formal relationship between each other rather than, say, be logically unrelated. Engel (1982),
for example, considered the rather disparate concepts of evolution, heat and pressure. Whilst these are both profitable and interesting areas to explore, the added possibility of the concepts being interrelated by students is worth developing. For this to happen, though, as Pope and Keen (1981) indicate, the topics and the situations under discussion must span the range which might be reasonably discussed by the participants concerned. There is no logical necessity that students will link the concepts together in discussion, but because of their curriculum 'proximity', the possibility is open.

This possibility is enhanced by using similar cards in different interview decks and by the interviewer using the opportunity to probe distinctions between terms. The decks of cards that have cards in common are of particular interest where a student is interviewed on more than one concept. Comparisons are made on their responses to the same card from different frameworks.

Secondly, the concepts are linked to energy because of its uniquely central position as a unifying concept in major areas of physics. Giancoli (1974) says of energy that:

'It is a unifying principle and helps to bring order to the natural world. Today many physicists feel that conservation laws are the most basic laws in nature. Therefore it may be that the law of conservation of energy is more basic than Newton's laws themselves.'

This echoes Freeman (1968) who says of the conservation of energy, that it is:

'without question the most significant and far reaching generalisation in all classical science.'

This significance is not lost on curriculum planners
and a brief survey of a selection of ten examining board syllabuses (Watts, 1982) shows it to be a major topic on each one. Energy features, too, in current curriculum proposals at national level as embodied in Department of Education and Science advice (D.E.S., 1982) and common 16+ examination criteria (Joint Examining Boards Committee for 16+ criteria, 1982).

For these reasons, then, of prominence within physics and prominence within curriculum material, energy is taken as a thematic basis for choosing concepts. The following sections describe the concepts and relevant research studies.

3.2: The Four Concepts

The four concepts are discussed separately in the order energy, force, heat and light.

a) The energy concept

The term energy derives from the Greek 'energia' meaning activity, and is noted as coming into general scientific use in the late nineteenth century. Elkana (1974) credits Helmholtz with formulating the essential features of energy conservation somewhat earlier, in the middle of that century. Earlier, conservation laws of sorts were in operation based upon the work of the mathematical physicists or upon metaphysical commitments. Leibiz in 1686, for example, proposed a finite quantity of 'force' in the universe. This took the form of 'vis visa' in moving objects, or 'vis mortua' in stationary ones. The latter
was possessed by objects with the property of position or deformation that allowed it to produce vis visa.

In school-science, energy is described as the capacity to do work. At the year three level it is often shown in terms of 'energy chains' whereby the different forms of energy are connected (sometimes by arrows) to show their successive changes (for example, in Lewis, 1977). The examples often cited include 'light energy' to 'heat energy'; 'chemical energy' to 'electrical energy'; 'mechanical energy' to 'sound energy' and so on. In years four and five this approach is continued with the added use of symbols and calculative manipulation (at O-level and sometimes at CSE level). This is the case in Nelkon, 1971; Johnston, 1980 for example. At A-level, the concept is commonly approached at a more formal level in terms of conservation; work; energy interchanges; power and the laws of thermodynamics (for example, in Wenham, 1972; Whelan and Hodgson, 1978).

In the early years, the terms work and power are seldom made explicit. Lewis (1977), for instance, talks of 'jobs of work' (hereby retaining the common everyday use) and of power stations and 'electric power'. Even at years four and five it is not always the case that work and energy are fully distinguished - energy as a quantitative measure of the condition of a system, and work as a process. Lehrman (1973) argues strongly against the common practice of providing pithy one-sentence definitions of energy in school science (like 'energy is the capacity to do work') because they fail to do justice to the complexity of the concept. In his words:

3.8
'... if it is not possible to write a satisfactory definition in a few words we will have to learn to get along without any such neat package.'

There is considerable debate about the teaching of energy in schools and the level at which it might be taught. Warren (1982), for example, argues that teachers should eliminate the word entirely from early science teaching, that it should appear only in advanced work and then be based upon a rigorous definition of work. He argues against a background of recent research that has explored both curriculum approaches to energy, and students' interpretations of it. There are a number of studies in which students' conceptions have been explored. Mentioned in chapter 1, they are considered here more fully. The closest in spirit to this study is that of Stead (1980) who used the IAI technique to explore perceptions of energy with younger students in New Zealand. She notes a strong tendency to anthropomorphism, in that youngsters relate the word energy to living things by way of being 'energetic'. She says, too, that it is often treated as a 'waste product' - energy is something expended, and lost, during some activity. Unfortunately, much of her interpretation of results remains as a simple categorisation of responses rather than any further elaboration of their implications. In this sense she fails to capitalise on some valuable data.

An earlier work by Clement (1978) considered explanations by American college students. He concludes by commenting on the lack of differentiation between related concepts shown by the respondents:
... notions of force, force of resistance, elastic force and energy are not clearly distinguished by the students as they are in physics.'

Viennot (1979) makes a similar point of Belgium physics undergraduates, that the concept of energy is 'inextricably mixed with the concept of force in a single undifferentiated explanatory complex.'

In Clement's study, he makes an interesting note of a particular conception he calls a 'source of force' model. From this perspective youngsters see some objects as having 'stores' of energy inside them that are then used to perform certain tasks. In Warren's (1982) terms this is a 'materialist' view that sees energy as a concrete entity, a substance that has objective existence. It is in sharp contrast to the 'conceptualist' view of energy as an abstract quantitative descriptor.

Solomon (1980, 1982) reports work with classes of students and discusses the responses they make in the course of everyday school activities. Two specific aspects of note are students' explanations of how bodies can be 'recharged' with energy (human bodies in particular), and the notion of 'useless' energy. When humans rest or sleep they are seen as giving the body the opportunity to restore energy 'lost' during the course of activity. The greater the activity, the more energy lost, the greater the need to 'recuperate' energy. 'Useless' energy is not similar to the 'expended' energy in Stead's study, rather it is seen as energy unavailable for tasks like the operation of machinery. Solomon argues that it provides a useful means of gaining entry to the complex notion of entropy, even with
younger students.

In none of these studies do students see energy as being conserved, a point amply made by Duit (1981) in his report. A particular model he discusses is the teleological nature of student responses. Energy is seen as an entity designed for human consumption, especially in technical devices. His study also comments on students' conceptions of 'work' which, like Osborne and Gilbert's (1979) study, simply underlines the richness and variety of students' own explanatory disquisitions. Pines and Leith (1981) also note the complexity, value and importance of students' propositional knowledge drawn from interviews about energy.

b) The force concept

In physics, force is related to energy through the notion of work. Like energy it is a concept remote from everyday experience and is no less complex. Unlike energy it is a vector quantity, with all of the associated implications. There is a need to distinguish between force, as one of the interactions of nature, and resultant force. The latter is concerned solely with the acceleration of bodies. Strictly 'body' should apply to particles: the extension of Newton's first two laws to cover extended bodies by applying them to the notion of the centre of mass requires the consideration of internal interactions within the body.

The interesting aspect of force is that it is central to Newtonian physics, as crystallised by his three laws.
In essence, his first law delineates a system of mechanics. The law suggests that unless a resultant external force acts upon a body, it will move with constant velocity. The decision as to whether or not a body moves with constant velocity requires a framework to define speed and direction. This aspect of course, raises the complex issues of frames of reference.

Warren (1979) is highly critical of the presentation of force in school texts to the extent that he says:

'young people studying mechanics are far too often exposed to a bewildering mixture of rigidity and chaos.' Nor are such criticisms to be reserved for British texts. Sjoberg and Lie (1981) make similar comments about Norwegian texts and courses; Jung (1981b) of German ones and so on.

As has been suggested, studies of student understandings of force have been the most numerous of all such single concept studies. Piaget's famous (1929) work with young children, reporting their animalistic responses, was concerned with force amongst many other ideas. As one of his earliest works, it forms one of the bases upon which he organised his theory of developmental stages. In more recent times, Fleshner's (1963) investigation of children's concepts of force and weight are apposite. She says of weight, that her students (between 11 and 13 years old):

'attributed weight only to those bodies they have weighed, it is for them the numerical result of the action of weighing.'

They did not necessarily relate weight with force except where a person had to use force in order to lift a heavy object onto a scale to weigh it. Force, for Fleshner's students, is limited to muscular effort, taking place mainly
in the actions of men or animals on any other body. These results presage a number of more contemporary studies (Watts, 1980; Watts, 1981; and Osborne, 1980). Before discussing these and other studies it is worth commenting on a further point that Fleshner raises. She argues that students succeed in applying newly acquired knowledge where this is close in situation to old everyday, knowledge. However, one group which she describes as being in the process of 'actualising' two knowledge systems (the old and the new) are brought to a stop and refuse to answer in the interviews. She suggests that there is no 'interlacing' of the two systems so that the students are aware of the deficiencies of the old without the consolidation of the new: 'I don't remember and I don't want to talk nonsense', she quotes one as saying. Chapter 5 and 6 of this study discuss similar features in the interviews with students. In the terms used here, students may have reached the limit of their range of convenience for their conception in a particular domain and may be attempting to construct a new range of convenience.

Some of the early studies include one by Leboutet-Barrell (1976), who indicates that high school and college students in America have misconceptions about force and motion (which are described as 'pre-Galilean') and which persist despite physics instruction. Helm's (1978) work on force has already been described as one of the central 'misconceptions' papers. He considers South African students' (and teachers') responses to pencil-and-paper questions and therefore again suggests that the misconceptions continue
during (if not 'despite') formal physics teaching.

A number of papers cluster round the IAI methodology. Watts (1980, 1981) for example describes animistic and anthropocentric responses using the method, and Watts (1983) presents an early version of some of the ideas presented here in chapter 4. As with the energy studies, the work closest to this in spirit and methodology is that by Osborne (1980) and Osborne and Gilbert (1980). He comments largely upon the anthropomorphism of many students' responses and calls them examples of 'everyday views'. Osborne tentatively suggests using anthropomorphic explanations in the course of instruction as a means of trading on this tendency. The work was conducted with New Zealand children of 9 to 14 years old using the IAI technique.

The allied methodology of IAI, discussed in the last chapter, has now generated a number of short studies on force. The original by Watts and Zylbersztajn (1981) surveyed about 125, 13 year olds in London schools and argues for a number of frameworks for force, motion and gravity. Of force and motion, the authors say that one of the major frameworks can be paraphrased as 'If a body is moving there is a net force acting upon it in the direction of movement. If a body is not moving there is no force acting on it.'

Two other studies using IAI have since been reported, first by Thomaz (1983) with Portuguese university students and school students, and secondly by Wright (1982) with Kenyan physics undergraduates. They both report very similar results showing that both undergraduates and student teachers in both countries have conceptions similar to those expressed
by the younger school students.

Sjoberg and Lie's (1981) work makes this same point a little more strongly. They also use paper-and-pencil tests with school students of between 16 and 19 years old, using some questions adopted and adapted from other studies. They highlight the strongly Aristotelian - or more appropriately, Impetus Theory - responses of their respondents. The Impetus Theory (commonly associated with Buridan in the pre-Newtonian era) conflicts with Newton's first law in a way that is similar to the framework outlined above. For Aristotle, the force that maintained a projectile in its trajectory derived from the air around the object. For Buridan the force was an internal impetus within the stone, received when it was thrown. This maintained the object in forward motion until a 'natural motion' (the vertical movement) gradually took over as the impetus was used up. Sjoberg and Lie conclude that a reasonable explanation of their data is that no learning of Newtonian physics takes place as students progress in their 'physics career'. Rather, more advanced students are better equipped to verbalise their Impetus theories than less advanced students.

They say:
'The only "development" which seems to occur is that some of the mistakes are more clearly expressed by the more mature students. One may argue that they then have the "tools" to express views already developed earlier...'

A number of studies have considered the overlap between force and other concepts, in much the way that Fleshner's interviews were designed to do. For example, Duit's (1981) study considers force along with work, power and energy, although concentrating on energy. The German students
responding are between thirteen and fifteen and associate force and energy through the German word 'kraft', meaning power. In Germany, a powerplant is called a kraftwerke - a direct translation might be a 'force' plant. Duit notes that many associations for force are linked to human affairs and that force is more related to qualities than is the word energy. He notes, too, that:

'Most students still prefer, after four years of physics instruction, conceptions stemming from everyday experiences. The conceptions which are to be seen among the students of grade 10 are more or less the same as those described for students in grade 7.'

Also in Germany, von Rhoneck's (1981) work explores the overlap between force and electrical voltage. About half of his sample of fourteen year old respondents describe electrical voltage as the 'strength', the 'force' or the amount of current, whilst current itself is understood as being energy. Watts and Gilbert (1983) consider three levels of overlap between force and energy. The two can be seen to be synonymous, separate but related, or distinct and unconnected. They point, too, to results similar to those of Viennot (1979) and Clement (1978) mentioned within the studies on energy.

These two last studies are primarily with undergraduates and in a recent paper, Clement (1982) makes the important point that:

'In conclusion, the data support the hypothesis that for the majority of these students, the 'motion implies a force' preconception was highly resistant to change. This conclusion applies to the extent that the students could not solve basic problems of this kind where the direction of motion does not coincide with the direction of net force.'

To emphasise the point that 'preconceptions' exist even at more exhausted levels, Peters (1982), in a paper entitled
'Even honours students have conceptual difficulties with physics,' notes that only 5% of a class of physics honours graduates identified the expected forces in the common example of a person pulling a heavy stone. Some, he suggests, indicate a 'lack of progression from a more primitive view of how the world works' and visualise force as a substance which is 'passed back and forth like a hot potato.' Similar points are made by McCloskey, Carmazza and Green (1980) for situations that involve curvilinear motion. In their study, college physics students argue that objects projected from a curved tube will continue to follow a curved path.

One further group of studies require some comment, ones that are typified by Champagne, Klopfer and Gunstone's (1981) paper. Champagne's work, and that of similar studies, is concerned with mapping and representing both 'novice' and 'expert' knowledge, often in computer programme form. They are directed towards enhancing novice knowledge structures in problem solving techniques (for example, Chi, Feltovich and Glaser, 1980). As such, they study student performance which is often limited to the solution of characteristic textbook physics problems, solutions which are then compared with the well-defined correct solution provided by the expert.

Similarly, DiSessa (1982) employs aspects from artificial intelligence and information processing to elaborate a theoretical model for students' Aristotelian responses to Dynaturtle, a computerised, graphical, problem solving situation. Using a single case study he crafts the 'robust' and 'surprising structure of discrete and definite theories'
that the student employs. Moreover, he suggests that conceptual development need not be governed by a general path in the transition from novice to expert:

'More profoundly, one can never rule out the possibility of radically different routes of development based perhaps on entirely different pools of naive knowledge.'

In contrast to Champagne's et. al., work, Disessa's is more akin to the majority of the papers reported here in being (in the main) more idiographic than normative.

c) The heat concept

Unlike the large number of studies completed on force and energy, comparatively little has been written about heat, In physics, the concept of heat conflicts with the common usage of the word in some important ways. Heat is energy being transferred solely as a result of a temperature difference - a body does not contain heat. When this process called heat (or heat transfer) takes place, work is done on a molecular scale but not macroscopically. Heat, like work, is a process. Work is energy being transferred as the result of mechanical processes (so that a body does not contain work either). These processes do not have to be purely mechanical, for example work can be done by displacing an electric charge.

In this way, heat is made distinct from a body's internal energy, which is assumed to be an aggregate of the kinetic and potential energies of its constituent particles. As Warren (1982) points out, heat is often made synonymous with internal energy. He adds that:

'To make matters worse, the term 'heat energy' is now often used, sometimes for heat and sometimes for internal
energy. As heat and energy are so essentially distinct, this is a meaningless term.'

Warren's (1972) too, is one of the earliest studies to consider students' definitions of both heat and internal energy. One hundred and forty eight university students were asked for their definitions, and to state the relationship between them. Warren reports that not one gave a 'meaningful definition' nor did anyone provide a statement of the first law of thermodynamics, which formalises the relationship. The most popular response was 'heat is a form of energy', along with a collection of 'diverse' and 'vague' ideas. In commenting upon the results, Warren censures teachers and textbooks for incorrect presentation of these two concepts. Of the students, he suggests that their patterns of thought have been 'inculcated' and are quite lacking in logical structure. It thus becomes 'extremely difficult to remedy these errors by later teaching.'

In contrast, Tiberghien's (1978) work is more idiographic in that her stated aim is a particular interest in 'some of the representations or types of interpretations which children give concerning heat.' She uses a range of methods with eight students between 12 and 13 years old: individual interviews, a logical reasoning test, filming of one pair of students working and the tape recording of others. She notes a number of conceptions; that heat is a fluid which moves over the surface of objects; that the 'transfer of heat' to the interior of solid objects is sometimes described by postulating holes for it to travel through; and that
'hot things heat; cold things cool'. This last conception sees heat as the property of the material of objects.

Albert's (1978) study is with younger students over a range of 4 to 9 years old. Some forty interviews are reported, conducted to a Piagetian model. She analyses the data first into the 'thought patterns' (which are seen to underlie the responses made) and then secondly, into convenient categories. In all, she argues for six categories which she sees as being arranged developmentally, according to chronological age. The last category, for example, is a conceptualisation of heat as being produced by mechanical energy. This conceptualising is expressed at eight or nine years old, but not before. The six categories follow in sequence from heat seen as 'hot bodies' (4 years); to it being 'labile' and a process (6 years); an independent entity, sometimes as a single dimension (8 years); and then energy as a source of heat, with some conceptualisation of temperature at 9 years old.

Erickson's work (1979, 1980) takes two looks at students' conceptions of heat. The initial study is interview based, first with 6 to 13 year olds and then a phase of ten in-depth, videotaped interviews with 12 year olds. The in-depth interviews are based upon experimental tasks and situations. Erickson presents his outcomes in terms of conceptual inventories and one particular conception is prominent: the existence of cold as an opposite to heat. Like heat, cold is endowed with a material property as it is transferred from object to object. In addition, temperature is sometimes described as the measure of the mixture.
of hot and cold inside an object - a mixture that all objects have. Other examples describe heat as a substance rather like air or steam. Erickson's second study (1980) reports a subsequent survey of 276 students in three age groups; 8, 11 and 14 year olds. Whole classes are asked to observe a demonstration and then to rate a range of explanations on an eleven point bipolar scale. An example of one scale asks the students to rate the explanation as 'very much agree' to 'very much disagree' with their own explanation of what takes place. The explanations provided for the students to rate are taken from three viewpoints, characterised as 'children's viewpoints' (based on the interview phase data); a 'caloric viewpoint' (derived from an interpretation of the historical view of heat); and a 'kinetic viewpoint' (a modified curriculum model).

The results suggested that the 'caloric viewpoint' is well subscribed and remains constant over the three age bands. Changes occur in the other two viewpoints, which Erickson construes as a shift from a more perceptual bound, common sense explanation of heat phenomena to a more abstract perspective. There is no overall clear developmental pattern shown, in that although there is a movement away from an intuitive set of explanations, some of the individual statements gain in popularity and strength of belief with age.

Stavy and Berkovitz's (1980) work concerns qualitative and quantitative judgements of temperature and amounts of water. For example, if cold water is added to more cold water, a youngster replies that the result is cold water of the same degree. However if water at $10^\circ C$ is added
to more $10^\circ$C water, the result is expected to be water at $20^\circ$C. Stavy and Berkovitz refer to these as questions of 'intensitivity' and are interested in the apparent conflict between two 'representational systems' related to temperature - a verbal one and a quantitative-numerical one. The youngsters (200 students between 4 and 13 years old) are presented with demonstration activities with hot and cold water, are asked to produce a judgement on temperature (before and after mixing) and for a justification of their answer. The authors argue that, by comparing the classroom instruction for groups, those students for whom a conflict is induced between their 'representational systems' improve their understanding. That is, by confronting youngsters with their contradictory answers, this awakens the 'need to resolve the conflict that has arisen'.

Anderson's (1979) questions are also about temperature, but more specifically about boiling points. He presents paper and pencil multiple-choice questions to over four hundred students in four age groups between 12 and 15 years. The questions concern the continued boiling of water over a five minute period and any possible change in temperature as a result. The responses of students in all age groups suggest that the longer the water is on an electrical hot plate, the hotter it will get, beyond $100^\circ$C; whilst a second popular answer is that the switch setting on the hot plate determines the temperature of the boiling water. Andersson maintains that there is a general progression, with age, towards the correct answer of boiling being the cause of temperature invariance. He points out that answers over
two questions (where the switch setting is first constant
and then changed) are consistent for most of the students
in the groups, in that over 70% give compatible answers on
both questions.

Two further studies are worth noting; the first by
Crookes (1982), a case study of a 14 year old boy, and the
second by Engel (1982), an extensive survey and interview
approach. Crookes' study follows a single student through
a series of discussions and practical sessions. Crookes
charts the student's changing explanations in the face of
discussion and discomfiting experience. In early sessions
he explains heat in terms of rays, but then moves to versions
of a kinetic model. The move resolves a number of problems
his early explanations raise but in turn generates more
problems, particularly concerning the expansion of solids.
The realisation that his previously 'solid' world alters
merely as a result of temperature changes seemed challeng­
ing. Crookes paraphrases the student's worry as:

'If everything does expand and contract, how can you
survive in this suddenly flexible world.'

Engel (1982) considers two age bands (12 to 14 years
and 14 to 16 years). In many cases these are the same
students who are questioned two years later. The questions
are paper-and-pencil ones followed up by selected inter­
views. Heat is just one of three topics investigated and
the questions range across a variety of situations, from
boiling kettles, bath water, boiling potatoes, ice, breathing
'clouds' on a cold day and so on. Engel analyses her data
into frameworks on two scales, ordinal and alternative
(parallel). She says of the heat frameworks that there is
no clear age trends and, for questions on the conduction of heat, there are no age differences. Students consistently give similar, or the same, alternative responses across a number of question contexts. Engel suggests that perhaps students find it easier to identify common scientific problems embedded in similar question contexts, which explains the relatively higher stability of alternative frameworks over other sets of questions.

This collection of studies, although few in number, raises a number of interesting points and here the stress has been upon noting the outcomes from the research questions. Interestingly some report a progression of ideas with age, or with specific instruction, whilst others are equivocal, reporting rapid changes in some contexts but not in others. These points are raised again later.

d) The light concept

If there are only a few studies reported on students' conceptualisations of heat, then there are even fewer for light. In physics, the wave-particle duality in the nature of light is fundamental to the core of the discipline. The nature of light in these forms has become a topic for school physics curricula with the inception of the Nuffield Advanced Physics courses (Nuffield, 1971a, 1971b). At lower age levels, students are commonly introduced to waves and to light although not usually in combination. Often waves are treated with respect to sound; light with respect to ray optics and, most commonly, the human eye.

The human eye is a complex system, and many of its
limitations are not discussed except, perhaps, in some A-level courses (Nuffield, 1971a). Some defects, such as the lack of proper curvature of the retina, are used to explain some of its lack of resolution. Since the retina has a finite number of light receptors, it is possible that the brain enables one to 'see' detail not clearly present on one retinal image by storing information from successive images and comparing different sets of information. At such points vision is indistinguishable from perception. It is no coincidence (as Schon, 1963 points out) that theories of light and vision have been transferred to theories of thought and reason. It is usual to discuss comprehension, understanding, and a host of other mental activities as 'enlightenment'; 'seeing' a point, 'envisaging' some action; gaining 'insight'; 'seeing through' an argument; an idea 'dawning' and so on. The resulting ambiguity in terms like 'see', 'observe', and 'indicate', for example, is a systematic ambiguity in that the metaphor is both extensive and pervasive.

The common sense view of light, and colour, is that these are seen as something an object possesses as a real quality rather than a set of wavelengths reflected by the object. In this sense an object can be said to be red even when in the darkest corner of a remote cupboard. It is a distinction, as Jung (1981) suggests, between potential and actual colour. Light itself is often conceptualised as brightness, the condition for actually perceiving colours through a transparent medium, given off by some body of a special kind.
This is, Jung claims, an Aristotelian account of seeing. In this sense, he says, light itself is not seen. What is seen is a streaming (an emission) of colours or brightness. This is one way in which the physics concept of radiation is seen to enter into the 'common sense' framework of ideas.

A long line in theories of light has been documented (for example, in Bray, 1938), some of the earliest being by the Egyptians as reported by Thales (640 BC). Until the time of Newton, light was normally considered to be pure, elemental, and white (Zylbersztajn, 1983). Newton's contribution is well known: he was led to the view that white light is a mixture of rays of many varieties and colour. He opted for a corpuscular theory, compatible with his work in mechanics, and away from Huygens' wave theory of light. As Andrade, Silva and Lochak (1969) remark:

'It was of course, difficult for (Newton) to be totally unbiased when there was such an obvious analogy between the 'particles of light' in the corpuscular idea and the 'particles of matter' in his own mechanics.'

It is said that Newton was impressed by the sharpness of light shadows and this seemed to him to be inexplicable if light consisted of waves.

Cantor (1981) uses the historical arguments between 'waves' and 'corpuscles' as a useful example for generating theorising and debate at sixth form level. The particle theory leads to the view that light has a higher speed when passing into a second medium whereas the wave theory predicts a lower speed. Cantor suggests that by rehearsing and reconstructing the arguments, and conflicting predictions, it is possible to stimulate students to consider their own
ideas before embarking on the more recent explanations of light. Zylbersztajn and Watts (1982) note that few school texts consider students' own ideas about light. One exception is a Nuffield text (Nuffield, 1976), where the authors suggest that colour filters might be seen by students as adding colour to an otherwise pure white beam of light. Zylbersztajn and Watts asked 150 thirteen year olds to describe and explain (in writing) why red light is seen to come from a red projector slide. Only some 2% of the sample give what might be considered to be a textbook answer in terms of the transmission of some frequencies of light, and the absorption of others. About half of them suggest that the light is transformed or changed in some way, two thirds of whom are non-specific whilst one third specify a 'dying' mechanism for light. Interestingly, some 13% of the sample indicate a model whereby the white light is not so much coloured by the filter but 'projects' the colour forward from the filters - a kind of 'knock-on' effect.

Three other studies on students' conceptions of light are worth noting. The first, by Guesne (1978) uses two interview formats (directed and non-directed) in parallel. They are described as separate but complementary exercises, probing the conceptions of 13-14 year old French students in Paris. The first asks questions concerning experimental situations - the student is asked to make a prediction of (or interpret) the outcome of some set of phenomena. The non-directed interviews pose questions such as 'What does light mean to you?' 'What does light do?' and so on. The research outcomes from the directed interviews suggest that
the students talk in terms of reflection for a mirror but not for an illuminated white sheet of paper. Lenses are seen as making light bigger, and candles visible at a distance are not considered to be sending light as far as the observer but are only capable of 'being seen'. In the non-directed interviews light tends to be associated with large, obvious sources like lamps or the sun. Responses are given in terms of affect (of 'warm' light), and of personal experiences of light and dark.

The problem of distances is taken up in a study by Stead and Osborne (1980). In Guesne's study, students thought that light would not travel far from a candle and yet it could be seen from a distance. Stead and Osborne query the relative distances travelled by light at day and at night. They use the IAI technique with thirty-six New Zealand students between 9 and 16 years old, and follow this with a survey of 144 9 year olds. For many interviewees, the distance travelled by the light depended on the size of the source. For example, fourteen of them answered that the light from the sun (obviously a large source) travels to the earth, whilst only five said the light from the candle would travel any distance. The results of the survey (a multiple-choice test) showed that most 9 year olds did not consider light to travel more than a metre from a source during the day, and only slightly more further at night. Similar results are obtained when Stead and Osborne tested other students, and those a year older, although both groups had recently completed a section of work on light.

The final study, reported by Jung (1981b) is with 12
to 15 year old students in Germany. The study concerns the conceptualisation of optical phenomena such as emission, absorption, scattering, reflection and image formation. In one part of the study students are asked to look through a double-slit at a distant light source and to explain what they see. Although explanations in terms of interference were not expected, some response in terms of image formation were. In the eventuality, students responded within Jung's 'common sense frame' in terms of the source radiating sideways. In describing mirrors and reflection, 90% of the sample of 12 year olds argued that their image was upon the mirror and not 'behind' it - a conclusion reached by the majority of older students too. An allied question is as follows:

'You are standing in a completely darkened room against one wall. A small bundle of light is directed against the wall in front of you. All the walls are black. Somebody tells you there is a mirror on the wall in front of you - could you decide if they are right or wrong?'

A typical response was that a small bright spot can be seen upon the mirror. Jung argues that this exemplifies a de-coupling between seeing the mirror, or the light lying on the mirror, and receiving light from the mirror, into the eye.

Although few in number, these studies in light and optics are valuable and illustrative of several major points, and Jung's term 'de-coupling' is a useful term. Put another way, in physics the concepts of 'sight', 'reflection', 'absorption' and 'refraction' are all interrelated. Their relationship is one of unification and not disjunction: they exhibit logical coherence, are 'coupled'. This coupling
is not something that students are necessarily aware of, or would formulate in a response to questions. In this example, seeing is a natural activity that means one can watch the goings-on in an outside world: the events that are taking place around them. The activities of light, and the occurrence of images, are just some of those events and it is not always necessary to conceptualise the observation of those events as being contingent upon the events themselves.

A person's conceptions of 'sight', 'seeing', 'being seen', 'watching', 'looking', 'looking at', 'noticing', 'catching sight of', 'glimpsing', 'staring at' and so on may well form a cluster of conceptions. This cluster may well be complemented by a range of operational descriptors that help to describe how this takes place. And such a complex of ideas may have only partial overlap with the advent of reflections, images and so on.

The next section takes up the issues began in chapter 1, and discusses groups of personal theories from under the mantle of Kelly's theory. In doing so, it considers the array of results that have just been described and attempts to set the scene for the empirical data to follow in chapter 4.

3.3: The Organisation and Fragmentation of Constructions

The arguments about concepts that have been presented so far have rejected a simple logical (either-or) view in favour of a polythetic view, seeing concepts as being found
on a number of continua. These arguments have been made on the basis that if one is to study students' conceptions of scientific concepts then this is best achieved by picturing concepts as differing in degree and not in kind. In order to view a person's natural concepts one has to allow that concepts can be natural. The suggestion here is that the process the person goes through in developing physics concepts is one of progressive integration and differentiation of their own natural concepts (conceptions) rather than the 'acquisition' of logical concepts that are of a different kind. Taking Bolton's (1977) description of a concept as a 'stable organisation' begs the question of what sort of organisation, and that is the topic of this section.

Conceptions have been described as mini-theories that have a range of applicability, or convenience, and with a central focus of convenience. In one sense, the word theory denotes a testable proposition, or group of propositions, that have withstood the process of testing. In another sense it is commonly used to refer to almost any set of ideas, whether speculative or principled. It is this latter (non-Popperian) sense which is used here. Whereas some of the elements of a person's theories are testable (and tested) not all are, or even could be. A person's mini-theory (conception) on any topic can be described as the set of beliefs, expectations and implications which (s)he is prepared to avow about it (Pettitt, 1978). In Markova's (1982) words, a person:
... is not an idle observer of the world around him, recording his experiences and then devising concepts and theories to fit them. On the contrary, he is always actively conceptualising and theorising, and his experience is laden from the beginning with concepts and theories which determine the form it takes.'

This is a similar point to those made earlier for concepts and fits well with Kelly's constructive alternativism.

Mini-theories, then, are not fixed. Some, clearly, are more stable over time than others, as Engel (1982) pointed out for ideas about heat; Jung (1981b) for light; Sjoberg and Lie (1981) for force and so on. Therefore some conceptions are less fluid and more ephemeral than others. They, too, span a continuum of stability, from durable (slowly revised) to permeable (quickly revised).

These are arguments against a simple dichotomised view of concepts as simple-logic sets, or ones that fall separately either side of a concrete-abstract division. In a way that is positivistic in outlook, Gagne (1970) for example, makes a distinction in kind between 'point-at-able' concepts and 'defined' (theoretical) ones. Here, following Newton-Smith's (1981) arguments, concepts can be seen as theory-laden even at the minimal, most concrete level - although some will be more theory-laden than others.

The proposal here is that conceptions are gathered together in clusters concerning particular topics, or within certain contexts. These clusters form distinctive, semi-independent subsystems, that are subsumed at some point by a unifying thread, some superordinate conception. This is a description developed from Kelly's (1955) theory - although here it is addressed in terms of conceptions, or constructions rather than bi-polar constructs. The contention
is that this description is sufficiently flexible that it survives and profits from this amendment. There are two main features of Kelly's theory that are pertinent here: the Fragmentation and Organisation corollaries:

The fragmentation corollary states that:

'a person may successively employ a variety of construction subsystems which are inferentially incompatible with each other.'

This is a picture of a flexible system, of situation-specific, differentiated domains. The way a person responds to a particular situation on one day cannot necessarily be inferred from their responses yesterday or the day before. Nor will they necessarily respond in a similar manner in the future. To the observer - or in this case, the interviewer - it may seem that one response could not be anticipated from the previous one and that grossly inconsistent responses and constructions are being offered by the individual. However, just because different constructions do not seem consistent with each other and one cannot be inferred from the other directly, it does not mean that no consistency exists for the person involved (or some other observer of the scene). One of the implications of the fragmentation corollary is that 'superordinate' constructions can be used to resolve apparent inconsistencies at lower levels (Adams-Webber, 1979).

The fragmentation corollary is, in essence, making two points. Firstly, it complements Kelly's 'organisation' corollary which says that 'each person characteristically evolves, for his convenience in anticipating events, a construction system embracing ordinal relationships between
constructs'. This is generally taken to mean the construct system as a 'whole'; that is, there is a degree of organisation concerning a person's entire repertoire of constructs.

The fragmentation corollary then allows for the whole system to be subdivided into relatively independent subsystems, which can be brought together under some superordinate constructs. This is tantamount to saying that, although one may have task-specific or domain-specific constructions which are separate from one another (fragmented) there is some level at which a person can bring together and co-join the subsystems. This is the trademark of rationality and lies behind the commonsense view commonly credited to 'normal' people in everyday encounters: that they are rational (Pettit, 1978). As Ryle (1975) contends, the fragmentation corollary is necessary to account for the generally observable fact that people can hold beliefs or make judgements which seem incompatible with each other and yet remain consistent and coherent to themselves.

There is an inherent circularity in this argument - where being rational is by virtue of having a degree of unity in one's argument, and where that unity is also used as a reason for describing someone as rational (as opposed to irrational). It is a circularity that Pettit (1978) recognises in his 'rational-man theory' and yet, fragmentation is not often used in this context of the coherence and unity of people's naturalistic personal meanings. Too often it is reserved for the extremes of thought-disorder rather than as a description of everyday construal. And yet the notion that, despite apparent conflicts and illogicalities, people are consistent at a superordinate level.
is a feature of rationality as argued by, for example, Foster (1983) in terms of self-evaluation.

This study is not a development of grid methodologies. It is more in the spirit of recent developments (for example, Pope and Keen, 1981) in terms of gaining access to constructions and discursive feedback and in terms of the reduction and reconstruction of personal meanings as aids to awareness and negotiation. In this way the term fragmentation is taken in its (and arguably Kelly's own) commonsense application as an expression of the 'topography' of an individual's clusters of meanings. As Adams-Webber (1979) points out, Kelly assumed that the systemisation of sets of interrelated constructs (that is, of separately functioning subsystems) increases the deployability and scope of the entire construct system as an operational whole. Such local domains, or contexts, can be developed and themselves integrated into a related network without (too much) due concern for inconsistencies or 'peripheral' counter-examples.

This picture of alternative constructions-within-an-operational-whole is reminiscent of Piaget's (1969): of 'the role played by a substructure (or functioning sector) in relation to the functioning of the total structure.'

However, there is no suggestion here that one can seek universal similarities between people or age groups. Moreover, the problems to be tackled do not so much consider the 'operational whole' as chart the force of the fragments, substructures, or personal constructions as they relate to these four concepts in physics. Attention is squarely upon capturing young people's descriptions of physical concepts as they see them and use them in explanations.
CHAPTER 4

ALTERNATIVE FRAMEWORKS

4.0 An Introduction to the chapter

4.1 A discussion of alternative frameworks

4.2 Some proposed outlines for frameworks
   a) Individual perspectives
   b) Categories of response
   c) Alternative frameworks

4.3 Frameworks for the main concepts
   E: Frameworks for energy
   F: Frameworks for force
   H: Frameworks for heat
   L: Frameworks for light
4.0: Introduction

It is a consequence of using open-ended questions, particularly in a loosely structured format, that the resulting data is very rich in varied, detailed and complex information. Each one of the 134 interviews in this study is discernibly different to its neighbours even where the same cards, the same age student and where similar interviewing conditions have prevailed (as far as this could be discerned). However, in only a few of the interviews have exactly the same pattern and order of IAI cards been used. Students have been happy to take the initiative and have been instrumental in shaping the interviews as they talk. In many cases the overriding impression is that such an arrangement (it would be inappropriate to call it a tactic) allowed the students a greater feeling of directing the pace of events and therefore the flow of their own responses. This was not always the case, of course, and on a number of occasions the interviewee adopted a passive role and control was vested with the interviewer. It was pointed out in chapter 2 that some seventeen students were used for more than one interview. The choice of student for revisiting with different decks of IAI cards was based upon their eagerness to participate and their willingness to be open and frank about their thoughts as they worked their way through the pictures. The upshot of this is that the scope and breadth of the responses in the interviews is very wide and therefore mitigates against any simple system of analysis.

It is not the purpose of this study to provide a
normative evaluation of students' correct or incorrect responses. It is not an analysis of errors, or of categories of appropriate or inappropriate responses. Instead it is an attempt to pick out the threads of the many arguments and accounts put forward as explanations for the situations depicted in the cards. The analysis, then, is couched in terms of frameworks of ideas, a structure placed on the variety of responses by the interviewer. This is made much the easier by the shaping that students have undertaken themselves as they order their own thinking in the course of the discussions.

Three themes are intertwined in this chapter - the three meanings by which frameworks have come to be used. Firstly, 'framework' has been used as a description of a particular perspective adopted by an individual interviewee. Secondly, it has been used to signify a unit of data analysis at protocol level and thirdly, (and more usually) to represent a research outcome. Whilst it is necessary to discuss each theme separately for conceptual clarity (rather than irreparably shred their interaction) an inevitable shaping for relevance - as opposed to comprehensiveness - will reflect this entwining.

Despite the advent of the rapidly growing fund of research reported in chapter 1, little has been written on the nature of frameworks to lead this discussion. The purpose of this chapter, then, is to extract and examine those small indications that have been made by others and to propose a clear use for frameworks. What follows is a description of those frameworks culled from the interviews in each concept area. They are illustrated by numerous
extracts from the transcripts in each of the three age groups. There is no suggestion that the frameworks are free standing - the intra- and inter-relationships between the frameworks in each concept area is the topic of chapter 5. Rather, each framework is a generalised, typifying case that spans a number of responses and situations.

4.1: A Discussion of Alternative Frameworks

The metaphoric use of architectural terms in academic disciplines is commonplace. Hence disciplines have 'foundations', one seeks 'support' for arguments, some of which may have been 'built on shaky grounds' and so on. Toulmin (1976) calls this pervasive metaphor the 'city of truth'. He says:

'Individual items of secure belief, or knowledge, resemble particular rooms or buildings - in spectacular cases, individual skyscrapers. Well organised theories resemble complexes of buildings whose different rooms or structures lend each other support, so that we can move with ease from one to another.'

He invokes this metaphor to make a description of the term framework. He argues that human rationality is the capacity to arrive at secure, strong, well founded knowledge. Experience provides the background and the plethora of events upon which the knowledge is 'constructed' whilst logic checks the design of the skeleton - or framework - from which the knowledge gains its security. The specific reasons that one gives in defense of particular beliefs demonstrate that a person is conversant with parts of that knowledge; that is, one shows that a particular belief is 'well founded' - one proves it - by pointing out
just where in the entire construction it is located and how it obtains the necessary firm support.

A framework, then, can be seen as a scheme - an ordered organisation - whereby elements can be linked together to provide substantive support for each other.

Within the literature previously cited, the term alternative framework is used broadly with varying degrees of specificity and sophistication. It is commonly a non-specific designation for responses to questions. Freyberg and Osborne (1981), for example, equate framework with viewpoint and make a distinction between an everyday mental framework and a technical mental framework. They suggest that the two frameworks are distinct and separate, being in 'sharp contrast' to each other, and are discernible in the responses that both teacher and student make, in particular in transcript data. They say:

'In our interview work a careful analysis of transcripts has often subsequently revealed to us that we, too, as interviewers have sometimes missed cues which would have told us that the children we were talking to have been responding from a much more everyday, or non-technical, mental framework than from the technical viewpoint we intended.'

The three senses in which the term can be used are intermixed in this passage. However, it is possible to derive a number of guidelines towards detailing frameworks from what has been described in other reports. Freyberg and Osborne, for instance, are suggesting that two frameworks can be discrete, that is, separate and distinct, whilst at the same time making reference to the same phenomena. Although the focus of conversation is common to the participants, there need be no overlap between their 'mental frameworks.'
In another paper, Osborne, Bell and Gilbert (1981) make lengthy reference to 'children's science'. This, they say, refers to the views of the world and meanings for words that children tend to acquire before they are formally taught science. They suggest that the term children's science now supercedes 'alternative frameworks', their implications being that the research community now:

'increasingly realise how sensible and understandable children's views are in terms of their experience.'

As with other examples of Osborne's work (for example, Stead and Osborne, 1980), children's science is consistently made synonymous with 'viewpoint'. In Osborne, Bell and Gilbert (1983), however, the authors characterise children's science in three important ways:

1. It is typically non-abstract reasoning and is usually ego or anthropo-centric, as children:
   'consider only those entities and constructs that follow directly from everyday life';

2. Children's science is 'not concerned' with a need for coherence and non-contradictory explanations across a wide range of phenomena;

3. The language base for children's own descriptions of phenomena is imprecise, ambiguous and non-technical.

These three criteria beg a number of questions - and are considered in more detail a little later. At this point, it is suffice to note that there is little in their description of children's science to encourage researchers to the view that it represents a more coherent or comprehensive entity than that more commonly termed framework. More preferable, because it lacks demeaning connotations,
is the term 'students' science' (Watts and Gilbert 1983), which is used as a collective noun for a range of possible frameworks.

In their original paper, Driver and Easley (1978) describe youngsters as having 'autonomous' frameworks for conceptualising their experience of the physical world. They emphasise this self-regulation in conceptualisation by describing frameworks as the product of pupils' 'imaginative efforts' to explain events. They point, too, to frameworks that will be 'in keeping' with youngster's own experiences, although they may also be recognised as partial explanations of limited scope. They point up two further features: frameworks are resistant to counter examples (a conclusion based upon Driver's own doctoral thesis, Driver 1973); and that there are features in common between children's alternative frameworks and some historically held scientific views.

In a more contemporary paper Driver (1981) refers to alternative frameworks as 'implicit theories', derived from prior experience upon which people base their reasoning. She argues that frameworks can be persistently held despite instruction (rather than simply before it, in the case of 'children's science') and that in some cases quite profound changes are required in students' frameworks before they can be 'emancipated' from one world view to another. She interprets Engel's (1982) study as showing that frameworks display a range of stability. In some cases, pupils' frameworks tend to be problem specific and are influenced by seemingly superficial characteristics of a task. Other
more stable frameworks appear to be discernible across a range of different tasks or situations.

In a joint paper Engel and Driver (1982) go further and make some additional points about frameworks. A framework, they suggest, is a description of a perspective from which a prediction about events can be made, a perspective which, at the very minimum, should be demonstrated in more than one question context. By making this stipulation they intend frameworks to be a way of thinking which is not simply question dependent and which has some generality within the sample of children. Again, these are useful indicators and are taken up as a summary of points is made.

Elsewhere (for example, Driver, 1983) she is less specific and more content to leave both the properties and referents of frameworks as more general notions. She exhibits the tendency already mentioned - of intertwining the meaning of framework between category of response, idiosyncratic commitment and research product. The term is used for both pupils' 'first time' answers, and for long held 'deep-seated' ideas. She suggests, too, that frameworks may be both useful explanatory devices and yet hinder observation. They may facilitate focusing on 'irrelevant' (from the teacher's point of view) details whilst reflecting 'relevant' ones. A further consequence, she argues, is that instead of acting as a source of ideas, well formulated and firmly held frameworks would restrict hypotheses and experimentation.

Seré (1982) suggests that pupils (who consider a number of experiments on pressure) would need some framework 'incorporating the concepts of mechanics' in order to interpret
the experiments. She implies that frameworks are elements within a person's interpretations and that they (or their organisation) are often inadequate: she too, sees them as representing obstacles — to the pupils' understanding of the properties of gases. In this case, framework is used in a strictly normative way: they are related to Piagetian stages (with some noted discrepancies) and are seen as barriers to correct concept learning rather than (say) as 'growth points.'

In contrast, Nussbaum and Novick (1981) propose using student frameworks as a basis for cognitive conflict and any ensuing accommodation. In their 'preparation' for cognitive conflict, they encourage students to state their ideas as clearly and concisely as possible thereby making themselves aware of the elements of their own alternative frameworks. Note that, in contrast to Seré's description, it is frameworks that have elements due for interpretation and not the other way round.

As with others (Posner, 1981; Pines and Leith 1981; for example), however, Nussbaum and Novick equate frameworks with pre-conceptions. There are a number of objections to this particular equation of terms. It is worth exploring these objections because, at one point, they raise a number of issues which have been used in arguments against the whole notion of 'alternative frameworks'. These arguments themselves are worth developing since, when the opportunity arising later to collate and propose some features for frameworks, it will be possible to suggest just what frameworks are not. Preconception is a commonly used term in
Ausubel's (1968) theory of meaningful learning. It denotes a learner's prior knowledge and contrasts with concepts at the highest order of abstraction. It is these high order concepts that Ausubel suggests are the most stable and useful. In this sense, a pre-conception occurs before the subsumption of a correctly abstracted (usually scientific) concept. Leaving aside the drawbacks to 'correct' concepts and to abstraction already argued, the term suggests that the complex of knowledge and experience held by an individual prior to the subsumption of some abstracted 'organising' concept is not worthy of the name conception. McClelland (1982) goes further. In a critique of Driver's work he challenges one of her examples of a framework (in Driver, 1981 and 1983). It is a case where a young boy, who needs to weigh some marbles, is unsure whether the height of the scales relative to the floor is important. The youngster recalls from experience that an object dropped from a greater height makes a greater impact on landing. McClelland interprets this as indicating that, prior to the weighing activity, the boy had a rule for weighing and a vague idea about gravity and falling which had never needed to be considered in conjunction. He says:

'Rather than having preconceptions which needed to be overthrown, he had no conception worthy of the name. The activity itself created conditions under which a clarification and merging of weight and gravity were needed for the first time.'

Using this kind of argument, McClelland seems to be arguing that a person's 'ideas' precede even their conceptions, which in turn precede their pre-conceptions. Nor does he grant a 'conceptual status' to weight or gravity to show
how these interrelate and co-join with both prior experience and the task at hand. Not to be too harsh on McClelland's comments, the problem he raises is real enough: what terms might best be used to denote various types of responses that youngsters (and adults) provide - from deeply considered carefully weighed answers to tautologies, circumventious strategies, or 'instant' first thoughts?

Sutton (1982), too, has been critical of the term framework as being too static a description of the fluidity of personal conceptions. He questions the 'stability' of frameworks over time - if they are transitory (passing phases on route to 'correct' science) then they deserve some other name than framework. A similar point is made in a more recent paper by Gilbert (1983). In this case, he returns once more to 'children's science' because it implies a more relativistic epistemological outlook.

It has already been suggested, reinforced by this summary of papers, that there has been little consensus in current literature to help explicate a description of terms. Needs necessitate, therefore, for proposals to be put forward for the purposes of this study.

4.2: Some Proposed Outlines for Frameworks

To begin, it seems worth wrestling some distinctions from the three uses of framework mentioned earlier:

a) Individual perspectives

Much of the work reviewed as studies in alternative frameworks is interested in charting an individual person's scientific theorising. This case-study approach, using a case of one, interprets changing verbal responses as changing
mental constructions. A point of interest is that (as in this study) the evidence for the nature and extent of a person's theorising and construing is commonly anecdotal narrative and necessarily involves frequent compression of events and language when reported by anyone other than the individual student involved. Such reporting involves complex assumptions and interpretations (as outlined in chapter 2) concerning the purposes and intentions of both participants in the data gathering process.

Here, the term conception has been reserved for the personalised constructions of an individual. It will be used to describe talk and accepted meanings which are either entirely idiosyncratic or generaliseable - in fact anything that is attributable to a single person. Some responses are very idiosyncratic where, for example, someone recounts a personal piece of experience or puts forward an opinion unrepeated in further interviews.

The example provided below is meant to fulfill three purposes. It will first of all exemplify the personalised constructions at issue whilst at the same time introduce the reporting procedure to be used extensively in this and the next chapters. Thirdly, it will illustrate the level of response that is the strong feature of all of these interviews, the direct and open disclosure of personal ideas.

The transcription process outlined in chapter 2 is modified in the reporting in only one or two ways. In some cases additional notes are included in the middle of the extract /in square brackets/. The talk is sequenced even where both participants have spoken over each other - a
feature not usually indicated in the reporting. The extent to which this happens might be gauged from the sample interview transcript provided in appendix III. The extract to follow is number one: all of the extracts to follow that are numbered sequentially throughout the study. Each extract is also identified by a suffix which indicates the interviewee's initial and their concept-year group. Consequently the brackets (A,3L) mean interviewee A from the year three about light, (as tabulated in figure 7 in chapter 2). The year three interviews about light have in fact two interviewees with the initial G. They appear as (G1,3L) and G2,3L), that being the order in which they were originally interviewed. A full list of the interviewees and some biographical detail is shown in appendix II. A further part of appendix II shows the extract numbers against each interviewee. Each of the interview cards is numbered (as shown in appendix I) so that, for example, the card that features in this following extract shows a flower in a pot, card L11 (card eleven in the light deck). Later extracts will refer to cards by an abbreviated name and the number (for example, 'Flower' L11) although here in this first extract the card is shown as figure 10.

![Figure 10](image)
Extract 1

I. .... a little flower in a pot

A. ... umh... it needs heat and light to survive otherwise the plant just dies off... on its own it doesn't give off anything, but with help /from other flowers/ it can brighten up a room...

Underlining in an extract (for example 'give off' above) is to indicate the emphasis that A gives to those words: that is, that although the flower needs heat and light in order to survive, it does not emit light - it is not an obvious source of light. As it stands this extract is only remarkable because of the ambiguity of the word 'brighten'. The paradox it suggests is that, given that a flower is not a source of light, how is it possible for it to 'brighten' the locality at all? There is no evidence to suggest that it is an ambiguity A had previously considered. Earlier in the interview he had described both a candle and television set as 'brightening up' a room, and immediately after the last extract was asked to say what light 'is' by being asked:

I. ... another question is something like this... say somebody had missed a lesson and came to you and said 'you did light last week - what is it?'... how would you explain what light was to them..?

A. .. umh... well I'd say light is a source of energy that... umh... brightens things up... er... so you can see them... umh... (A,3L)

From the theoretical standpoint argued for in chapter 1, there is necessarily a wide range of possible interpretations of A's responses. Here the interpretation is made on the basis of A's responses within the context of the whole interview. Added to this is the close scrutiny of the audio-tape recording for emphasis and intonations, and the many field notes made. Not least, of course, are the
researcher's own hypotheses, being both interviewer and analyst, and therefore present at the time of the interview.

To brighten up a room is an expression in everyday language that is infused with affection: it has emotional overtones. This is true of much of the way light-related terms are used, stemming quite probably from religious origins. In these interviews, light as 'warming' is a common response. In contrast, space is seen as both dark and cold (and therefore an inhospitable place to be). In A's case, the point of light (and of candles and flowers etcetera) is to brighten objects so they can be seen. It is a very anthropocentric conception of light that sees its purpose as being for the benefit of human beings.

Before continuing with discussion of the overall analysis of the interviews it is useful to make two more points about conceptions. Firstly, in the interviews time is taken at the start and during the course of the interview to explain the nature of the task and its purposes. None of this is included in the extracts to follow. It is not that it is unimportant: the seating arrangements, the role expectancies, the immediate setting, perceptions of the task, the air of relaxation and so on must all contribute to shape the conceptions of each individual. However the purpose here is to focus on the substance of the person's responses; the method, to talk to them individually as close as possible to their own classroom setting. In this sense then, the term conception can be taken as being the interpretations made by the researcher of responses made by the interviewee only where they concern some aspect of the content.
of the picture cards, some further development of that, or some feature or fact of the nature of the particular concept in question.

The second point, though, is that not all talk can be seen as evidence for particular conceptions: they are not amorphous conglomerations of information. As Hewson (1980) contends, a conception is only useful to a person if it forms a whole which is somehow more than the sum of its parts. In turn, he quotes Anderson (1977) in a pertinent comment as saying:

'The force of the /notion of a conception/ is to direct attention to the patterning of elements. What the elements are and how they interrelate cannot profitably be addressed as separate issues.'

This picture of a conception, then, is of an organised structure of interrelated information, hypotheses, opinions, local theories and emotions. They are, empirically, commonly evidenced from at least two statements in a transcript, although occasionally a single, strong, statement is revealing. They carry with them sets of expectations and limits to their range of convenience - as in the case of A above. Such limits can be evidenced from explicit statements and implied from strings of anacolutha, and from interpretations of non-verbal behaviour.

b. Categories of Response

In the context of this study, to categorise responses is to construct groupings of responses which are construed as having very similar intended meanings. Responses are extracted from a range of interviews and are used as exemplars of the category. Osborne (1980), for example, makes categories
of one line statements from interviews in this way. He categorises 'viewpoints', which he equates with children's science and gives each category a name, for example, a Human centred viewpoint.

Needlesstosay, categories can be established on any one of a variety of bases. Most commonly they have been on the basis of responses that directly approach the researcher's question. Engel (1982) limits categories to one response per question for each participant and admits that mixed protracted responses, with different parts of the answer fitting into different categories, were common. More importantly she admits that in operating a set of 'ground rules' to overcome this problem, she is aware of making certain assumptions about the coherence of students' ideas and the conviction with which they are held.

A somewhat similar approach is adopted by Zylbersztajn and Watts (1982) who categorise students' written responses to questions about colour filters.

In this sense, then, categories of response can be seen as simple classifications of (often) propositional data under some loose, but convenient, heading. They are not individualised and represent an interpretation of statements at a general, but functional level. The example below is a categorisation of responses to one particular card in the heat deck. The card shows a block of ice melting. The interviewees are asked to discuss this in terms of heat. The students represent those in the oldest age range in the heat interviews - group 6H, a total number of nine. A copy of the card is shown below as Figure 11 (card H6).
The nine respondents are identified by their initial; where initials are the same they are designated a number for the order in which they have been interviewed. Thus the students are:

P; C; N; J1; M1; S; J2; M2; L.

Category 1: 'Heat in the Surroundings'.

All nine of the students respond in terms of heat being in the surroundings to the ice. In each case this is taken as meaning the air around the ice rather than, say, the surface it is on. Eight of these suggest that the heat in turn comes from the sun, radiators, gas, electricity, lights, bunsen burners and so on. Only one (J1) says she does not know where it comes from. P is uncertain as to whether sunlight is (or contains) heat. She decides that sun-heat and sunlight are separate, but is not sure, because 'light is quite warm, isn't it?'

Two more (C, N) go further by discussing movements of heat in the surroundings. N says that heat spreads out in the air, is 'spilled' out through an entire room - unless there are draughts. She does not elucidate on what the
effects of draughts would be. C says that cold air falls. This 'goes to warm air' and then, as we move about a room, we move the heat around. That is, warm air is circulated by people moving around in an enclosed space.

**Category 2: 'Ice has Heat/has no Heat'**

Seven of the respondents argue that ice itself has no heat. Since the ice is at zero degrees centigrade, it is the air around it that has heat and is causing the ice to melt (as the picture shows). If ice had heat, it would melt itself (P). Two, however, (S,J2) maintain that the ice itself does have heat. S says it has heat because its temperature is slowly rising and it is therefore melting. The temperature would continue to rise until the ice is all water. J2 thought that ice does have heat but 'isn't sure! She had seen something recently on television about ice having heat but couldn't remember what was said.

**Category 3: 'Molecules'**

Four of the students (M1, S, M2, L) discuss heat in terms of molecules. The elements of the discussions are similar in that 'warmer' molecules move about more and in moving apart change from a solid to a liquid. As they gain heat they move faster and farther apart to form a gas. For M1, warmer molecules 'get active and spread out'. S suggests that water doesn't want to be heated or cooled, but if it is 'forced' to, then it will go through the changes outlined above. For M2, water molecules receive heat from the surroundings and in turn take energy from the heat.
This enables them to move and so to melt. S suggests that the heat expands the space between the molecules so that they spread out. Molecules are given energy by the heat and move about. This kind of response is dealt with in greater detail (as the 'hot-molecule' model) in chapter 6.

Category 4: 'Energy'

Only two (E2L) discuss melting ice in terms of energy and this has been mentioned above in the last category.

Such categories, of course, do not catch all of the talk concerned with this card since it is only where the talk has some similarity with that in another interview that it can be brought together. As suggested, they are groupings of particular responses to specific questions.

c. Alternative Frameworks

The case to be made here is that alternative frameworks are also generalised, non individual descriptions. Their relationship to the transcript data, however, is one level further removed than the categories of response. Whereas the categories are simple groupings of responses, frameworks are intended as short, summary descriptions that attempt to capture both the explicit statements made and the implied intentions behind them. They are thematic ways of responding, stylised, characteristic, mild caricature of the talk made in interviews. A framework typifies a range of responses in the same way as one might typify the views ascribed to parts of the political public - the opinions of a typical Tory voter, member of the Labour left
and so on. Consequently, from this description, an alternative framework is more depersonalised than either a category of response or conception.

The important point is to see each framework as a 'family' of responses, to borrow a term from Wittgenstein (1958). That is, they are a tool for grouping and organising in a manageable way the many types of individual responses which students have given. Such a grouping - of a small number of broad frameworks - serves to highlight the similarities and differences between students' dispositions towards the various situations depicted in the cards. The frameworks therefore help to focus attention on a range of student approaches which may not have previously been apparent. They are not, however, an attempt to classify students. Rather, they offer a way of organising young people's responses to depict the threads of argument they use - and transfer - across a number of settings.

At least three immediate consequences arise from this description of a framework. First, the frameworks will not necessarily match tidily with the particular conceptions of an individual student. Some conceptions (as illustrated in chapter 6) are sufficiently idiosyncratic as to either cross framework boundaries or escape them altogether. It follows from this that a particular response could be used as evidence for two different frameworks. Responses have to be taken in the context of the whole interview for the thread of argument to be discerned. Second, the frameworks can only organise the responses that exist in the transcripts and so may or may not match well with findings in other...
studies. As is indicated in the next chapter, in many ways frameworks are bound to the questions that precede the responses. Third, the frameworks do not attempt to be comprehensive in the way that a categorisation of responses could be. Thus the personalised discussion, the clarification of the task at hand, criticism of lessons, personal attitudes to physics and a host of other detail in the transcripts is not incorporated in the frameworks.

There are some advantages and disadvantages to this view of frameworks - more to be considered in a moment.

First it is necessary to outline the elements that might compose a framework. The construction of a framework is a third stage of analysis. From individual conceptions it is possible to generate categories: from an examination of categories it is possible to construct frameworks.

As Engel and Driver (1982) suggest, a framework can be constructed from perceived commonalities between categories so that it is applicable beyond a single question context. As noted earlier, they contend that:

'A framework is a description of a perspective from which a prediction of events can be made, a perspective which, at the very minimum, should be demonstrated in more than one question context.'

The construction of a framework too, they argue, is influenced by the reporting of similar outlooks in other research studies: that is, outside even of the immediate research context. The inclusion of a 'predictive' element in a framework is important. For the frameworks to be useful, they must facilitate the construction of consequences from a line of argument. For example, Nussbaum and Novick (1981)
use frameworks in a classroom situation. The first part involves a teacher eliciting responses to a question about the evacuation of a glass flask by a hand pump. Students are asked to show on an outline drawing of the flask 'which part of the flask is left without air?' or 'where do you place the 'empty space'/'Vacuum' in your model?' The responses are not categorised in a formal way, the teacher moving around the class selects representatives of each type of drawing. In some way this can be seen as the enactment of implicit frameworks by the teacher selecting 'typical' drawings which are also going to allow her to raise points about it, what Nussbaum and Novick refer to as helping to 'differentiate meanings'. In the second part the students are asked to predict and apply the frameworks to explain a second event and question (to operate in another question context). The process is one of classroom debate where students are encouraged to make open and explicit their reasoning, hypothesising arguments and counter-arguments.

From this description, then, frameworks can be seen as 'arguing points', autonomous (in that they do not have to be personalised) and stable, across small, local, shifts of context.

In making this conceptual distinction, between conceptions, categories and frameworks, there is no suggestion that anyone is preferred to the others. Each has its own focus and limits, both in content and functionality. Conceptions focus on the personalised theorising and hypothesising of individuals. Each person's knowledge is unique (though not infinitely diverse) which greatly limits the generalisability of the single case. Categories of response focus on
multiple data. They represent plausible, functional subdivisions of bulk data according to some features ascribed by the researcher. The number, and type of categories depends upon the nature of the data (and the data gathering methods) and of the choices made by the analyst (as is argued in Bliss, Monk and Ogborn, 1983). What the frameworks lose in failing to represent closely the responses of any one individual, they gain in generaliseability across a narrow context. Frameworks focus upon a characterisation of responses and are more consistently stable because they (by design) bridge small local changes in context. They might, however, be seen as 'labels', in the manner of any stereotype, by which to classify individuals: Sutton (1982) hints at such a possible misuse of them. Such a use would indeed be a misrepresentation given that, as defined above, frameworks are to be seen as two levels removed from individual conceptions.

Both categories and frameworks are illustrated further in the next sections - conceptions in the next chapter. To summarise this discussion use is made of a diagram in Engel and Driver (1982), in this case modified and amended to highlight the points made here.

![Diagram](Figure 12)
The dimension on the vertical axis reflects the degree of individuality or generaliseability of the accounts in the data. The horizontal axis suggests a dimension between delicate and gross levels of accounts of the data, in a similar way to the terms used by Bliss, Monk, and Ogborn (1983).

Before moving to the next section a comment is necessary about the choice of extracts and about some of the questions they portray. The extracts are not always the most powerful examples of a particular framework. They have been chosen largely for five reasons:

a. They are good examples of the framework
b. They are fairly concise and short.
c. They make explicit reference to detail in instance cards.
d. They span more than one card.
e. That, for any one framework, there are examples from at least two of the three age bands.

It is important that an extract should exemplify the framework and at the same time span more than one specific instance card, in order to give some indication of the generality of the framework. Some effort has been made to indicate the cards under discussion each time. It is not always possible to choose extracts that are concise enough, in that discussion may take place over several transcript pages and can be returned to, as a developing topic, over several sections of the interview. This commonly occurs at the end of discussion of each card as they are compared to others. This extended development of arguments is an
feature of the interviews since early tentative conceptions are strengthened and modified in the light of continued discussion. This makes the choice of pithy extracts difficult since many of the references within a given section may be in previous (and in some cases future) discussion. Here, the terms exophoric, anaphoric and cataphoric, are borrowed from linguistics to describe referent predication.

Exophoric reference is where an item relies for its interpretation on the presence of information in the context of the situation (that is, outside the transcript text). In such cases an extract has not been used unless augmented by specific /bracketed/ field notes. Students may point to one of an array of cards (referring to them as 'those' 'that' or 'it'), or to apparatus in the room, pictures on the wall and so on. Anaphoric reference (references backwards in time in the interview) to 'it', 'that' etcetera again need careful documentation. In the interviews it has often been simpler to make explicit what is being referred to. 'You mean the melting ice' is a typical interviewer interjection to make clear on the tape recording the subject of discussion, or of previous discussion. This is not always possible since over, say, a five minute period of discussion it is abundantly clear to both participants what the topic of discussion is, and repeated confirmation by the interviewer for tape recording purposes is a barrier to animated and cohesive talk.

In a few cases, where students commandeer the pack of cards and make reference to cards yet to be discussed, their comments can be seen as forward referencing, or

4.24
cataphoric. Again, this makes the extract difficult to use unless carefully annotated. Some of the extracts concern only one card and in such cases an extract has been chosen where the discussion begins in the specific detail and context of the situation but then becomes more general and wide ranging.

The vast majority of extracts are intended as serious discussion except where some humour is signalled and this is noted by a laugh. A laugh sometimes indicates embarrassment and this is noted separately. In the interviews humour is generally quite obvious. In the following extract for example, Y is teasing the interviewer for his picture in the light card 'a bright red painting'. The card is presented as a black and white line drawing and the work of art as an impressionistic doodle. Y finds it funny to consider a red painting in black and white and then suggests that it might be:

Y. yes... its a fire engine in a red sunset on Mars... yes very good. (Y,4L)

The extracts, too, illustrate the style and type of questions employed. On the whole, they intend to be facilitative ('what do you think...?'); as classificatory ('what do you mean by...?'); and as reflecting some part of the previous response to encourage further comment. Some questions are more probing (usually 'why' questions), and 'challenging', in the sense that the interviewer contrasts two sets of response that might be seen as conflicting. Desirable as it is to portray an adept and untainted interviewing performance, a close scrutiny would undoubtedly reveal some
examples of leading or loaded questions. Such issues are discussed in a later chapter under 'methodological checks'.

The following sections describe frameworks for the main concepts and ways in which they are seen to be related.

4.3: Frameworks for the Main Concepts

The frameworks for the four main concepts are discussed in the order energy, force, heat and light. Each set of frameworks is presented in a summary table and then elucidated and illustrated with sample extracts from the transcripts. The extracts are numbered sequentially and, as has already been indicated, are suffixed with a (bracketed) group number that relates them to one of the three age groups in the table in figure 7. In some cases the extracts have been tidied and de-personalised in minor ways; the utterance numbers used in the original transcripts (see appendix III have been erased, along with some of the anacolutha and redundant repetition of words. For example in some instances, as a person attempts to form a sentence to express a difficult argument, they may repeat a word like 'if':

'if.. if.. if.. if.. if.. you really mean....'

This type of anacolutha is highly suggestive of deep consideration and deliberation but is omitted here for the sake of clarity and brevity. It is not all removed in some descriptions (often of individual conceptions) where it is used to evidence some changes in argumentative stance or base. The extract numbers and suffixes are cross referenced in the table in appendix II.
E: The Energy Frameworks

A case is made here for each of the frameworks in turn. They are summarised in figure 13 and are presented in alphabetical order according to the characterising name they have been given. Clearly there are many interrelations between the frameworks both within a particular concept area and between concepts. Here the frameworks are detailed and discussion of the relationships is left for the following chapters.

A-E: Anthropo-morphic/-centric Framework

This framework bridges two main categories of response and generally concerns 'human centred' responses. These two relate to human-like and human-caused action. The framework encapsulates responses where energy is seen as a vitalistic entity concerned with living creatures. Other active, but inanimate, objects are described analogously in humanistic terms. There is clear evidence in some responses that the descriptions are analogous, in others it is more difficult to separate analogy from a literal, animistic use of descriptors. The three following extracts illustrate the framework.

Extract 2

I. ... someone pushing a box up a hill... what about that one?

C. ... yes I think it would /be an example of energy/ because umh...(10)... I think that's why we eat to .. umh... collect the energy to push things to... umh... kind of walk... so I think I'd put it /as an example/ because he is a source of energy... he pushes on the box up the hill.

I. has the box any energy?
<table>
<thead>
<tr>
<th>A-E</th>
<th>Anthropomorphic Anthropocentric energy</th>
<th>Energy is 'human centred'; certain objects are endowed with human attributes; it is internal to the object and lasts for an active 'life time'.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-E</td>
<td>Depository energy</td>
<td>Energy is seen as deposited in certain objects, is inherent to their composition. This results in different kinds of energy, each kind internal and consumable - of relatively short duration.</td>
</tr>
<tr>
<td>F-E</td>
<td>Functional energy</td>
<td>Energy is deliberately contrived, often a commodity for technological convenience. It is manufactured, external to objects is in continuous supply on demand.</td>
</tr>
<tr>
<td>I-E</td>
<td>Ingredient energy</td>
<td>Energy is not continuous but is a triggering of dormant ingredients. A combination of items and events produce discrete bursts. There are different kinds of energy depending on the various combinations.</td>
</tr>
<tr>
<td>O-E</td>
<td>Ostensive energy</td>
<td>Energy is described in terms of overt occurrences during the performance of some activity. It is often signalled by participle phrasing.</td>
</tr>
<tr>
<td>P-E</td>
<td>Produced energy</td>
<td>Energy is generated as a consequence of some mechanism - a continuous process of energy production. There is one kind, internally produced, externally released, often as a 'surplus' to needs.</td>
</tr>
<tr>
<td>T-E</td>
<td>Transfer energy</td>
<td>Energy is transferred from place to place, object to object. There is one kind which 'metamorphoses' and appears in different guises. It is externally derived and in continuous supply.</td>
</tr>
</tbody>
</table>

Figure 13
C. ... (4)... no... because its just a box.  
(C1,3E)

Extract 3
/card: sledging down a hill, E9/

C2. ... obviously the boy or the man has used energy to get the... sledge up the hill... like the man pushing the box up the hill /referring to another card already discussed/... and it's exhilarating coming down the hill fast so he's enjoying it... so to him its worth pulling the sledge up the hill... to come down really fast at the end and sit down... umh... energy... I don't see any real energy there... apart from the man using his own physical energy to push the sledge up the hill...  
(C2,3E)

Extract 4
/Card, E11/

I. an alarm clock... this is one of those ones with a luminous dial and a bell on the top.

S. ... well... I wouldn't have thought there's energy... /not/ the same sort of energy as the sledge because that's /the clock/... doing something automatically... its just doing it... it hasn't got much thought behind it.

I. how do you mean?

S. well you actually make the sledge go down the hill but that /the clock/ is just there... it doesn't do much.  
(S,4E)

The clock is not regarded in the same way as the sledge because it is not seen as having a part in purposeful (human) action - it has no 'thought' behind it. Similarly, in the second extract the sledge itself is not seen as having energy, rather the focus of the discussion is the exhilaration and fun of sledging that is entirely human centred. As in the first extract, energy is seen as being in fairly short 'lived' human physical exertion and not in inanimate

4.29
boxes or sledges.

Stead's (1980b) work has already been discussed, the similarities in methodology and approach noted. She reports a category of response she calls 'everyday' uses of the word energy where it is used very anthropocentrically. The children interviewed used it to describe actions by way of being 'energetic'.

Animistic or anthropomorphic comments are more commonly restricted to short phrases where an object may 'want', or 'not want', may 'try' or not be able to 'manage' to do something. A clearer example of an animistic response is extract 5:

**Extract 5**
/Reaction, E6/

J. ... they /two reacting chemicals/ have energy in them... I mean they don't go around talking to things... but I mean they've got energy in them... so I suppose in their own sort of way they are living.

(J,6E)

**D-E: Depository Energy**

This framework typifies two categories of response. The first categories, those responses where students regard energy as resident within certain objects, so that batteries, chemicals, water, coal and so on, all have their own internal source of energy. The second category collates responses where such energies are seen as being intrinsically distinct and having different names. In this way, the energy within chemicals is known as chemical energy and is treated as being in a separate taxonomic group from, say, electrical energy.
For many students, to name a type of energy as being involved in a situation is itself a reasonable response. That is, to name it is to describe it - which in turn goes some way to explaining it. When pressed, the energy is discussed as a causal agent distinctive of the material or objects under discussion - inherent to their composition. The energy in turn acts upon other objects to compel them into action. As the cause is removed, or the energy consumed ('used up'), so the activity stops.

Extract 6

I. what would you say it /energy/ is?

M. ... something in lots of different forms... it can come from inside ourselves so we can produce energy... to do everyday things... and the sun will produce energy ... there's electrical energy and heat energy... all sorts of examples. (M,4E)

Extract 7

J. ... well energy's different sorts of things really... like energy in the body... and energy used up by things like /electrical/ power... and there's chemical energy.

I. what do you mean by chemical energy?

J. umh... energy's... I don't know... chemical energy is energy produced by chemicals

(later)

J. ... if something moves its got to have energy... its got to be there... its going to have energy inside it.

I. do you think that everything has got energy inside it?

J. no not really... I mean I don't know if a table's got energy in it... I suppose it has but I'm not really sure.

I. you said something about moving... what if it /an object/ moves... what then?
J. well if it's moving... yes... it'll have energy inside it.

I. why do you say that?

J. .... because I think the energy ... that if it /the object/ is still... the energy's going to be building up inside it... well potential energy... and then it moves. (J1,4E)

This rather longer extract is intended to illustrate the framework, showing both the naming and categorising of different energies and their interiorisation within certain objects. Chemical energy is the energy in chemicals; potential energy is an inner - pent-up - motive energy. The framework is pithily summarised by Clement's (1982) expression, a 'source of force'. Some objects are seen as having inner deposits of energy which are sometimes re-chargeable (as in humans, or electrical cells) and sometimes entirely consumable (oil, coal and so on).

The notion of an internal, active agent has, according to Elkana (1974), a long history as an explanatory device; the 'power' within things enabling them to act has often been used in the same terms as these descriptions of energy. Saying so much is a point of passing interest rather than an ontological premise.

F-E: Functional Energy

This framework incorporates a teleological component. Energy does not occur 'naturally' but is purposefully produced in order to do work - that is, some 'useful' activity. In this sense it is contrived as a matter of convenience. In extract number eight below, for example, J makes a distinction
between activities that are 'natural' and require no energy, and those which are purposeful and therefore require energy to be produced for them.

Extract 8
/Card El8/

I. listening to a radio and falls over a cliff... what do you think about that?

J. well the radio's got energy... no I don't think he's got energy if he falls over with the radio /laughs/

I. why do you think the radio has?

J. well its... its like its got wires in it and all that. .. like transmitting energy... that's what I think anyway... its like a little power station... its got a transformer so its sort of like a power station... and.. yes... if its a power station its got a lot of energy hasn't it

I. why do you say that?

J. because that produces the energy... they have it for houses... and put the energy in... it goes in all the wires to go where ever its going

I. how does it produce it?

J. ...... chemicals I suppose...... scientists make it /later, card E9/

I. somebody just sledging down a hill...

J. ... the person's got some energy to hold on... if he was weak he'd let go and fall off... but the sledge has no energy... it's the hill just slows it down naturally... anybody can fall down

I. I see

J. the person's got energy to grip... to keep his balance

I. but the sledge hasn't?

J. no... well if you put anything on the edge /of the cliff, the brow of the hill/ it'll fall down because its not balanced properly... but no... like if you touch the sledge you wouldn't get an electric shock would you... you're not putting chemicals in that to make it work are you? (J2,3E)

4.33
J2 is making the point (quite forcibly with his final rhetorical questions) that falling over the cliff is not a deliberate act and so requires little or no energy, that energy is manufactured (by scientists) in power stations and that were the sledge to be 'energised' it would require either electricity or chemicals. Extracts 9 and 10 are much shorter but make similar points:

**Extract 9**

J. energy has... got to make something else work... like if it was electrical... you know, like that tape recorder... making that work... I think there's energy all around us /points to equipment on shelves and benches in the prep. room/

I. /indicating 'power station' card/ why do they call them power stations and not... say... energy stations?

J. .... because there's energy there... but it gives power to something else... gives something else the power to move or something else the power to work (J2,4E)

**Extract 10**

H. ... well we need energy to move things and that... and to... you need energy for electricity and that ... if you didn't have energy you wouldn't be able to have lights or anything

I. uha

H. ... well you need energy to work things don't you

I. what are you thinking of?

H. like the fridge or something like that... hair dryer ... or the washing machine (H,4E)

Duit in his (1981) study, notes a similar tendency in students' responses and says that 'for a life without

4.34
technical aids it seems no energy would be needed'. This framework suggests an externalised, manufactured general purpose type of fuel that provides the motive 'power' for mechanical devices (for example 'power tools' or 'power packs'). Actions can occur without it, but, in such cases, the occurrences are 'natural' or are instigated by some other causal agent. It is in continuous supply as required (or, as some suggest, whilst world stocks last). Like the other frameworks this goes beyond one particular situation card context or specific question.

I-E: Ingredient Energy

In this framework energy is not so much a causal agent, a catalyst to action, but is more a dormant ingredient awaiting some catalysing mechanism to release it. In differing situations the emphasis will shift between the ingredients themselves and the triggering mechanism. For example, for some the presence of energy in food is less important than the process of eating it - it is this that produces the energy. As Solomon (1980) points out:

'pupils believe that energy is not stored in food, it only 'gives you energy when you eat it'". For others, the mechanism occurs but is overshadowed by the necessary ingredients since, were they not present, no amount of triggering would produce energy. This framework pervades much of S's transcript on energy, extract number eleven, of course, being only part of it.
Extract 11

/S is discussing energy in relation to food, E7/

S. ... well its actually when you eat it... you sort of ... its sort of all stored up and then its released into... wherever you want... the part of your body its needed

I. do you mean it is part of it? /food/

S. it is... but... you've got to do something to it before it can release the energy

I. so when you digest it?

S. yes... its sort of like coal... you've got to burn it before you can get the steam out of it to produce the energy

/later/

S. there is energy... some sort of stored energy in the wires and in /a/ battery... but you have to join the whole circuit up.. before the energy can be let loose to go to the bulb and light it up

I. what sort of form would it take in the battery when its stored?

/S has introduced the notion of 'forms' of energy in earlier parts of the transcript/

S. ........ well I suppose it is just there....I mean its just waiting until its let loose. (S, 4E)

Extract 12

J. Things have energy stored in things... its there but needs another energy to... sort of... another form of energy to sort of make it come out... you know what I mean... like a seed needs... its got energy inside it to grow but it needs the sun... another form of energy

I. I see... and here? /indicates the 'chemical reaction' card, E6/

J. umh... one chemical needs another chemical to react (J1,4E)
Extract 13

/M has been asked if the card depicting a battery and bulb (E2) seems to her to be similar to any of the other cards she has discussed/

M. ......... I'd say that one /a card depicting two people before, and as, they collide (E,12)/... of them

I. why that one?

M. because it /the battery/ isn't connected up... isn't producing any sort of energy... when its joined up it'll produce energy

I. and what of the people? /in the collision picture/

M. yes... they're not producing anything until they've sort of banged together or connected together like that /in the collision/

(M,4E)

Extract 14

/D is discussing the flower-in-a-pot card, E14/

D. yea... well the flower receives... light energy from the sun... heat... and that gives it the energy to grow

I. the energy to grow

D. yes... from the sun... from its food it gets its food from the sun, from the soil.. water... that gives it the energy to grow

I. has water energy?

D. ......... no... umh... things all combine to make energy... then they all get together to produce energy to get it to grow

(D,4E)

Some see energy, then, as being present but requiring some other action to make it apparent whilst others see it operating in combination as ingredients come together. It is not continuously produced, is intermittent, and is of different kinds depending upon the various combinations. As the extracts have been chosen to show, the framework spans
a range of situations and contexts.

O-E: Ostensive Energy

Responses across a range of cards suggest that energy is seen as obvious, manifest activity. Not only is activity in some form used as a means of identifying energy, the activities themselves are often called energy itself. The most common example is that of movement, and is commonly signalled within the descriptive discourse of the transcripts by students equating energy with verbs. Hence energy is moving, doing, running etcetera.

Extract 15
/card E9/
I. sledging down a hill... what about energy in that one?
G. it's in moving downhill... going fast... its the sledge
I. the sledge... why that?
G. its... creating energy by moving fast (G,E9)

Extract 16
I. what about something like clouds? /introduces the card on clouds' (E16)/
S. ... uh.... that hasn't got much energy
I. no?... is it similar to any of the others? /cards she has discussed/
S. ...... I suppose the snow one but... the snow would have slightly more energy than that because... well the snow's actually doing something but they're just sitting there
I. you mean that /clouds/ is sort of snow up in the sky?
S. yes.... that snow is actually... doing something... its moving... its got the energy there where it's let loose whereas that /in the clouds/ sort of stored I suppose (S,4E)

Extract 17
I. what would you say energy was?
C. its movement... like anything moving... like umh somebody going down a hill is energy (C,4E)

Extract 18
I. here they are running /'collision' card (E,12)/
J. yes that has /energy/... the running's got the energy ... the movement... that's an energy but I don't know about this
I. what... where they've clashed together?
J. yea... well they stop and it /energy/ stops as well (J3,3E)

Whilst these extracts have emphasised 'doing', 'going' 'running' and 'moving', other verbs like frothing, boiling, ringing, shouting and so on have also been used as students own examples of energy.

P-E: Produced Energy

Much discussion of energy describes it as being 'produced'. It is produced 'by', 'when', 'as' things happen and seems to be in addition to some event. For example, if two chemicals react they produce energy rather than, say, requiring energy for the reaction, or being energy themselves. Some students describe at length the process of production (in

4.39
terms of, say, resistance to electrons within the filament of a light bulb), a mechanism which produces energy both for the needs in hand (to continue the electron movement) with a surplus amount (to appear as light in the bulb). Commonly there is only one kind of energy though many processes of production, it is produced internally within mechanisms yet released externally, is continuously produced which, since only certain amounts are used, results in the surplus. Stead (1980b) has also noted such responses. She describes them as treating energy rather as a waste product, as with smoke, sweat or exhaust fumes, is 'produced' and 'given off'.

Extract 19
/card E6/
I. a chemical reaction...
J. ... umh... when they react it gives off energy... and the energy produces something...
I. what are you thinking of?
J. umh... sometimes it produces colour /in the reaction/... sometimes sugar... things like that (J5,3E)

Extract 20
K. There's definitely energy involved /in a chemical reaction/... it was originally caused by some mechanism in the atoms... the atoms of whatever have been reacted and it is now released as heat... into the surroundings (K,6F)

Extract 21
/card E2/
J. ... umh well there's... in the bulb there's a little wire and it is... umh... its like a resistor to the electrons flowing through and... and as the electrons
flow through it's just like a force... like a pressure... and it sort of holds them up a bit as they come through the bulb...

I. and what about energy?

J. yes... and as the electrons flow through the bulb... it becomes hot and it produces energy and it gives off light

(J2,4E)

Extract 22
/card E7/

I. eating a meal /introduces a new card/

P. ...... there's energy in actually taking in the meal...

I. how do you mean?

P. well there's energy produced when the meal is eaten... then the meal is actually giving you energy to do something else... it builds up in you

I. I see

P. if things are still /do not move/ the energy sort of builds up and as they move... they sort of use the energy

I. if they are staying still they're building up energy?

P. yes... well if they're staying still they're using up a only a little bit of energy but not as much as if they were doing something

/later/

I think the energy's... well they're building up energy for the next day... but their body is also using up energy to... make sure everything's alright inside the body as well... using /it/ for a heartbeat... flow of blood round the body... I think there's energy in the muscles as well... building up for the next day

(P1,4E)

Similar conversations surround discussions of power stations where energy is seen as produced in continuous manufacture somewhere in the innards of machinery, and is then released externally both as a necessary artefact and, sometimes, as
a waste product that is lost (by heat, disuse and so on)

**T-E: Transfer Energy**

This framework embodies what Warren (1982) calls a 'metamorphosis' model of energy. He makes the point that it is both an implicit and sometimes explicit assumption behind the way in which the concept is commonly taught. In being transferred, energy is seen as being capable of flowing (fluid-like) from system to system, and from object to object. It is essentially the same kind of entity that appears in different guises or 'forms'. In this way it can be 'transferred' 'given to' and 'be seen as'. Energy is thus (sic) externally applied and in continuous but changing modes.

**Extract 23**

/K is discussing the 'battery and bulb' card, E2/

I. and the energy?

K. but the energy is on the electrons as they travel round... it is given up when they come to the light bulb and the electrons are still there to travel back to the battery

I. and would they have any left?

K. I should think they must have some left yes... (8).

I. what are you thinking of?

K. I'm trying to think of how energy is stored on an electron... to be given up... I don't know exactly how an electron gets round to carrying some energy to a certain point in the lead where it can then give it up and then... you know... travel on its way... it
obviously is doing that because we've got energy at
the light that wasn't there before
(K,6E)

Extract 24

/Card E2/

M. I suppose there's energy all along the wires but you
can't see it and... the only way you can see that
there's energy is with that... when its in the bulb
/points to bulb/
(M,4E)

Extract 25

/L is discussing the card depicting a beaker of hot water,
E,4/

L. well energy would go into the water... the glass of the
beaker... the thermometer whatever...

I. aha

L. and the air above the water... and where it's /the
beaker/ been on the bench... but if you say 'where is
the energy' then its never going to sort of stay in
one place at one time... its going to go anywhere...
sort of around... its slowly going somewhere like
to the bench and so on
(L,6E)

Extract 26

/G. there's a number of ways you can do it /operate a
power station/... nuclear reactors... nuclear reactions
form heat energy... which through a process is trans­
formed into electricity and sent out /along cables/
... you've got oil reactors... gas..... which is
basically used to give heat to water till it boils...
it gives steam... drives a turbine... to form elec­
tricity... there must be energy going into all that
through the boiling water. or burning oil... you're
putting energy into the water... which is then sort
of driving the turbines so... to get energy out
you've really got to put energy in
(G2,6E)
Whilst some of these extracts concentrate on energy in conjunction with electricity - either electricity being the energy that flows, or 'carrying' the energy along - these are not the only transfers. Energy is seen as going from rain, into soil and then through the roots into a plant for instance.

The relationships between these frameworks, and those in other concept areas are discussed in the following chapters. The next section here deals with the frameworks for force.

F: The Force Frameworks

The force frameworks are presented here in a manner similar to those for energy. First the summary table (Fig. 14) is presented and then the frameworks are discussed separately, in alphabetical order.

A-F: Affective Forces

The term affect is chosen to imply 'desire, especially as leading to action'. It is an attempt to summarise the anthropomorphic and anthropocentric features of students' responses. Osborne (1980) comments on these features of children's talk and calls them children's 'everyday views'. In this sense to be 'forced' to do something, or 'forcing' oneself to act, is contrasted with it happening 'naturally', or accidentally. This is an anthropocentric view, where objects are forced to do something by someone, and anthropomorphic where one object 'forces' another to act. More animistic terminology is included, too, where objects 'want'
<table>
<thead>
<tr>
<th>Framework</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-F</td>
<td>Force is 'human centred', some objects are endowed with human attributes. It is internal to the object or person and is short lived. It is an obligation to act, or a resistance to such an obligation.</td>
</tr>
<tr>
<td>C-F</td>
<td>Here, force is external to objects and is what keeps them stable, upright and in position. It acts continuously and ubiquitously and accounts for lack of movement.</td>
</tr>
<tr>
<td>D-F</td>
<td>Force is seen to 'activate' objects, those that 'have' force are those most likely to create an occurrence. It is internal and continuous - it is an inherent feature of certain objects. It is applied externally.</td>
</tr>
<tr>
<td>E-F</td>
<td>As an event takes place forces will appear at certain points: 'pressure points'. They do not always produce movement but can combine in different ways. They are temporary and are different kinds of forces and external to objects.</td>
</tr>
<tr>
<td>I-F</td>
<td>An obvious situation where forces occur is in collisions, both before the collision and as an immediate consequence of it. Hence it is both internal and external, usually only for the duration of the event itself.</td>
</tr>
<tr>
<td>M-F</td>
<td>Forces associated with movement are the most commonly reported, and often the only one commented on. They last only for the duration of the movement, are externally applied and of the same kind.</td>
</tr>
<tr>
<td>O-F</td>
<td>In this framework the event or activity seen as taking place is the force and accounts both for single activities and for a chain of events, force is of one kind, consumable and signalled by verbs in discourse. It transfers internally through objects.</td>
</tr>
<tr>
<td>S-F</td>
<td>Force is limited to large occurrences, not to small ones; is of one kind and happens intermittently</td>
</tr>
</tbody>
</table>

Figure 14
to return to a position, or 'try' to remain in place.

Extract 27
/V is discussing a large stone being dragged along by two people, F1/
V. ..... they're being forced to do it... when they don't want to...
I. I see
V. maybe in this one /in this picture/ they might not want to pull this... they might have been told to drag a huge stone... with some force here... they might be a bit upset and don't really want to do it (V,3F)

Extract 28
/Y is considering similarities between a number of cards already discussed: 'dragging the stone' (F1); 'being told what to do' (F3); and the 'rocket at take-off' (F2)/
Y. ... well they're all moving something against it's will aren't they... I mean look he's getting him to do something against his will /person being told/... they're trying to get the stone to move against its will and in this /rocket/ they're trying to get the rocket up against the will of... against the will of... you know ... the earth pulling it down
I. ahmm
Y. ... the earth says 'stay on the ground'... you know... but the rocket is saying 'no I want to go up'... so they're all trying to overcome that (Y,3F)

Extract 29
/D2, is discussing someone diving off a diving board, F4/
D2. ... umh... well... the... er... springboard's trying to force itself back upright because it was made straight and so it wants to remain straight. (D2,3F)
Extract 30

/D is considering a golfer hitting a golf ball (F8)/

D. ... umh as he /the golfer/ has swung around... he's hit the ball... and the ball was stationary... not going anywhere, just sitting on it's tee and... he's forced it to rise up in the air... against the will of gravity... the will of gravity was perfectly okay when it was sitting on the tee because it /the ball/ didn't want to do anything else... umh... except hold onto the tee... but as it is he's forced it to... to go away from gravity... he's forced it to rise up...

(D,6F)

Extract 31

/D3 is discussing the 'balloon' card (F12)/

D. ... it /the balloon/ has no force on it

I. none?

D. no force... /if released/ it just sort of travels along... like a spaceship that hasn't got any force /she refers to the 'rocket in space' card/

I. would it /the balloon/ ever come down again?

D. .... only if the balloon burst... if it bursts open

I. why would that bring it down?

D. ... 'cos you know the air in the balloon is gas... there is gas in the balloon which makes it float away... well all that will go in the air... and the balloon hasn't got that gas anymore, it opens up... so it goes back down again and the gravity is so happy that it can have the balloon back now... see its like that

(D3,3F)

Previously, D3 had been arguing that objects that rise are breaking 'gravity's rules', hence when they return to the ground they are presumably complying with those rules - to gravity's great relief.
C-F; Configurative Forces

A range of student responses can be interpreted as suggesting that objects have force by virtue of their position within a particular system or situation. It suggests some 'bonding' between objects that maintains them in a stable relationship with each other. Moreover, the suggestion is that without such forces objects would not stay in position, but would move apart. It is a framework that attempts to account both for the absence of movement and the restoration of objects to their 'normal', 'natural', 'usual' place or position. It is a force external to the object and is often referred to in non-specific terms as a 'force that holds it (sic) there' and so on. In many cases, this in reference to a gravitational effect, holding things in place, but sometimes the impression is created that it is a 'blanket', overlaying objects and keeping them immobile.

Extract 32

/S4 is talking about gravity in relation to a number of cards, in particular to the 'golfer' card (F8). She is arguing that gravity does not act on everything, but will on the golfball in flight./

S4. ... and that's a force... gravity is forcing it /the ball/ to come down

I. I see... you haven't mentioned gravity before

S4. no..... there's no gravity here /in the other pictures/ .... we're not liable to float up... are we?..... . unless we're on the moon /S laughs/... but here /the golfer card/ the gravity's not going to do anything to him... and here /people dragging a stone (F1)/ I can't see any gravity because it /the stone/ is actually stuck to the ground... and the same here /the diving board (F4)/ its forced to be actually stuck to something ... its secured .. but this /the golfball/ is free to go and to have gravity...

(S4,4F)
In this case, S reserves the term gravity for objects that can be projected and brought back down again, whilst the other objects she refers to are stuck and forced to remain grounded.

Extract 33

/L2 is discussing her own example of forces on a motorcyclist turning a corner/

L. there's something keeping him up... so he doesn't fall on the ground

I. how do you mean?

L. it's a pressure or something like that but I'm not sure

I. you think it's got

L. well its something that's keeping him up when he goes over... like that /she indicates the book-on-the-table card (F11) which she had argued was 'being held down. held in place'... it keeps him in position as he rides../ (L2,3F)

Extract 34

/C2 considers the 'diving off the diving board' card, F4/

C. I think there's probably some force here

I. what do you mean?

C. on the board... potential force I think... its holding it /the board/ back and its going to spring up and he's going to jump off it... and also gravity force as well... not now /as the diver is on the board/ but when he jumps up and falls into the pool... its pulling him down

I. and what happens as the person comes off the board?

C it rebounds and goes back to its normal... straight... position.

I. why does it do that?

C. well there's a force on all things keeping them in position and he /the diver/ uses a force to push the board down... and... well it gets pushed up again to /it's/ normal place (C2,4F)
Many of the responses used as evidence for this framework seem to focus on one particular object within the situation as 'having' force, or of forcing other objects. Force is seen to activate bodies and those that 'have' most force are those that are deemed most likely to create an occurrence. In many instances it is not a case of simply ignoring or disregarding other objects in the situation but of suggesting that they do not have force at all. The designated bodies are often those of people and so there is overlap between this framework and the affective framework. In this sense then, it is humans, (gas-filled) balloons, golf balls, and astronauts' boots, and so on, that have force and not their surrounding environment.

Extract 35
/card F13/
I. an astronaut in space... what about forces there?
J2 ... (16)... /laughs/
I. ....... what are you thinking of?
J2. /laughs/ well yes and no because ... umh... it can't be affected by gravity ... and yet he's so he's using ... well he is the force... himself because... I mean well he is moving (J2,4F)

Extract 36
/card F5/
L. yes /there is a force/... yes where the wind's blowing the tree there... the wind is the force in that one
I. and what would happen if the wind was to stop?
the tree would come back up...
why? why would it do that?
because there's no force... and it would just go straight back up...
does the tree have force?
no... that is how it is normally... it's a bit like rocket at take off/ the force is in the rocket that pushes it off the ground... well the wind pushes the tree... the diver /diving off a diving board/ is pushing with his feet... they're pushing the diving board

Extract 37
/T summarises her views over a number of cards, the 'golfer' (F8), 'rocket' (F2) and 'balloon' cards (F12)/
the force is contained within the guy /the golfer/... and... the golf club... and here there's something inside /the rocket/ forcing it up
and the balloon?
well... I can't see it having any /external/ propulsion ... its just in the nature of it... or in the nature of the gas inside it... I suppose it is a force inherent in the object.

Extract 38
/N is talking about the 'astronaut falling over on the moon' (F14)/
well he wouldn't fall backwards would he?
why not?
because they float about on the moon don't they
I see... so having tripped like that what do you think will happen next?
he might go like that /in an arc down towards the moon's surface/ but then he'd kind of just float around and of course... they wear those really heavy boots which brings them down nearer the ground... so they don't go flying off
I. how do the boots work?
N. because they're heavy... which pulls them down... there's a force in them because it pulls them down (N,4F)

Similar lines of argument were presented for the sledge moving down the hill (F9), the lit torch (F15) and so on. Seemingly, where something is seen to be happening, or about to happen, then it requires some force to make it occur.

E-F: Encounter Forces

This framework suggests forces that are not ubiquitous or general in any way, rather, many responses suggest immediate forces that apply at specific points and then cease to operate. In accounting for forces in this way, students often name them and catalogue them as different varieties of force. In some cases, for example where pressure, velocity, acceleration and power are all classed as different kinds of force, they might be seen to operate in combination to produce a particular effect. They are externally produced forces. The reason a golfball travels in an arc, for instance, might be because of a combination of (the 'force' of its) velocity, speed and gravity.

Extract 39
/D is discussing the 'golfer' cards (F8, F1) before including an example of his own/

D. so this force /from the golf club/ will only last to rise it /the golfball/ twenty feet and once it gets there it's tired out... it's finished and so gravity overcomes the force given to it and eventually pulls it down and... because it is going with such a velocity as it hits the ground it has elastic force inside... so it bounces and it bounces and it bounces and he gets an eagle or birdie or whatever /both laugh/
I. the bounce is smaller in each case isn't it... why does that happen?

D. the bounce is enough to get rid of gravity for a while so it bounces up but it wasn't quite as much as the initial push... so gravity is pulling down again and as it's pulling down it has accelerating force... so it punches the ground again...

/a moment later/

D. well if you exert a force against a football... it has done some work force for you... so it's finished... you've given that /the football/ some energy and it has shot off but... in shooting away its had to fight away other forces like friction on the ground and friction from air and gravity... rather force from gravity so its done work for you...

(D,6F)

This rather long extract gives some indication of the complex responses sometimes generated by the cards. Anthropomorphic aspects (like the golfball being 'tired out' and 'finished' its own forward force having to 'fight away' other forces) are intermixed with many other aspects like energy, gravity, elastic force, workforce (!), acceleration force and so on. Another extract indicates a similar argument:

Extract 40

/P2 considers the 'tree blown by the wind' card, (F5)/

P ...... yes well there's a force of the wind because of its speed... the speed of the wind... and there's a resistance here as the tree tries to push back... and its weight acting down...... when it /the tree/ moves... it has a sort of elastic force in a way it sort of springs about so its got a force which makes it spring back but the wind is much stronger so it blows it to one side...

(P2,6F)

In other studies, similar points have been made. Trowbridge and McDermott (1980) report how college students in an
introductory physics course use the concept of velocity in a number of different ways whilst also being able to give the orthodox definition of it. Saltiel and Malgrange (1980) show that for French eleven year olds and fourth year university students

'Forces and velocities are often intermixed even when all motion is uniform. Our results, together with our co-workers, point to the fact that velocities and forces exist 'per se', independently of reference frames, and are endowed with causal properties so that they are invoked to explain motion on a quite similar basis.'

I-F: Impact Forces

This framework and the following one are similar in that force is explicitly associated with motion. In this case, force is associated with the impact of collisions and the potential impact a moment before the collision. The force is in the movement: the act of moving means there is force present in the movement. This contrasts with the next framework where the force is given to an object to make it move, but is distinct from the movement itself. Both frameworks are common to those cards that indicate movement, particularly fast movement, like the rocket, golfball, sledge and so on. When, during the course of the interviews the students are asked to say what force is, some answer in the way of the first extract below:

Extract 41

I. what would you actually say a force is?

N. ... er... umh... a force is when something that's moving comes into contact with something that isn't ... or something that's moving slower... and then it moves it

(N,4F)
Extract 42

/V is discussing the 'rocket at take off' (F2)/

V. hum... the forces are the propulsion and you get a g-force from the speed

I. and what is a g-force?

V. when you're already taking off... at the height of speed... you're pushing into the air /in the rocket/ ... can really move..... 'cos you're travelling at such high speeds (V,3F)

Extract 43

/Card F8/

I. this one /card/ is a golfer...

D. umh.... the force of the ball travelling through the air... umh... yes... umh the movement... its moving through the air

I. this one /the golf ball landing/ is the next part... are there any forces here?

D. yes again there's movement force... the ball bouncing along... hitting the ground... its in the impact with the ground (D2,3F)

'Movement force', then is a way of describing the movement of an object in terms of force. It has echoes of the physics concept of momentum, but in these cases it is clearly not conserved in any way. Responses of this sort contrast with the following framework where movement is given by a force instead of being the force. It will be argued in the following chapters that such use of prepositions as 'under', 'on', 'by' and 'with' etcetera are useful guides to distinguishing conceptions - particularly where these have been picked up on, queried and clarified during the course of the interview.

4.55
M-F: Motive Forces

As in the case of the last framework, forces are commonly associated with movement - both as a means of identifying the presence of forces and of defining them. In this way, students will often declare an instance to be an example of force because 'there is some movement'. When asked for a description of force it is frequently 'something that produces movement'. One distinguishing feature between these two frameworks can be seen in answer to the question 'what happens when the golfball slows down?' For those who see the force as the movement (Framework I-F) then the focus of attention is on the speed of the ball. For example, they will say that the ball's force is reducing because the ball is slowing down. In contrast, those who see the force as external to (and the cause of) the movement, will reply that the ball is slowing down because the force given to it (by the golfer, club etc.) is being used up, or wearing off. Two somewhat longer extracts serve to illustrate this framework:

Extract 44

/C2 is talking about the 'golfer' (F8) and green (F9) cards together/

C. there's force on the ball... /the golfer/ hitting the ball... making it move

I. has the ball any forces on it at the moment? /in flight/

C. yes

I. where do you mean?

C. it's got forces of pushing there /on the ball/... they're pushing /he points in the direction of the ball's movement/
I. here the ball has landed... it has bounced and gone into the hole... what do you think is happening in that one? /I indicates 'golfing green' card/

C. the force is... it /the ball/ is falling down... it's loosing the force and then being forced back up and it bounces and then it just falls down the hole /he laughs/

I. each time the bounce gets smaller... why does that happen?

C. because it looses more force and because it's lost the force it hasn't got enough force to push it back up... higher

I. what do you mean when you say it looses the force?

C. it's just going... with that /the golf club/ the force is strong... and then it'll get lower up here somewhere /in mid air/... then it'll fall back down here... it'll bounce and each time it bounces it looses energy... like force...... in a car when it looses petrol... it sort of can sort of go up a hill with petrol and it can't make the same hill again with less petrol then when it hasn't got any petrol it won't bounce at all... like ... or move

I. I see... and what does energy have to do with force?

C. energy is a force... because it is being made to do things in machines (C2,3F)

Again, a long extract like this is indicative of a number of frameworks, particularly this final discussion about force and energy. This kind of overlap is discussed later. Here the extract is useful as an indication of the tendency to see forces as pushing the golf ball along in flight and being lost ('up there') and as it bounces.

Extract 45

/C1 is again discussing the 'golfer' (F8)/

I. what is happening here?

C. well the man's putting force from his arms into the
stick and hitting the ball and the ball's going where its told to go... well not always... if you're a good golfer it does

I. I see

C. and the ball's being forced up just like the rocket is... its got no choice... its being hit and it has to go up ... so the golfer's giving force to the ball

I. I see

C. but if the ball hadn't any force it would just stay there

I. and what about the ball now then? /in mid air/

C. well the force that the man put through the stick... through the club onto the ball has swiped it up into the air and eventually it will land and stop

I. this is the next part /indicates the 'ball landing' card, (F9)/

C. ... well that's where the power goes out... off the ball... I mean.. at first it had been right up in the air so it must loose power... and every time it bounces it looses power I suppose.. like a car will slow down if you take your foot off the accelerator

I. and what has power to do with force?

C. well... power is a force (Cl,4F)

Although both of these extracts are set around the golfball cards, similar arguments are put forward for the sledge coming down a hill, and as an argument for why the book on a table has no force. There would not be force unless it were to be given a force to move it.

O-F: Operative Forces

A number of responses depict forces in operational terms. That is, forces are known by what they accomplish rather than where they are sited or for their involvement
in movement. Thus a force is that which bends, twists, turns, moves, acts, pushes and generally produces occurrences. Force is not restricted to movement alone and is used to account for both isolated occurrences, and for chains of events. In this latter case, there is a sense of force being transferred internally through objects rather than being applied to them. Objects need to be in contact with each other or are sometimes 'joined' by air.

Extract 46
/P2 has been asked to describe what force is/
P. well the forces in these /pictures/ are... well they're tangible things that produce an effect... you can feel the effect... it's a physical thing
I. I see... what do you mean by tangible?
P. well you see... yes you see the result of a force... in this /dragging a large stone/ it is the result of the tension in the strings... that will move it (P2,6F)

Extract 47
/T is considering the 'tree blown by the wind' (F5)/
T. yes... I think where the wind is actually moving the tree then there must be a force.... I suppose the air is moving the force in.. into the tree and taking it with it..... actually going up the tree and pushing it and pulling it (T, 4F)

Extract 48
/S4 is talking about a person robbing a bank (F10/)
I. what would it have to be like for there to be a force?
S. well the bank robber would have to be in contact with the cashier in some way... either actually touching the cashier or having some sort of medium between the two
I. what do you mean by medium?

S. well it doesn't have to be a physical medium... like wind, you can't see wind but you can see the effects of wind

I. you mean in the tree one /card/?

S. yes... that would be the actual air molecules I should think

I. how do you mean? are the molecules the medium?

S. they are a mixture of both /a force and a medium/ the force is actually in the air... its provided by air currents but it uses itself as a medium... but if there is a physical force between two people then the people would be using themselves as a medium... pushing the force from one to the other... in the rocket picture they're using the thrust as a medium between the spaceship and the ground... (S4,6F)

This line of argument is one that accounts for forces by their actions and not by name or external pressure. It contrasts with framework D-F for instance, where forces are recognised at source. If there is an obvious seat of activity, then that is where the force is. Here, as in other cases, some event is taking place and students attempt to trace back from the event to a cause. And in doing so, they need to postulate an unbroken causal chain.

S-F: Substantive Forces

This framework is one that describes a size limit for forces. An action only qualifies for the name force if it is over some limit. That is, for some students, some situations fall outside of the range of convenience of their conceptions of force if they are associated with small events.
Extract 49

/T begins with the 'people dragging the stone' card F1/
T. there's force there...
I. why do you say that?
T. it is heavy... it looks quite heavy it's like that one /the 'rocket at take-off', F2/
I. why's that?
T. because the force comes down and makes it go up and its very strong and that's force... a very strong thing (T,3F)

Extract 50

/P is discussing the 'golfer' cards (F8) she decides that the instance of the ball on its way up is an example of force, but on its way down it isn't/
P. because it's quite high up there /in flight/ and here it gets smaller.... it doesn't go so high because that one /landing/ is not big like that one
I. what about here where it /the golfball/ lands?
P. no... that's not a force..... as that one /hitting the ball/ is... its got to be big to force it (P,3F)

Extract 51

/D1 has been asked to describe what force is/
D. ... forced to do something... umh something hitting something... like a hammer... yes something really big
I. what are you thinking of?
D. a car crash or something... colliding very fast... you wouldn't say force about something small like a feather (D1,3F)

This kind of framework, where the magnitude of the causal agent is involved, is not apparent in the energy interviews. The youngsters it would seem, are willing to
countenance very small activities as being within the range of convenience of their term energy. For these students, however, it would seem that force is synonymous with being large, so that students would use it in the same sense as power or powerful. To have force, or to be forceful, in this sense is not seen to be the property of small things.

In a similar way, there are three 'substantive' frameworks in the next set: the frameworks for heat. Each one has a range of convenience that embraces heat only in certain ranges of scale. Along with the other frameworks these are described in detail in what follows.

H: The Heat Frameworks

As before, these heat frameworks are set out in a summary table (Figure 15) and are then established and exemplified separately. The three frameworks mentioned above are here called 'Conspicuous heat' (C-H), 'Normal heat' (N-H) and 'Standard heat' (S-H). As with the other frameworks these are presented in alphabetical order in amongst the other ones, and the clear and obvious links to be made between them are left for the next chapters.

C-H: Conspicuous Heat

This framework summarises those responses where heat is seen as the property of obvious, prominent sources. Heat is associated with things that are very hot (as opposed to merely warm or cool) and is 'given off' to the surroundings. No mechanism is offered for the 'giving off'. Hot
Conspicuous Framework

Heat is very obvious hot sources; it is given off by hot objects. Other objects in the surroundings receive heat from such external sources. Heat is anything that is very hot.

Dynamic Framework

Heat is associated with movement. It both produces movement and is produced by movement. It is commonly generated internally and expended externally.

Motile Framework

Heat is transferred, by a range of mechanisms, from one location to another. It is not static but spreads out, or is 'given off', into the immediate environment.

Normal Framework

Normal heat is body temperature, so that cold is seen as anything below normal and hot anything above. It is an anthropocentric framework that sees heat, and the norms for heat, as being concerned with humans.

Product Framework

A distinction is made between 'manufactured' and 'natural' heat. Natural heat is seen as a consequence of other activities, as a by-product of the central activity.

Standard Framework

Ice is used as an external standard so that cold is seen as being below freezing, to be above 0° is to have heat. As in other frameworks cold is the absence of heat, in this case the melting point is the mid point of the scale.

Regional Framework

Heat is static and pervades a particular location. In cooling it remains in certain locales and reduces. Some of the localities are the periphery of objects, others the central regions.

Figure 15
things are obvious, often need no further explanation, and are detected by sensory experience (touch, luminescence, colour, etcetera). Objects in the surroundings receive their heat from such external sources. Some of the terms used express heat as a verb so that things 'are heated'; heating is what heaters or hot things do.

Extract 52

/P is considering a flower in a pot (H7)/
P. ... no.... that's not hot... there's no heat there
I. why do you say that?
P. I just don't think there is... no
I. how would you describe heat to somebody?... what would you say it is?
P. ... well... just heat is hot... they should know what heat is
(P,3H)

Extract 53

I. how would you describe /heat/ it to... say a friend?
J. oh I'd show her the fire and I'd show that's heat coming out... that is heat.central heating and things like that
I. anything else?
J. umh... hot water... a cooker... the fire and central heating... lighter... matches... the sun... the sun, that's hot
/a moment later she reconsiders the card showing ice melting, H6/
and that's not hot... no heat there at all
(J,3H)

Extract 54

/P is discussing the card showing a person throwing a stone off a cliff (H11). She has decided that there is no heat present/.
P. ....... there isn't any heat given off there as far as I can see... no. I can't see any heat coming off there at all /laughs/

I. go on... why do you say that?

P. because heat is something that is given off... when something is hot.... I know that's not a very good way of putting it... but for example, if you light a match and put your hand over it you get burnt... heat is hot and heat is given off in that way... something gives off heat.... a flame's hot...

(P,6H)

Despite P's modesty about her description, this is a suitable summary of a common point of view. Objects are described as 'visibly' hot, 'noticeably' hot to the point that, when one student was asked to describe heat to a mythical friend he said 'he'd be pretty backward if he didn't know what it is'.

D-H: Dynamic Heat

Dynamic, here, is intended as active, energetic, or allied to (concerned with) motion. There are two main aspects to the framework:

a. heat produces movement

b. movement produces heat

In some cases the framework can be evidenced from general statements students make about both movement and heat, in some cases, they are more specific and describe particular mechanisms. For example, some suggest that body heat is produced by 'internal friction' in the movement of limbs and examples of this are given below. In a number of instances both aspects of the framework are used without any perception of tautology, circularity of argument or sense of contradiction.
They are often seen as complementary aspects where both heat and motion are concerned. For instance, heat is seen as being required in a person's body (generally derived from food) in order to perform exercise (one needs to do 'warming up' exercises and so on). This movement, or exertion, then in turn generates heat which is 'given off'. Extracts 55 and 56 below, give some examples of this set of responses.

Extract 55
/C2 first discusses the 'flower in the pot' (H7) and then, a moment later, moves on to the card that shows two people having an argument (H13)/

C. it /the flower/ needs to be fairly warm otherwise it will die.... it won't be able to make its food

I. make its food?

C. yes but not the way we do... we digest our food... we take our food in... as chemicals... it gets changed inside to produce heat and to move about and to do things /later/
yes... they /the people arguing/ are giving off heat because they're moving as they get worked up and bothered

I. what does that mean?

C. well if you move... generally you produce more heat...
.... sometimes if you're moving a lot... if you are in an argument or something you produce a lot of heat (C2,4H)

Extract 56
/N is discussing a class experiment where someone is hammering a piece of lead, and then she turns her attention to a range of the cards/.

N. when you bang it.... it probably releases heat

I. why does that happen?

N. because when you bang your hand all this heat comes out /laughs/... because when you bang it you're giving

4.66
Molecular movement is a common theme and is used to explain increased blood flow during exercise because the blood molecules would circulate more quickly, and the operation of an electric kettle by the electricity galvanising the water molecules by shocking them into increased activity. This framework considers only the role of movement in the generation of heat and not the movement or transfer of heat itself. This is considered in the next framework.

M-H: Motile Heat

The term 'given off' is by far the most common description for the transfer or, usually, the end-point for heat. The means by which it moves - and the reasons for it to move - are varied. One or two students use terms like radiate or conduct, though these terms themselves disguise a range of modes of travel. Some suggest expressions like heat 'beaming', or heat 'rays' without a description of the mechanism. Motile means capable of motion and this framework summarises those responses over a range
of cards where heat was not viewed as a static entity.

**Extract 57**

/C1 is talking about a house standing in sunshine (H9)/

C. yes there's heat coming from the sun

I. from the sun

C. yes it's something to do with molecules

I. what do they do?

C. no... its beta rays or something like that... umh minus electrons or something like that... and they give out rays

I. and they're coming from the sun?

C. they're being given off... well they are coming out of it yes... and they just surround the whole atmosphere I suppose... wherever the sun is /C later describes photosynthesis in a flower, H7/

C. well its /the flower/ got like veins and that... that carries the food and keeps it alive

I. you said something about sunshine and photons... what are they?

C. I imagine they are probably the beta rays that come from the sun.

(Cl,4H)

**Extract 58**

/C1 describes an iron bar which has one end in a burner flame and the other under a flow of tap water, H5/

C. I think the water at the end would be getting warmer

I. why do you think that?

C. because its a conductor of heat... well slightly... the metal is anyway... it conducts the heat

I. what do you mean by that?

C. conductor?... its when the molecules that have been heated move along isn't it? they vibrate along

I. I see... and what happens to the molecules?
C  well they just move about everywhere and... we did diffusion yesterday in biology... and heat is when they sort of spread themselves out... I think it's with water and gas mainly but I suppose it would happen with the molecules in metal... they would spread themselves out.

(Cl, 3H)

For Cl (3H) heat is conducted by the molecules spreading out down the bar and this fitting with a model of molecules vibrating in a conductor. It also seems coherent with a diffusion model (taught the day before) for gasses and liquids. Cl (4H)'s model is also a 'particulate' transfer of heat, in that case, the particles being beta particles.

As suggested, a mechanism for 'spread' or 'flow' is not always given but does suggest that students treat heat as capable of movement.

N-H: Normal Heat

The norm for normal heat in this framework is body temperature. The framework summarises responses which are very anthropocentric. That is, heat is seen as anything hotter than 'me', cold is anything colder than 'me'. The range is continuous from very cold to very hot with body temperature at the mid point. Again, this is a common type of response: in extract 59 below, D1 has argued consistently that this is the case. He then goes on to describe an experience at an outdoor swimming pool.

Extract 59

/D1 talks first about a poster showing mountains by the sea - as part of the 'rain cycle' - that is on the wall/

D. yes that would be hot on there /the mountains/ because
if you go and stand next to a wall when the sun is kind of beaming on it... it'd be hot... it is for me anyway... the water /sea/ might be hot because when it rains the water is hotter

I. oh?

D. I've found that out... when we was at some open air pool and it poured down we went in... it seemed to get hot for some reason

I. the water in the pool?

D. yes... if it is raining then the water in the pool gets hot but if the sun was on it it won't get so hot

I. that seems funny somehow doesn't it?

D. yes I know... I don't know why... most probably because the umh... rain that's coming down is warmer

I. and when you got back in

D. yes it was hotter... as soon as it stopped raining we got in it felt much hotter (D1,3H)

Extract 60

J. that /some melting ice, (H6)/ is the total opposite to that /a hot pie (H3)/ for a person

I. opposite?

J. yes its lack of heat /ice/ to hot /the pie/ with umh a... human comfort point in the middle somewhere (J,4H)

Extract 61

/R1 is describing the 'iron bar' picture (H5)/

R. right... the iron bar is being heated up by the bunsen burner because of the flame... so this /end/ will be warming up... it should be getting quite hot... but if this is a cold water tap that's on there it will be cooling so that will be cold

I. and what will happen in the middle

R. in the middle... well there's no cold in the middle... the molecules will be moving so there's no cold... it will be normal (R1,4H)
Many more the the students referred only to human participants in the pictures; deciding whether they would be warm or cold as they threw stones, were running or exploring space and so on. Some described 'normal' as a 'comfortable' heat and noted objects, like houses, as being 'nice and comfortable' suggesting a pleasant human temperature as a norm.

P-H: Product Heat

In describing heat, many students feel a need to make a distinction between heat generated deliberately for a purpose and heat that occurs incidentally. Many of the former responses would be examples of a 'conspicuous heat' framework since to generate heat deliberately (in an electric fire, for example) would be a clear and obvious illustration of making something hot in order 'to heat' something. In the second case, however, heat is seen as a consequence of some other activity and is then classed as 'natural' or a 'by-product'. In this case, it is described simply as being 'produced' and then 'given off'.

Extract 62

/J is discussing the 'flower in a pot' (H7)/

J. no........ not heat as in sort of.. being hot... I think more of heat being used /in this instance/ by the flower... rather than being radiated and given off

I. what are you thinking of when you say use heat?

J. well it's starch stuff.. you know... respiration and you know all food and that.... yes heat is a by-product isn't it? ... well not actually a by-product but it's produced when you do all these other things... you need a certain amount of heat yes... but it is
Extract 63

/card H2/

P. when two substances combine and form another substance heat is usually given off

I. why is that?

P. well it depends.... I'm not sure why it happens but it just does its umh an exothermic reaction... that's when heat's given off and that's what is happening here /in a chemical reaction/

I. are all reactions like that?

P. no some are endothermic when heat's taken in I think ... it just depends what sort of reaction it is

I. what sort are you thinking of?

P. when some two chemicals would combine together and heat's given off... when umh... salt and an alkali with an acid is combined... its an exothermic reaction and heat's produced and given off to its surroundings... we've done that in chemistry... and that could be happening here (P,6H)

Extract 64

/S is making a distinction between heat and temperature/

I. if you had to describe to somebody what heat was... what would you say?

S. I suppose its a rise of temperature sort of

I. and what is temperature?

S. what is temperature?... something that measures heat /laughs/

I. I see /laughs/

S. yes there's sort of... natural heat... body temperature ... the sun... and there's unnatural heat.. sort of electricity... fires and that

I. and the electric mixer? /points to the 'mixer' instance card, H12/
S. well there is some sort of heat... any electrical appliance does get hot after a while... but this is not actually meant to get hot its meant to do something else like mix cakes. (S,6H)

These three extracts explore similar themes across differing instance cards. In each case, heat is both a sense of 'genuine' heat and accidental heat. This framework is a summary of accounts of the latter - the incidental occurrence of heat. This next one is the third of the 'substantive' frameworks.

S-H: Standard Heat

Here the norm at the focus of the range of convenience is neither hot objects or 'normal' heat but the zero temperature: the melting point of ice. Although this is clearly intended as 0°C celsius very few (perhaps one or two) mention the temperature scale, even as a centigrade scale. More commonly they speculate about temperatures simply as degrees. The responses that exemplify this framework, then, see cold as anything below freezing and would allow that melting ice would have some heat whereas frozen ice would not. The scale extends in both directions, down beyond 'freezing cold' and up beyond 'boiling hot'.

Extract 65

/R1 is discussing both the 'ice melting' card and the 'refrigerator' (H14)/

R. ... ice melting... well ice melts at above nought degrees so the atmosphere will have to be above nought degrees for it to melt and there must obviously be heat to melt it. if it was freezing it would still be frozen in a block of ice.
I. where would the heat be?

R. the air around the refrigerator... to melt it...
    the air gives off heat to the ice

I. and has the ice any heat?

R. no /laughs/... if it had any heat it would melt itself...
    (R1,4H)

Extract 66

/C2 is discussing changes of state in terms of molecular activity across a range of cards - the 'ice melting', H7, the refrigerator (H14), in particular/

C ice changes at different temperatures

I. how does it do that?

C. well... the molecules in the ice are frozen ones and it could actually stand ... in the liquid though... because that's water... there's more heat... they're /the molecules/ moving... and more heat turns it into a gas - steam...... although if it cools down it'll condense back into water and then if you want it... back into a solid... you have to freeze it... take all the heat out of it
    (C2,4H)

Extract 67

/C1 is again focusing on the 'melting ice', H7 and then generalising to other cards/

C. well there's got to be... heat of some sort... well no not necessarily heat... it could just be nought degrees where its melting point... so it doesn't have to be really heat it just... if it is one degree then it'll start melting anyway.

I. why do you say that? why one degree?

C. because the melting point is nought degree centigrade so anything above that and it will start melting

I. and how do degrees relate to heat?

C. ....... /laughs/.. when you measure heat you use a thermometer and one degree is a certain amount of heat and here /at the ice/ there doesn't have to be much... it could be just slightly higher than the melting point of ice so there doesn't have to be a lot of heat.
    (C1,4H)
The extracts to illustrate this framework are clustered around the 'melting ice' card for obvious reasons: it is ice that is being used as the distinction between heat and no-heat. These types of arguments, however, are made general at different points, usually where there is discussion about change of state, or thermometers.

**R-H: Regional Heat**

This final one of the heat frameworks contrasts in some senses with the motile heat framework. Here heat is more static than mobile and is situated in regions. As students account for the distribution of heat they sometimes discuss it as flowing or spreading from area to area though - as in this framework - it is sometimes described as simply being somewhere.

**Extract 68**

/C describes the 'iron bar' instance, H5/

C. well when the cold water reaches the heated bar it cools it down

I. and what happens to the heat?

C. well the heat... I don't think it actually... I don't think the heat moves... it just moves the particles but then when water comes onto the particles it just cools them down... so it's /heat/ not a moving thing itself...

/a moment later/

well I don't know really... I don't know /about the heat/ .... its not a moving thing... its sort of just saturated into the material

(C,6H)

**Extract 69**

/R considers some sugar being stirred into a cup of tea, H16/
I. what about heat in a picture like that?

R. what.. you mean on the cup?

I. what do you think?

R. well there's some in the room and on the bottom /of the cup/... perhaps round the sides... that's about all.. oh yes.... on the tips of the handle /of the spoon/... where they are rather hot (R,3H)

Much of this kind of discussion would not have heat 'spreading out' or dispersing but being located in certain areas and the heat simply reducing as it cools. Hot pies taken from an oven, for example, do not 'give off' heat but cool down and 'get cooler'. Engel's (1982) work has pointed to similar tendencies - particularly where heat is seen to be present at the periphery of objects, rather as in the case of R(3H) and the cup of tea. Some responses to the picture of the iron bar suggested that the whole bar would be hot except for a small region of cold under the tap water. That is, that the 'mid' point where hot and cold meet would be on the far right of the bar in the picture. The heat is not seen as moving so much as the water cooling that end of the bar and reducing the heat of the bar. And since no heat is moving there would be no temperature difference between the water under and over the bar.

The frameworks have failed to develop a number of interesting points, in particular the connections to be seen between heat and temperature, energy and light. As before, these relationships are the domain of the succeeding chapters.
L: The Light Frameworks

There are seven light frameworks which are again presented in alphabetical order and are summarised on the following table in figure 16. Some of the frameworks can be seen as contrasting with one another. For example, the normal daylight in a room is perhaps difficult to conceptualise in terms of rays and beams. Some students consider this 'natural' light and describe it more as a static 'pool' of light. In contrast, direct sunlight coming through a window is described in terms of a directed beam, can be re-directed, deflected and aimed to 'hit' something. As one youngster argued, it was not possible to 'dazzle' a friend using a mirror with ordinary daylight; one needed a thin beam of light. The argument was not that daylight is not 'strong' enough, simply that it is not going anywhere and so cannot be re-directed for a purpose. This 'stagnant' light is described in the first framework.

A-L: Ambient Light

As suggested, a distinction is sometimes drawn between overt luminous objects and the daylight one might get even on an overcast day. The latter is frequently called natural light (as opposed to sunlight). In this sense, it forms the mid-range on a continuum that goes between 'very light' through 'normal' (natural) light and 'dark'. It is not often connected to a source and is simply present, everyday light.
Ambient Framework

Light is discussed as a general glow of one kind, as static and natural. It is contrasted with 'dark'. Only some ambient light is discussed in terms of sources, it is normally external to objects.

Composite Framework

Light is considered to be of composite nature - either a 'fibrous', striated collection of rays, or granular and being composed of 'bits'. The various parts can behave differently.

Decoupled Framework

Objects and events are observed from a vantage point that does not entail a direct link between the illumination of the situation and the retinal image. Light is separate from seeing.

Illuminative Framework

An anthropocentric framework that considers light to be for human purposes - of teleological intent: objects and events are lit in order to be seen.

Modal Framework

Rather than one kind of light, there are many kinds, or forms of it. They are commonly generated by different methods and mechanisms and have differing properties.

Obvious Framework

Light is associated primarily with obvious prominent and conspicuous sources. It is a property of the sources. Light is very luminescent objects.

Projected Framework

Light is a directed beam that has palpable effect. It has tangible properties, moves at speed and can be stopped by barriers. Terms like 'bounce' 'throw' and 'hit' are used to evidence this framework.

Figure 16

4.78
Extract 70
/J1 is talking about shadows/
I. well what is a shadow?
J. when umh... there's something between a strong light and say a wall and the light can't pass through the flesh and bones and that's why you get a shadow... but not in natural light they don't happen
I. and why's that?
J. nor in darkness... you need a strong light to do it (J1,4L)

Extract 71
/A is talking about the mirror, L1/
A. no I don't think there's anything there about light... because if you're in the dark you can't see yourself in the mirror unless there's ordinary light... no I don't think there's anything special
I. nothing special
A. no... unless you're going to reflect a light onto it and then it would light it... it would reflect light... that's about it (A,3L)

Extract 72
/P is talking about seeing light reflecting in a shiny surface/
P. well umh... the reason they reflect light is its a shiny surface... well... a shiny flat surface.... they're straight
I. what light do they reflect?
P. well it's all... from all around... from the windows... the general light in the room... lighting up the room and shining on the mirror... /later/ light is a natural substance... which allows you to see... umh... its the opposite of darkness.. (P,4L)

For some students the gradation is not a sharp one, but one of increasing 'strengths' of light, with 'daylight' as the norm.
C-L: Composite Light

This framework represents those responses where students describe the composition of light. Some treat light as a single entity, simply with different strengths, as in the framework above. Where light is considered to be composed of invisible elements, these are described as 'rays' or 'beams', sometimes colours, sometimes as rays of different colours. In some cases the composition is almost fibrous and students speak of 'strands' of light.

Extract 73
/P is discussing a person sunbathing, L8/

P. it's the light rays that causes your skin to.... tan browner

I. what are light rays then?

P. ..... /laughs/... its umh... I was going to say a piece of light from the sun... because sometimes if you look at the clouds and the sun you sometimes see these streaks of light coming from the sun.... and that's a light ray... it just sometimes appears to be a line of light from the sun.. /normally/ they're all clustered together... whereas as you see breaking in between the clouds you can see them separate apart (P,4L)

Extract 74
/R1 is discussing a rainbow, L4/

R. /raindrops/ splits it up... splits the light up into the basic components of white light... which are those coloured rays... and which are then all stuck together to make white light (R1,6L)

Extract 75
/I. well what would you say a ray was?

C. ...... well if you've got a torch it gives off a beam
... and I suppose a beam is made up of... millions and millions of rays... like waves... single lengths... like a piece of rope I mean... a piece of rope is quite thick usually... I mean even the thin pieces... but they're made up of very... you know... loads and loads of very thin strands... and I suppose its like that and you've got to build them up and make... and make beams...

(C1,4L)

This last extract is a particularly graphic portrayal of a beam of light. Nor does it contradict the notion of a 'wave' since the strands can undulate amongst each other as they are emanated.

D-L: Decoupled Light

The name for this framework comes from the study of light by Jung (1986) already discussed. He uses the term 'de-coupled' to describe the responses students make that suggest that the action of seeing is removed from the illumination of a particular event. Situations need light so that they are lit up; which means that they can then be seen. The observation of a scene does not of itself imply that light is reflected off all of the objects and must then impinge on the retina of the viewer. This kind of argument is used in a number of cases, for mirrors, lenses and a slide projector. For the latter, it is argued that the light is emitted from the projector, through a slide and puts the image onto the screen. The screen is not reflective; if that were the case the light would be deflected off onto another surface. The light is not reflected off the screen, any observer simply looks at, and sees, the screen.
Extract 76
/card L5/
I. somebody looking at a bright red painting
M. ... no... there's no light there it just has to have light shining on it so you can see it.. but it's no light otherwise
I. what light are you talking of?
M. the ordinary light that's everywhere... you've got to have light there to see it but it's not giving off any (M1,4L)

Extract 77
/J is talking about the 'bright red painting' card (L5) and some of the others/
J ...... well we can only see the picture if there is light... and you can only see the image.. or your reflection in a mirror if there is light... I don't think I'd put it with light /along with other cards she has in a pile/... its got nothing at all to do with light... I dont think they're made by light... (J2,4L)

Extract 78
/S is talking about images in connection with a projector L2/
S. the image is what's on the screen... the object is what's being projected
I. what is an image then?
S. the image is what is being projected.. no hang on.. the image in a mirror would be what you see and the image on the screen would be what you see on the screen
I. is it like a mirror?
S. no... no its being projected onto the screen... so its not sort of bouncing off.... because that /the mirror/ is a reflection and you're seeing your image coming back... but this /the projector/ is something going away from you and you see it on the screen... (S,4L)
This is an interesting example because it exemplifies the difficulties in conceiving of something being projected away, and projected onto a screen, as coming back to any one of a roomful of (possible) viewers. The 'projection' then, is de-coupled from the 'viewing'.

I-L: Illuminative Light

It is intended that this framework represent those numerous examples of anthropocentric, teleological responses. If there is a purpose of light (and there is) then it is generally described as making it possible for people (and animals) to see. As in the last framework, the implicit assumption is that, since we need light to see, then it is produced for that purpose. Some make a distinction between 'natural' light and 'generated' light, but these are the subject of other frameworks. In this one the emphasis is upon the general purpose of light: to illuminate objects for us to see.

Extract 79
/I has asked R to describe light/

R. what is light? ... well its obvious... you can see where there's light of course... light makes things light... you can't see when its dark can you... unless you turn the light on (R,4L)

Extract 80
/Card L10/

J2. well of course you can make light ... and you can control it... well you can control an image by turning on and off... and you can actually make light with a battery and a bulb to do things... something that
helps us... if we didn't have light we wouldn't be able to... if it was only darkness we wouldn't be able to see what was going on around us.

(J2,4L)

M-L: Modal Light

A number of students suggest that there is not just one kind of light, but many. These are different in kind and are discussed as being generated by different means. They are sometimes called different forms of light.

Extract 81

/C1 is discussing the person sunbathing, L8/

C. that's obviously a lot to do with light and heat together... I mean the sun gives off not only light as we know it... from an electric light... just light on its own... I suppose light from an electric light is virtually pure... but light from the sun is mixed with all sorts of other light... ultraviolet light ...

and radio active light I suppose

(C1,4L)

Extract 82

/J1. I mean there are lots of different kinds of light isn't there... there's daylight and that sort of blue light...... umh... light produced by electricity from a battery and light made from chemicals like burning magnesium and infra red light... and fluorescent light.

(J1,4L)

Different kinds of light have different properties so that some are strong, some produce heat, some are responsible for suntans and some, like 'X-ray light', allow one to see through a person's body.
O-L: Obvious Light

Direct sources of light are perhaps the most straightforward to identify. Light is the property of obvious, conspicuous luminous bodies.

Extract 83

I. what would you say light is?

J. ..... the sun... something that you can see... that you can see throughout a darkness... I'd associate it... it with something that's producing light... that makes it...

(J2,4L)

Extract 84

/M1 is talking about sun, moon and stars, L13/

M. they /stars/ don't need the sun to shine on them... they're lit up by themselves but the moon can't light up on its own so it hasn't got any light of its own

I. oh?

M. so it needs the sun to shine on it... somethings are light and some things aren't.... some things if they are small lights have to have dark behind them so they can show up and they... /stars/ we only see little spots because they're very far away.

(M1,4L)

Extract 85

M. .. to have light you have to have powerful lights .... to produce lots and lots of light... like electricity generators and hydro-electric power because light is energy and you need sources... well like the sun really... you know to get power to light the whole of London an all

(M2,4L)

P-L: Projected Light

A large number of responses treated light as a substance that is projected, 'hits', 'bounces', 'rebounds',
and so on. In some instances light is seen as 'picking-up' colours and transporting them; 'carrying them onto the screen', 'striking a wall' etcetera. In the second extract below, C describes how light must slow down having hit a screen. It travels at such a speed that it is only by slowing down that it can be seen at all!

Extract 86

/Y is explaining how a television set works, L3/

Y. and umh... there is a light say from the back of the television and it is producing light from the screen .... its actually hitting it... it is working like the sun sort of... bombarding the shirt /in a previous card/ to make it whiter... so you get the rays at the back of the TV bombarding whatever it is the stuff on the screen.... it hits it and starts up something in the screen glowing

Extract 87

I. and what is an image?

C. umh... it is something that's been projected... its something that's been thrown somewhere else... /later, card L2/ ... the projector's throwing it out... at the speed of light because obviously light will move at the speed of light and then... just sort of abruptly hitting the screen... and stopping... throwing the image and then going back like the original /object/ ... it's /the screen/ just like a barrier I suppose ... whereas a television just slows it /light/ down

(C1,4L)

In other examples students talk of using a beam of light and directing it so that it 'shoots out' and reaches a target object. They give the impression of a fast jet of water that can carry things ahead of it, and along which things can be transported.
The next chapter looks at the relationships between the frameworks and with the questions that give rise to them.
CHAPTER 5

FRAMEWORKS, FOCI AND BOUNDARIES

5.0 An introduction to the chapter
5.1 Frameworks within the concept areas
5.2 Inter-framework relationships
5.3 Overlaps in meanings
5.4 The incidence of frameworks
5.5 Summary
5.0: Introduction

The twenty-nine frameworks described in the last chapter, evidenced by the many extracts from the interview transcripts, are now to be used to view the responses themselves. The frameworks have been described as constructed 'types', useful as a way of denominating a variety of students' responses and as means of representing sections of transcript. The aim here is to use them as a unit of analysis, to turn the frameworks back on to the data that generated them as a method of exploring the various arguments and explanations the students have put forward.

This procedure carries with it a number of assumptions. Whilst some of these have been made explicit there is benefit in further discussion here. One analogy for the use of frameworks has already been made - the way in which political points of view are typified in common reporting. A second analogy might be that of classifying schools of art and artists. Cubism is a description of a style of art that does not belong to any one artist, nor can any one artist be said to be (entirely) a 'cubist'. It is a general term to describe that geometrical style characteristic of a number of works by different painters. It is also, then, possible to use it to describe a phase in an individual artist's output as he or she exhibits what might be called a 'cubist period'. Similarly an alternative framework can be seen as a generalised description across a number of interviews with different students which can, in turn, be used to describe various parts of an individual

5.1
There are limits to this process. Firstly, to examine interviews in terms of a framework is to consider the match between individual conceptions and the interviewer's construction of several such responses. The individual transcripts will vary in many forms and degrees from a characterising framework. Some indication of the variety of response can be seen in the example of a 'category' concerning the ice cube (E8) in the previous chapter. For some students there will be a very close match: they may even be pithily articulating the very essence of a framework. For others, there will simply be a tendency, a disposition evidenced from a range of expressions used, towards a particular framework. One limit to the political, or artistic analogy used before is the level of interaction between the respondents during the course of the development of ideas. One might presume that the community of artists must have been in varying degrees of cooperation as new and different techniques and ideas are formulated. How much of this is true of groups of students is an open question. The origins of an individual's conceptions have not been explored here and can only be hinted at. How much they rely upon peer interaction, upon the classroom milieu or upon personal experience is not possible to know. What is important to remember, however, is that students are largely unaware of the analyst's frameworks as they talk: the responses come first and are not somehow a regeneration of some widely held opinion. Being interviewed individually they are not privy to the detailed responses made by others. The frameworks did not originate from an overtly cooperative venture.
between students.

Secondly, a student's conceptions are treated as minimally internally coherent. That is they make sense as a systematic, continuous, presentation of ideas - to the students - unless there are signals of specific contraindications. That is, the way in which a word is used in one situation is provisionally taken as indicating how it will be used in the next instance unless there is a notable change of ground, or a clear signal (verbal or non-verbal) that the new instance implies a shift of perspective and argument.

A major assumption all along has been that it is possible to detect such changes, both in terms of an individual's conceptions and of the boundaries of the more generalised frameworks. Making these limits presents different problems in both cases. In the interviews the task of marking changes in conceptions is often straightforward. Students will simply say 'ah, it is different in this case' or will group together pictures they see as similar and which are also different to others. Their actions and reasons are clear indications of different conceptions. On numerous occasions they ask themselves the question 'is that the same meaning here?' (or words to that effect) and proceed to answer it. Another indication is where students negate the instance as an example of the concept and this allows for clear distinctions in usage to be clarified. It is at this gross, and obvious, level of indication that changes in meaning can be, and have been, evidenced.

The boundaries between frameworks are sometimes more
difficult to argue and since this occupies the sections to follow, the examples will be left until then. One of the major reasons for describing and using frameworks at all - particularly this description and use - is as an attempt to discern simplifying threads of argument amongst what are (in the event) some widely differing responses to the IAI cards. For example, to return to the ice cube categories in the last chapter, the responses were indeed very varied. One student claims the instance an example whilst another, for seemingly very similar reasons, claims it a non-example. Conversely, amongst those that do see it as an example, they do so for what can be seen to be very different reasons. The classification of examples and non-examples on its own is a poor guide to the conceptions of a student. This chapter, then, uses the frameworks as attempts to construct some general patterns across some very varied conceptions.

The four parts of the chapter are as follows: the first considers the frameworks in each concept area, their focus of convenience (or key theme) and the limits, or boundaries, of their convenience. That is, the kinds of situations (and therefore the IAI cards) for each which each framework seems applicable as a summary of the explanatory accounts provided. The second part compares the frameworks across the concept areas in terms of some broad similarities in each set of frameworks.

The third section makes a departure in order to examine these similarities more closely. Students' conceptions of force, heat, and light occur frequently in the context of the energy interviews - as they are bound to, given the
design of the cards described in chapter 2. Equally, energy and light (perhaps less so force) will be described in heat interviews and so on. During the course of the interviews, the students weave a network of meanings for a variety of terms, only a few of which can be explored in any detail. The scope and range of all the ideas presented in the 134 interviews is so vast and varied that it is as much as can be done to focus on the four target concepts already described. Terms like power, pressure and friction in force; temperature, melting, boiling and exothermic in heat; image, reflection and refraction in light are all the inevitable casualties of an analysis system that tries to delineate just four concept labels amongst many. The analysis in this section, then, looks at the overlaps in meanings across the interviews in each of the age ranges.

The final section takes the analysis one step further and makes a comment on the pattern of distribution of the frameworks across the three age bands.

5.1: Frameworks - Their Focus and Limits

The frameworks in each of the four concept areas have been summarised in the tables in figures 13, 14, and 15 and 16, in chapter 4. The purpose of this section is to consider the relationships between frameworks within each of these concept areas and to exemplify, as far as is possible, some of the distinctions to be made between them. To do this, it is useful first to develop a set of distinguishing
terms based upon a notion of question types, an idea that itself needs explicating.

Gilbert and Pope (1982) observe of their own study of frameworks that different types of framework appear to be evoked by different types of question. Given the particular theoretical basis outlined in chapter 1, this observation is to be expected. That is, there can be no suggestion that an individual's conceptions are somehow not dependent of the question being asked. Nor, of course, are they entirely independent either - responses are not made 'out of the blue', nor would one expect the same response from a variety of questions. The relationship cannot be simple and straightforward. The frameworks have been distinguished from conceptions as compositions of responses (designed to bridge immediate contexts) and are therefore one level removed from single direct questions. The point to be made here is that they can be related to question 'types' and in this sense Gilbert and Pope's work is a useful indication to an approach.

In order to examine the frameworks in each concept area, six question types are suggested as a means of loosely categorising the many different questions used in the interviews. These are:

a. Locative questions, concerning the whereabouts of energy, force, heat or light in particular situations.

b. Descriptive questions, requiring some description of a situation in terms of the concept, and perhaps some description of the concept itself.

c. Operative questions. These questions concern the
way in which the entity behaves, how events occur and so on.

d. Predictive questions. Since frameworks are designed to be predictive in some way, such questions concern what is likely to happen and how it might occur within a situation.

e. Scalar questions which ask for some notion of size, or relative size between instances.

f. Contingency questions: given that something is the case, what else might one expect of it.

The central issue is not that frameworks are entirely dependent upon specific questions but that they are weighted towards question-types. For example, in response to a question such as 'Do you think this picture is an example of energy?' a student might start by referring to the energy inside a leaf. This in turn might lead to a question of why the leaf and not, say, the stem, petals, pot or the whole plant. The arguments put forward might be taken as evidence for Depository Energy in a way similar to the extracts used in chapter 4, particularly where similar arguments are put forward elsewhere in the interview.

This is not a straightforward relationship, then, between question and framework since locative-type questions might both initiate - and be initiated by - a 'location' framework.

Two points arise from this discussion. Firstly, frameworks vary in their weighting. For example, a student might argue that energy is **not** to be found in any one place but is the action of running or colliding. When the running stops then so does the 'running energy'. Running is a

5.7
description of the energy - a response that might be used as evidence for an Ostensive framework, weighted towards descriptive questions. Given a strong disposition to this view then it would seem uncertain that a locative question would evoke a locational framework. This can be seen in the following extract:

**Extract 88**

/B is talking about the card 'a bad smell' (El3) where a person holds up a dead fish/

I. it doesn't have to be a bad smell of course it could be a pleasant smell like Channel number 5  
B. (laughs)  
I. is there any energy in that? /instance card/  
B. in the smell... no...... no the smell hasn't got any energy in it... but I suppose you smelling it is an action so there's energy there (B,4E)

What is (in ideal circumstances) a poorly framed leading question by the interviewer is accepted by the student as a means of differentiating her application of energy in the situation, to reject a conception of energy indicative of a Depository (locational) framework for an Ostensive energy one.

Secondly, there is a sense in which a student, whose personal conception closely matches a particular framework, would respond to a range of question types quite appropriately. Staying with the energy frameworks as examples, a student might have a conception of energy for which a Depository framework is a good description. From this,
they might feel able to answer a variety of questions concerning the site of the energy, its actions, its description, future possibilities, size and so on. Hence, the weighting of a framework is not to be seen as an exclusive feature. As suggested, each has a predictive element as a deliberate part. The question-type weightings for each framework are shown below in figure 17.

As has already been argued, the frameworks are not intended as mutually exclusive categories and it is sometimes difficult to attribute a section of transcript to a particular framework. This is particularly the case where the section of transcript, or a specific response, is short. For example, responses featuring people as the focus of discussion could be used as evidence for Anthropocentric, Depository and Functional energy frameworks. In such cases, the context within the transcript is clearly important. The response is taken to be consistent with previous statements unless some indication is given to the contrary.

The remainder of this section is taken up with each of the concept areas in turn. Each one is considered in terms of the descriptions above and, where relevant, example extracts are used to illustrate the point being made. Each set of frameworks is accompanied by two tables. These show the most popular frameworks that can be evidenced from the responses made to each of the cards. As suggested earlier, the cards are all shown, with appropriate numbers in appendix I. The second table is a revamp of the first, where the cards most likely to evoke typical framework
<table>
<thead>
<tr>
<th>QUESTION TYPE</th>
<th>ENERGY</th>
<th>FORCE</th>
<th>HEAT</th>
<th>LIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locative</td>
<td>Anthropomorphic A-E Depository D-E</td>
<td>Affective A-F Designated D-F</td>
<td>Conspicuous C-H Regional R-H</td>
<td>Ambient A-L Decoupled D-L</td>
</tr>
<tr>
<td>Operative</td>
<td>Ingredient I-E Produced P-E Transfer T-E</td>
<td>Operator O-F Encounter E-F</td>
<td>Motile M-H Product P-H</td>
<td>Projected P-L Illuminative I-L</td>
</tr>
<tr>
<td>Scalar</td>
<td>Substantial S-F</td>
<td>Conspicuous C-H Normal N-H Standard S-H</td>
<td>Obvious O-L</td>
<td></td>
</tr>
<tr>
<td>Predictive</td>
<td>All of the frameworks have some predictive weighting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contingency</td>
<td>and are open to contingency questions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7

5.10
responses are shown against each framework in turn. The tables are not a statistical exercise and are intended only as a guide to the more popular response 'types' and the most evocative cards. Not all of the cards are needed in all of the interviews: where students have manoeuvred the cards for themselves, or where time has been short, certain cards have not been used. The number of times a card has been used is indicated in the third column after the card reference number.

Two more points are worth making about the tables. Firstly, the number of times the card is perceived as a non-example of the interviewee's conception is recorded as a number of 'nonegs'. The negation of a concept is often a very direct way of being able to distinguish between various conceptions. For example, in the table in figure 20 showing the cards for energy, it can be seen that the 'ghost' card (E3) is commonly cited as a non-example of energy - in seventeen of the twenty-three interviews in which it was used. This may not be surprising, except that in five interviews, including two 6th year ones, it was seen as an example of energy. However, the point here is that the reasons for it not being an example provide strong clues as to the conception being used ('there is no fuel', 'there is no person there'; 'it is not alive' etc). These responses are in turn used as evidence for the various frameworks listed.

Secondly, the 'counting' of frameworks is a difficult task. By definition, that type of response will already have occurred at least twice in an interview. The figures in
the table give no indication of this, nor of the strength of commitment to that kind of response. Moreover, a wide range of frameworks might be evidenced from a single card. A long protracted discussion about the person eating a meal (card, E7) for example, could include a range of subsidiary conversations, the revisiting of cards, the revamping of ideas, and so on. Each set of responses would be evidence for, possibly, very different frameworks. What can be said is that in the analysis of each card these are the frameworks that could be evidenced best from what is being said. In what follows, the frameworks are discussed in the same order as before: energy, force, heat, light.

1. **The Energy Frameworks**

   The energy frameworks, in alphabetical order, are shown below in figure 18:

<table>
<thead>
<tr>
<th>Framework</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropocentric/morphic</td>
<td>A-E</td>
</tr>
<tr>
<td>Depository</td>
<td>D-E</td>
</tr>
<tr>
<td>Functional</td>
<td>F-E</td>
</tr>
<tr>
<td>Ingredient</td>
<td>I-E</td>
</tr>
<tr>
<td>Ostensive</td>
<td>O-E</td>
</tr>
<tr>
<td>Produced</td>
<td>P-E</td>
</tr>
<tr>
<td>Transfer</td>
<td>T-E</td>
</tr>
</tbody>
</table>

*Figure 18*

These frameworks can be grouped in a number of ways. The frameworks A-E and D-E are clearly connected and both can be seen as locative frameworks as depicted in figure 19. A-E characterises those responses where humans are the
central focus of discussion.

![Diagram](image)

**Figure 19**

In this sense it can be seen that A-E is a special case of D-E, where energy is internal to (located in) **objects** and is consumable in a similar way. There is a difference between the two; often energy seen as deposited in a lump of coal, for instance, is a once-only kind, whilst living things are 'refuelable'. An example of this distinction is given below:

**Extract 89**

/A is discussing the flower-in-the-pot, E4/

A. I think there's energy here but not too much
I. what are you thinking of?
A. .. the roots.... in the pot...
I. why there?
A. well if it's just a **cut** plant... if there isn't a root there... it'll **die**
I. you mean if I cut the plant and stuck it in your button hole or something?
A. yes... it couldn't get energy from its roots then... from the water an all that
I. what about water?
A. well the water's got energy... it comes with it... and the plant uses it... if you cut it off and put it in water... it **may** stay alive for a while.... like sometimes it grows roots in the water and then you can plant them again
I .... and what about the water's energy?
A. .... well that's used up.... water doesn't have energy then ... but the plant is alive isn't it and so it's got energy in it (A,3E)

The energy in the water is denied to the plant when it is cut and yet is still consumable. A similar case is made for oxygen, batteries, food and so on. Some substance to this can be seen in the tables in figures 20 and 21. The box (E1); battery (E2); meal (E7); collision (E13); and flower (E14) cards all have a short 'life time' of activity. Whilst a number of other cards also have a short time of action (for example the hot water (E4); the sledge (E9) and the clock (E11)), they do not seem to evoke the same level of anthropocentric and depository responses as do the others. How much the anthropocentric tendency pervades other responses in terms of implicit anthropomorphism is difficult to say. If a battery or flower has a 'life' span, a period of activity before cessation, then it might be quite straight-forward to continue the metaphor to other situations. The depository framework is not explicitly anthropomorphic and a number of students make the kind of distinction illustrated above. However the distinctions are not always that easy to make.

Functional (F-E) and ostensive (O-E) energy can both be seen as descriptive frameworks (Figure 22).

![Figure 22]

Figure 22
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|           |     |            | IE (1) | Noneg (1) | IE (2) | Noneg (1) |        |
| Stars     | 15  | (16)       | AE (1) | IE (1) | DE (4) | PE (1) |        |
|           |     |            | DE (2) |        | FE (1) | TE (1) |        |
|           |     |            | FE (1) | Noneg (1) | OE (2) | Noneg (3) |        |
| Clouds    | 16  | (16)       | AE (1) | OE (1) | DE (4) |        |        |
|           |     |            | DE (3) |        | OE (4) |        |        |
|           |     |            | FE (3) | Noneg (2) |        | Noneg (3) |        |
| Tripped   | 17  | (8)        | AE (1) |        | DE (2) |        |        |
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Figure 21

5.19
The F-E framework describes energy generated purposefully in order to make things work; O-E in an action, or a chain of actions that take place - the obvious display of activity. In many cases for O-E, students appear to find it sufficient explanation simply to name an activity. For example, 'running energy' might serve as both an explanation and a description of the energy present before two people collide (El2). At the point of collision there might be 'colliding energy' and afterwards no energy at all since nothing is happening, or no one is 'doing' anything. Functional Energy (F-E) summarises responses that contrast energy with something happening naturally. Consequently, ice melting, or the wind blowing, might not have energy at all: they are natural. In this sense energy is a deliberate, purposeful contrivance.

As mentioned before, it is the negation of energy that often makes it possible to distinguish between various responses as evidence for frameworks. So when a student answers of the sledge (E9) that it has no energy because 'it has no engine', this is used as an indication of a Functional framework. O-E, on the other hand, relates to descriptions of events which are energetic and so 'melting' 'blowing' or 'sledging' would all be energy.

A-E and F-E both revolve around human purposes. A-E considers humans as deposits of energy whilst F-E treats energy as designed for human use. It is a distinction well illustrated in extract 90 below.
Extract 90
/J3 is talking about the person eating a meal, card E7/

J. ... we need energy anyway to do what we want to do... we've got energy in us so we can walk and eat and all that... 'cos if we didn't we couldn't do the things that we want to... could we?

I. I'm not sure... what are you saying? do we need energy to eat or do we need to eat to get energy?

J. well it's different at different times... at some times there's energy in us to do things we want and everything and other times you need more energy to move things and so you go and eat...

(J3,3E)

Here the phrase 'different at different times' marks limits to J3's conceptions. It is a clear indication of a change from one bounded set of meanings to another (or others). Such phrases are the clearest kind of contraindication for a single conception and points to plural, different, conceptions ('ah... but its different here', etcetera). To reinforce this point a second extract is included to illustrate a similar distinction between F-E and A-E.

Extract 91
/J2 has been discussing power stations and has moved on to consider differences between the energy there and the 'human' energy he has previously been elaborating/

I. ... well what's the difference then?

J. .... like energy... (3)... alright... you can go on for a certain time and the energy there /in a power station/ can go on for a long time..... the average person's not all that fit.... their strength is going to wear out sometime or other... and a plant is going to die sometime but the power station is going to carry on and on because people make it to have in their houses and that

(J2,3E)
The other three frameworks are operative ones: they are weighted towards 'what happens' questions (Figure 23).

![Operative diagram]

Figure 23

Ingredient Energy relies on some input or initiating action for it to be noted; Produced Energy is generated and then released, 'let off' or is 'given off' as a side effect of the action; Transfer Energy 'flows' from system to system. Energy would seem to be 'produced' typically in the battery circuit (E2), the chemical reaction (E5) and the meal (E7), although in a number of other situations too. These cards (particularly the electrical circuit E2) evoke the I-E and the T-E frameworks too. The distinction lies in both the forms of discussion and again, in the negation of energy. In the following extract T is talking about the 'meal' card (E7) and fastens first on instigating the energy (I-E) and then on transferring it from place to place (T-E).

Extract 92

J. ... yes there is energy there... its to do with the food...

I. what about the food?

J. well it gives you the energy and sort of goes round... its the vitamins I think

I. has it any energy now... on the plate?
J. oh no... you have to eat it and then when the food is inside you it starts to give you energy... when you get it in your blood...

I. what do you mean by 'it goes round'?

J. well when you've got some but it's sort of leaking out

I. why do you say that?

J. because it might be cold and your energy is going into the air or into the ground through your feet

I. what if the weather's nice?

J. well it's still going... when you do things its pushing out of you into other things...

(J2,3E)

The negation of energy in the food on the plate is again a useful indicator - in this case of an ingredient framework. As one youngster remarked, if the food had energy on the plate it could move about on its own. Similarly, if the ice cube (E8) had energy it could melt itself. Ingredient energy allows for situations where something is about to happen - when something else acts as a catalyst. Therefore it is often in a situation which is a non-example 'but....'

These are not the exclusive features of each of the energy frameworks. Each one, and not just the Ingredient framework, can lead to some element of prediction and contingency. What happens to 'running energy' (O-E) for example, when people cease to run (card E12)? Unlike the example of Transfer Energy above, where energy might 'go into' some other place, typical Ostensive responses invoke some other energies such as 'colliding energy' or 'sitting energy'. On the other hand, Depository Energy is 'used up';
human energy is replaced; and produced Energy (P-E) is simply 'released'. In this sense, the eventual outcome of the energy is also used as a guide to the framework that can be evidenced from the responses.

2. The Force Frameworks

In summary the force frameworks are:

- Affective A-F
- Configurative C-F
- Designated D-F
- Encounter E-F
- Impact I-F
- Motive M-F
- Operator O-F
- Substantial S-F

Figure 24

There are a number of parallels between the energy and force frameworks and whilst these are discussed later, one particular similarity is drawn on here. As in the energy frameworks there is strong tendency for students to respond in animistic terms. In some senses this 'source' of animation in the framework A-F is a subset of D-F. Both are locative frameworks, the latter being a 'source of force' generally, the former an animistic or human orientated one. Both frameworks are elicited from a wide range of cards as shown in the table in figure 26. Moreover, the range of popular cards is fairly similar across the three age groups: force is located in certain parts of
such situations.

\[\text{Figure 25}\]

As before, typical responses might be within a framework either because the instance is, or is not, an example of the interviewee’s conception. For example, in one of the two occasions that the rocket (F2) was seen as a non-example of force it was because 'rockets do not need people in them to fly'. On other occasions, students have said that rockets do have force because they have people in them.

There is a distinction between the two frameworks and this can be illustrated by the extract 93 below. R is debating as to whether a book on the table (F11) has any force or not: whether the book is a 'source of force'.

\textbf{Extract 93}

R. it \textbf{could} have force especially if it's a heavy book.. but no.. I wouldn't say there is any force there either /having discussed other cards/... there's only \textbf{pressure} on the table from the book... but no forces at all

I. pressure

R. yes... for \textbf{forces} its got to have someone to move something (R,4F)

Configurative (C-F), Impact (I-F) and Motive (M-F) frameworks are descriptive (figure 28). C-F refers to that family of responses where position or some configuration of aspects of the situation are fastened on. They are often
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Figure 27

5.30
static features that form part of the argument. For example, an object at height is said to have 'more force' than one at a lower level - at the bottom of a slope, for example (F7). The book on the table (F11) has force that it would not have on the floor. The interesting card for this framework is the one of the astronaut in space (F13). It is frequently seen as a nonexample (in about half of the interviews in which it was used) and the C-F framework is evidenced from both points of view. The astronaut is seen to have force in order 'to stay still where he is'; 'there must be some force to keep him up there', and so on. Conversely there is no force because he 'is just floating'; 'there is nothing holding him there'; 'there is nothing holding him down', etcetera. The astronaut's local position is sometimes at issue, too. When asked 'what will happen next' some responses were that he would orientate to a vertical position with respect to the sides of the picture card. That is, his feet would 'sink downwards' to the bottom of the picture rather than remain in the 'horizontal' position depicted.

This search for 'binding' forces to restrain objects, or forces by virtue of a stable 'position', contrasts with the other two frameworks I-F and M-F.

Figure 28
Impact Forces (I-F) are collision forces, 'hitting' forces. Thus a faster moving body has 'more force' than a slow or stationary one. Whilst it is unlike the Motive framework (M-F) - which is associated with any movement, collision or no - they are clearly linked. In some cases M-F, as the more general framework, subsumes I-F. These can be seen in figure 27 in that whilst many of the cards are common to both frameworks, M-F is represented in rather more than I-F. The two do not entirely overlap and some distinctions can be noted:

Extract 94

/N is considering the size of forces present in the golfer picture (F8) compared with the golfball landing on the green (F9)/

N. well its got more there /at the golfer/ 'cos it's just been hit

I. I see

N. well not there /at the golfclub/ but here-sh where it gets off the ground /she indicates a point before the position of the ball in the picture/

I. what... sort of between the ground and where it is now?

N. yes sort of thing... where its moving

I. and what about this one where it bounces? /the other card/

N. no force in... not really in that one no... not really force... it just bounces (N,4F)

This kind of argument favours a distinction between M-F and I-F - again by negating force in the second aspect of the situation. In other cases it is not the M-F but the I-F framework that is indicated:
Extract 95

/T considers the balloon card (F12)/

T. ... there's no force anywhere... well there is a slight force because the balloon is still pulling but he /the person/ stops it you see... because he's bigger than it

I. ... what if he actually lets go?

T. it goes up out of sight because its lighter than air

I. does that mean a force?

T. no unless it comes into contact with something and bumps into it and that will be a force (T,4F)

In some cases the difference between the two is one of magnitude - the 'force of impact' often being greater than the 'force of movement.'

E-F and O-F frameworks are operative ones; as suggested in figure 29.

![Figure 29](image)

**Figure 29**

Encounter Forces (E-F) are combinations of features described as forces and which indicate how situations occur. Hence 'pressure', 'power', 'strength', 'energy', 'speed' and so on are described, and included, as forces in order to account for changes. There are many occasions when such terms are used when they are differentiated from forces; R's extract 93 about pressure is a good example of this. In E-F they are used as forces, and this tendency is common - as indicated by the wide range of instances from which
it can be evidenced. Operative Forces O-F are discussed as a form of transmitted 'action', as a means of accounting for a chain of events - somewhat like a shock wave. One distinction between the two is whether responses depict some notion of sequence. E-F summarises those 'forces' which influence events simultaneously; O-F where they are in succession, S-F is a scalar framework. The table in figure 27 is misleading in the way it might give the impression that S-F occurs only infrequently; it is the kind of response that occurs 'between the cards'. Like the word 'power', force is not something that comes in small doses. The societal meaning of force ('force of personality'; 'by dint of brute force'; 'by sheer force' etc) makes it inimical with something small and gentle. Force is therefore not often perceived in the context of feathers, babies, 'floating' balloons (F12) or drops of water (F16): more so with large stones (F1) and space rockets (F2). The dialogue at the end of the presentation of each card often revolves around comparisons between it and previous ones. It is during these points that additional, comparative, comments are made that are evidence for S-F.

3. The Heat Frameworks

To recap the heat frameworks, they are listed as follows in figure 30.
Conspicuous C-H  
Dynamic D-H  
Motile M-H  
Normal N-H  
Product P-H  
Regional R-H  
Standard S-H  

**Figure 30**

The tables of the frameworks for the various cards, and the cards associated most with each of the frameworks are shown in figures 31 and 32.

Two of the frameworks have a strong locational weighting, Conspicuous (C-H) and Regional (R-H), figure 33. For the first, heat is located at, or nearby, very hot objects.

In this sense C-H is a 'scalar' framework also; heat is to do with hot (and not just warm) bodies. Regional heat is local heat, and as such allows for 'warm' (as opposed to hot). It is an area of suffused heat rather than a conspicuously hot body. It is static and remains local - it simply reduces in intensity as it cools. In the next extract D1 makes a distinction between the two in relation to a flower in a pot (H7).
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**Figure 32**

5.40
Extract 96

D. well there's no heat here at all...

I. no heat

D. no I don't think so... nothing that's hot... I don't think you're supposed to put flowers in heat are you?... 'cos my mum always used to leave it on the window shelf or something... if they've got a lot of heat they don't usually... grow they'd die

I. why on the window shelf?

D. well I suppose they have to be warm you know... warm in themselves... around them... but not next to any hot thing (D1,3H)

However, these two are not the only scalar heat frameworks. In that they signal a scale of hotness then Normal Heat (N-H) and Standard Heat (S-H) are also scalar (figure 34). For these frameworks, heat is not so much located in (or nearby to) objects, rather these frameworks typify responses where reference is made to some norm. For a student to refer to something's (or someone's) 'normal heat' is a common occurrence in the interviews. Some indication of this is given by the wide variety of cards that elicit this kind of response as shown in figure 32.

Figure 34

For S-H, the norm is melting ice. Not surprisingly it occurs most commonly in those situations where ice is
depicted in the situation, for example in the melting ice (H6), fur-coat-and-dustbin (H10) and the open fridge (H14). However, it is not exclusive to these cards and appears in responses to the iron bar (H5) and flower (H7) cards amongst others.

Both N-H and S-H can also be seen as descriptive frameworks as descriptions of heat in terms of a hotness/coldness dimension and differ only in their norm. In both cases, cold 'cancels out' hot to produce 'normal' or 'nought' in either case. From a Normal Heat framework, ice would have no heat - it would be decidedly cold. From an S-H framework it would simply be zero heat. In this extract S is struggling to make a distinction between the two.

Extract 97
/melting Ice, H6/

S. yes... it's changing it's melting
I. how is that happening?
S. it's being forced to... the water's not wanting to be heated or cooled.. but if it is.. it will go through a change because of the heat
I. and is it similar to any of the others? /I refers to other cards that have been discussed/
S. yes some... it depends on the materials... (6)... umh I don't know... some materials have different boiling points. melting points so they might be frozen at normal heat
I. what are you thinking of?
S. I'm not sure... I just know that there are.. well other things with high melting points... which is just another way of measuring heat... I can't remember if it /heat/ starts at ice or at a melting point...
I can't remember which...
(S,6H)
Leaving aside the anthropomorphism of ice not 'wanting' to be heated (but being 'forced' to) S is unsure as to quite where heat 'starts' and what melting points mean.

Dynamic Heat (D-H) is also weighted towards discription (figure 35) in that the movement or activity involved describes the action of heat. Heat produces motion - a description often in terms of molecules and particles. One subset of this is discussed in the next chapter and (as has already been mentioned) is called the 'hot molecule model' - a variation on the kinetic theory of matter. D-H is more general than one specific model and concerns other kinds of heat-action responses too. It encompasses people arguing (H4), projected stones (H11), cake mixers (H12), people running (H15) and so on.

![D-H, N-H, S-H](image)

**Figure 35**

![M-H, P-H](image)

**Figure 36**

Both Motile (M-H) and Product (P-H) describe the operation of heat. Motile Heat is a fluid-like flow that is reminiscent of 'caloric' arguments about the spread and diffusion of heat. Product Heat is a by-product of other activities - or as one youngster called it, a 'side-effect'
of doing something. Motile can be contrasted with Regional Heat in that the latter remains stationary in, or around an object. The following extract (already used as extract 68) is an example of this distinction being made:

Extract 98
/C is discussing the ironbar picture, H5/

I. what happens to the heat at this end /the tap-water end/ of the bar?

C. well when the cold water reaches the heated bar it cools it down

I. and what happens to the heat?

C. well the heat... it isn't actually... I don't think the heat moves... it just moves the particles /of the bar/ but then when water comes onto the particles it just cools them down... so it's not a moving thing itself like water... if you pour that it flows along

I. not like water

C. well I don't know.... I don't know it's not a moving thing it's sort of just saturated into the material (C,6H)

C had previously described the heat as moving the particles along the bar and vibrating them, which is part of the 'hot molecule model' already mentioned and is taken as evidence for a Dynamic Framework. That is, it produces movement without itself moving: it just 'saturates' the bar and when affected by the tap-water merely reduces in intensity and 'cools down'. Motile heat, on the other hand, is evidenced from other accounts as flowing or radiating out, being 'given off', by various bodies like hot pies (H3), the iron-bar (H5) and so on.
4. The Light Frameworks

A list of the light frameworks is as follows:

- Ambient  A-L
- Composite  C-L
- Decoupled  D-L
- Illuminative  I-L
- Modal  M-L
- Obvious  O-L
- Projected  P-L

**Figure 37**

As before, the tables that follow in figures 39 and 40 show the most popular frameworks that can be evidenced from the interviews for each card, and the cards that correspond most to each of the frameworks. Two of the frameworks are biased towards a sense of location. Ambient (A-L) and Decoupled (D-L).

**Figure 38**

A-L is concerned with the responses that invoke 'normal' light or 'natural' light as being something that is around in the daytime and by which we see. It is not necessarily associated with sunlight, a term which is often reserved for direct light from a visible sun. 'No, not sunlight, I mean the ordinary light in the room now' is the sort of phrase that distinguishes between A-L and O-L.
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Figure 40
(where the sun is the obvious source). Although the term 'when it gets light' might refer to the period after dawn, it is often taken to refer to a normal, more customary state of affairs. Similarly, having hidden in a dark cupboard, a youngster might come out 'into the light' - an unspecified source, the normal circumstances.

In some ways the Decoupled framework (D-L) is an extension of this. Being able to see something is not taken as meaning that light is being reflected off it into an observer's eye. Or, put another way, the notion of a 'picture', seeing an image of something, is not always attributed in cause to light. Certainly light might be reflected off a picture as one might see an overhead light reflected off the surface of a glossy photograph. However, that light is not the cause of the picture, the detail of the photograph being seen. This is a distinction, then, between direct sources of light (O-L) and the light one needs to be able to see something (D-L). Not surprisingly this kind of response occurs for those cards where some viewing is involved - mirror (L1), projector (L2), painting (L5) and the television set (L3). The example extract gives an indication of this where a television is concerned. A television set is not seen as a direct source of light, but as something to be seen or watched. Moreover, this can be done in the dark:

**Extract 99**

I. do you think a television has anything /to do with light/ then?

J .... hum... no... other than...
I. other than what?
J. do you want the honest truth (laughs)
I. yes please tell me the honest truth (both laugh)
J. you'll laugh... my mother always watches the television in the dark and the only thing I can say is that there doesn't have to be light there /in the picture/
I. why does she/the mother/ do that?
J. I don't know... she says she finds it a better atmosphere to watch it and she says things about too much light being bad for your eyes... especially when you're concentrating... (J2,3L)

O-L has been indicated in figure 41 as a descriptive framework, along with the composite and modal frameworks.

Figure 41

In extract 100 below, T makes a case for an O-L framework by saying /about the television card, L3/

Extract 100

T. well you can see it in a dark room so it's probably ... no... it must be a light source in itself... it certainly doesn't have a separate light source just to reflect the light from it... hmmm... I suppose that's the point isn't it.... everything's either a reflector or a light producer and so that / the television set/ is a light producer... (T,6L)

This is a useful example of two contrasting implications being drawn from similar statements. The statement 'you can watch television in the dark', is likely to be
taken as evidence for two different conceptions of light—dependent upon the predispositions of the person involved. The O-L framework is common to a large selection of the interview cards, but particularly the candle (L6) and those where the sun was discussed (the sunbather L8; the flower L11).

The distinction between a Composite and a Modal Framework is straightforward. The implicit (if not direct) question is whether there is one kind of light which is composed of componential subdivisions, or whether there are many different kinds of light.

In the next extract R2 is discussing why the red painting (L5) should reflect red light.

Extract 101

R. the light is reflected from the painting into your eye... though it's not reflected like the other one /the mirror, L1/

I. how do you mean?

R. it's not reflected in the same way because it doesn't give a perfect image... well you can actually see an image... but if someone was standing next to you in front of a red painting you wouldn't be able to see them in the painting

I. so what do you mean by reflect?

R. I'm trying to decide if it is a different kind of light that comes out or just a part of the light that's falling on to it...... well I think the light that goes into it /the paint/ is made of different colours but... when they're in the within the substance they are turned into red

I. how does that happen?

R. because I don't think it actually absorbs all the energy I mean it doesn't get hot or anything... so I think most of it is turned into red light...

(R2,6L)
This conflict is a recognisable debate: is 'pure' light pure because it is a single elemental entity from many similar kinds or because it's purely constituted from its various parts? R2 seems to opt away from a composite view and, rather than have just one small part of the light reflected, he argues for the substance turning all of it into a different (red) light.

Although the notion that light 'splits up' into various colours in a prism (and a rainbow (L4)) is used quite often, the C-L framework is not used as often as the M-L one. It is much more common for students to argue for different kinds of light in order to explain various effects like suntans, Xrays, photosynthesis, fluorescent lighting and so on. Artificial light must be just that; a synthetic (in its pejorative sense) manufactured light that is different from natural light, or daylight. A second extract makes this point. M is talking about the candle picture (L6).

**Extract 102**

M. this is different... because... I don't know why... I mean its sort of a natural source of energy... I mean its there... you don't have to make it... well there /battery L10/ you have to make that light and you have to make this /projector L2/.... well there you need that sunlight /sunbathing L8/ but I mean all there you have to make the light... sort of artificial while there /candle/ its all for natural .... its like plastic is artificial and leather is sort of natural (M2,4L)

The operative frameworks here are I-L and P-L (Illuminative and Projected) and operate in the sense that they are
Figure 42

indicative of responses that describe what happens to light, or what it does. A Projected Framework summarises very mechanical responses about light, how it hits, bends, strikes, and bounces off various objects. Illuminative light, on the other hand, summarises anthropocentric responses, a 'light is for us to see (... otherwise it wouldn't have been invented)' kind of argument. P-L is very popular, encouraged no doubt, by the mechanical metaphor of light that pervades commonday language. It can be evidenced from almost all of the cards that are used, in particular the projector one (L-2) (whence the name) where light is seen to be 'thrown' out to 'hit' the screen. In the following extract P makes a distinction between P-L and A-L when someone is sunbathing:

Extract 103

P. its the light... the light from the sun causing him to tan

I. how does that happen?

P. the light rays hit him and pass through his skin... right through... and hit his cells and knock out his colouring in his skin cells... I mean you can't get a tan in ordinary light because it doesn't hit you hard enough... its got to be the streaks of light coming from the sun and hitting your skin... (P,4L)
Having considered each of the concept areas in turn, the next section now considers relationships between the frameworks, across the concept boundaries.

5.2: Inter-Framework Relationships

Given a degree of coherence in the analyst's constructions of the data, it is to be expected that there will be some similarities between the groups of frameworks already described. Four major similarities can be argued for and these are as follows. Firstly, there is a strong tendency to anthropocentrism in each of the concept areas. Two of the frameworks, in energy (A-E) and force (A-F) have an element of anthropomorphism built in as well, in that they are described as 'human orientated'. Leaving this aside for a moment, it can be seen that the Functional Energy (F-E), Normal Heat (N-H), Decoupled Light (D-L) and Illuminative Light (I-L) frameworks all have some anthropocentric features. A-E and A-F summarise responses where human beings are seen as a prime source of energy and force and as will be described in the next section, there is often a close overlap within this set of meanings for the two words. In the interviews youngsters are being asked (and often ask of themselves) to account for the causes of occurrences and events. Many such accounts are made in terms of human causation, even when it is not obvious that a human being is concerned in the immediate situation. When a person is present in the environment they frequently become the focus of the responses so that other features
are not commented upon. In this sense both of the words 'force' and 'energy' are subsumed within another often used expression - power. It is humans that have the power (the inner force, the active energy) to accomplish tasks, for example:

Extract 104

I. if you had to describe it to someone what would you say force is?
A. it is the power you have to do things (A,3F)

Extract 105

G2. energy is... it's the power to do things (G2,6E)

It is in this context that animistic responses are included in both of the A-E and A-F frameworks. Piaget (for example his 1929 work) devoted a considerable amount of time to describing animism and 'artificialism' in young children. He generally maintained that such tendencies are not apparent in (his description of) their later stages of development (after 11 years). More recent studies with adults (for example, Looft and Bartz (1969) and Brumby (1981)) however, have cast doubts on this. Whatever the case, in the energy and force interviews here, a large number of animistic responses have been recorded at each of the three age levels. For example, the tree-blowing-in-the-wind card (F5) is often described as 'trying' to get back straight; of 'wanting' to straighten up, or 'fighting' against the wind. When asked to explain these expressions,
it is commonly along the lines that 'the tree has its own force that helps it to go straight when the wind stops', or 'it forces itself up' etcetera.

Within this discussion of anthropocentrism, two other frameworks are similar: Functional Energy (F-E) and Illuminative Light (I-L). In both cases the entity is seen as having been designed for the benefit of human beings. It is not that we merely avail ourselves of a natural resource, but that we contrive it as a commodity for our own purposes. Light (or energy) is for us to see by (or to make things work for us). The other pair of frameworks is Normal Heat (N-H) and Decoupled Light (D-L). Both use human beings as a reference point, although in different ways. In the first, body temperature is the reference by which judgements of heat are made in terms of 'hot' and 'cold'. The second is a more detached notion where light is conceptualised as a brightness (which is the condition for perceiving a scene) that is separate from the mechanism by which the scene reaches the person.

The second area of similarity between frameworks is more of a linguistic nature - the use of the words energy, force, heat and light as nouns, verbs or adjectives. In everyday language each of the concept labels can be (and often is) treated as a noun - can be nominalised. In taking on a real existence in this way the words become 'entity denoting'. That is, when the word energy or heat is used in this way in an ordinary context it commits the user to the presupposition that it exists, that it is a particular kind of physical entity as such. This is what
Lyons (1981) refers to as 'existential presupposition'. One consequence is that it allows energy, force, heat and light to be located within things. This can be seen in the Deposited Energy (D-E) and Designated Force (D-F) frameworks which construe energy and force as sources of activity within objects. It allows for heat to be located at hot objects (C-H), and light at obvious light sources (O-L); all those frameworks that are locative in the way described earlier. As a noun, force is probably the most awkward - it is an unusual question that asks (for example) 'does a book have force?' Interestingly, such a question is permissible in French where the term 'fort' has a wider meaning and includes the notion of 'strength'. This makes it difficult to ask compatible questions to those used by Piaget (1929) for instance, when he asked if something like the wind has 'fort'. This difficulty of translation has been noted by others (Brown and Deforges (1979) for example).

In a different vein it is possible to use three of the concept labels as verbs - 'to force', 'to heat' and 'to light'. 'To energise' is possible rather than 'to energy' though it is much more common to treat energy as a noun and to 'give something energy'. This conceptualisation of the 'doing' of the presence of the entity in the performance of an action, is apparent in the Ostensive energy (O-E) framework.

A third area of similarity between the frameworks is the level of perception allied to each one. Both heat and light are 'pointatable', are direct sensations and are therefore 'obvious'. Conspicuous Heat (C-H) and Obvious Light (O-L)
frameworks encapsulate this emphasis. Substantial force (S-F) has a similar (large and obvious) sense. In a number of ways this emphasis hinges on an allied distinction between the frameworks. Some can be seen as ways of describing a single body or a focal object and attempting to account for its behaviour. Others can be seen as attempts to explain the same behaviour but in a slightly wider vein; by reference to other aspects of the environment. The balloon card (F12) in the force interviews might serve as an example. In that instance, students might argue in terms of the forces inside the balloon (D-F), being given to the balloon (M-F) to make it move, or at the person (A-F). In contrast, they might discuss it in terms of the way the force operates and is transmitted through the person's arm, the string, the air (O-F), or by treating other features like pressure, energy, or 'floating' as forces (E-F).

A rough division between the frameworks along this line of focus, between an object and its interaction, is shown below as figure 43.

<table>
<thead>
<tr>
<th>ENERGY</th>
<th>FORCE</th>
<th>HEAT</th>
<th>LIGHT</th>
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<tr>
<td>OBJECT</td>
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<td>A-F</td>
<td>C-H</td>
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<td>D-F</td>
<td>N-H</td>
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<td>M-F</td>
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<td>INTERACTION</td>
<td>F-E</td>
<td>C-F</td>
<td>D-H</td>
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<td></td>
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<tr>
<td></td>
<td>O-E</td>
<td>I-F</td>
<td>P-H</td>
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<tr>
<td></td>
<td>I-E</td>
<td>E-F</td>
<td>S-H</td>
</tr>
<tr>
<td></td>
<td>T-E</td>
<td>O-F</td>
<td>M-H</td>
</tr>
</tbody>
</table>

Figure 43

5.58
A final comment in this section concerns those frameworks on the bottom line of the table in figure 43: (T-E), (O-F), (M-H) and (P-L). In each case, the framework incorporates some suggestion of 'transmission' from place to place. Each one describes responses where something is seen as moving from one region to another - usually through some medium. Light is often depicted as being projected through air (as in cards L2 and F15); energy through objects or from one object to another (boxes E1; electric cables E2; and the digestive system E7); force through various media (like trees F5; diving boards F4; and air F5) and heat along iron bars (H5) and dustbins (H10).

The next section considers some of the facets of the frameworks in greater detail.

5.3: Overlaps in Meanings

This section is best begun with an extracted quote. R is discussing the golfer card (F8) in the middle of a force interview:

Extract 106

R. the person is using energy to move the ball... there isn't any energy really in the ball because ... there's nothing that makes... how can I explain this

I. what are you thinking about?

R. there isn't that inside it that will help it move .. that makes it move..... it hasn't got an engine inside it right?

I. you have been talking about energy... what's the difference between force and energy?
R. the force you have to really move something has energy... you have got to be healthy if its you that's got to move it... so you need your energy... or when its to do with aeroplanes or something you need engines and chemicals in it... petrol... like a car needs petrol... thats its source of energy (R,4F)

There is evidence here for a number of frameworks. Firstly energy is associated with people - the person has energy to move the ball; one needs to be healthy to move things and energy is associated with health. This is evidence for an A-E framework. Secondly energy is also seen in terms of engines, aeroplanes and fuel for cars - evidence for a Functional (F-E) framework. Thirdly, a different notion, force needs energy (for things to be moved). Put another way, energy is needed to produce force.

This section uses the frameworks to explore the overlaps between the concept labels in the interviews. This is made possible at two levels:

1. Some cards are common to two or more of the IAI decks. These are listed below in figure 43.

   Battery/Bulb Circuit E2 L10  
   Lens E6 L9  
   Stars E15 L13  
   Reaction E5 H2  
   Ice E8 H6  
   Flower L4 E14 H7  
   Sledge E9 F7  
   Astronaut F13 H13  

   Figure 43

2. Many of the cards evoke a wide range of responses. For example the 'torches' card (F15) is obviously about
light in the context of a force interview; some of the discussion of the cakemix card (H12) is about the relationship between frictional forces and heat.

The overlaps to be detailed here are those that are indicated by the solid lines in figure 44.

![Diagram](image)

**Figure 44**

The two dotted lines represent overlaps where, although there are discussions of the concepts in question, they are fewer and less extended than the other four. Here they are described where they do occur without so much detail. Before discussing the data, three more points need to be made.

First, students often change their mind and/or give seemingly conflicting explanations during the course of a single interview. Where each response is sufficiently clear and detailed then they are used as evidence for the appropriate framework. Consequently one interviewee can generate more than one kind of overlap.

Secondly, in presenting the data, one example extract will be used to illustrate the general area of overlap, rather than a large number of extracts for each subdivision. The first tables show the levels of response in each pair.
of interviews; for example how many times force is discussed within energy interviews and vice versa. As an initial sorting process the responses have been categorised as being
1. Separate and distinct - where no specific relationship is perceived between the two;
2. Synonymous - where force and energy, for example, are seen to be the same thing and are used interchangeably.
3. Separate and related - where the two labels are treated as being clear and distinctive and yet some relationship is perceived between them.

These sorting categories have been documented elsewhere (Watts, 1983b; Watts and Gilbert, 1983). The age related trends in the data are left for discussion to the final part of this chapter.

Thirdly, on numerous occasions, students make no mention of the other target concept during the interviews. These are recorded as a no-response (N/R) in the appropriate tables. It is an interesting question in itself that if a student does not mention energy during the course of a force interview, then what words/labels does (s)he use? One indication of this has already been given; students in this context frequently use terms like power, pressure, strength and so on.

The overlaps are discussed in the order:

A. Energy ↔ Force
B. Energy ↔ Heat
C. Energy ↔ Light
D. Heat ↔ Light
E.  Heat  \rightarrow  Force
F.  Light  \rightarrow  Force

A.  **Energy  \leftrightarrow  Force Overlaps**

The data here derives from both of the sets of interviews of force and energy for the three age bands; 34 energy; 43 force interviews, 77 in all. The data is combined and is discussed more in terms of frameworks rather than specific concept interviews. The figures are shown in the table in figure 45.

<table>
<thead>
<tr>
<th>ENERGY</th>
<th>FORCE</th>
<th>TOTAL</th>
<th>GROUPYEAR</th>
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<tr>
<td>34</td>
<td>43</td>
<td>77</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 45**

To illustrate the complexities of responses in this overlap area between force and energy, an extract is taken from an energy interview with S in group 4E. She spends a considerable period of time during the interview framing a distinction between 'natural' energy and 'man-made' energy. It is obviously a distinction she feels is important. It is one she draws between energy that occurs 'naturally' (wind, clouds, the sun, stars) and energy that is manufactured in power stations, turbines and so on. Natural energy occurs as a matter of course - quite 'naturally', whilst manmade energy is quite deliberate and
contrived. She begins by discussing the sledge card (E9) which she decides is able to come down the hill on its own - 'automatically', because:

Extract 107
S. it's just doing it... it hasn't got any thought behind it

She continues by introducing an example of her own when someone shouts and produces an echo. This, she argues, is another example of natural energy:

S. it just happens... I mean it's nature it just happens ... we don't make it /the echo/ happen... we don't force it to happen

In the conversation that follows the interviewer picks up the word force (this is the second time it has been mentioned in the interview) and asks:

I. you have mentioned force once or twice... what would you say the difference is between force and energy?

S. ... well it depends what sort of force. I mean... there's when you aren't forcing something to do something... which is natural force... and then you've got force when you're forcing something ... like cutting steak... (both laugh)

I. I see... a tough steak

S. yes... you're actually forcing that to be cut whereas the sledge is sort of natural force and the echoes ... are natural force..

In this sense S seems to be using the terms force and energy synonymously. Her major distinction is not between force and energy but between natural and 'forced' occurrences.

In the discussion that follows she goes on to forge a further argument. Both natural force and energy occur without
premeditation (they just 'happen') whilst deliberate force and energy require some input or triggering agent to generate them. She discusses some hot water (E4) and says:

S. it hasn't got that much energy because..... it wouldn't stay hot very long
I. why's that?
S. .... because that has got to be given energy to produce energy... that sort of forced energy
I. how do you mean?
S. like you've got natural force and that /the hot water/ is a pushing force sort of thing
I. that's a pushing force?
S. yes you force energy into it and then it produces steam... which we can use for energy again... so a sort of chain reaction
I. I see
S. yes we force force into it to produce force... to make force
I. umh
S. and once the steam's used up... it just goes back to cold water again and it hasn't got much force in it..
(S,4E)

This is a long and rather involved extract (later ones will be shorter) but it does serve to highlight the complexities of the responses. S is not confused or in doubt, she knows what she wants to say... she is a good example of a student who enters into the spirit of the interview and in the course of it engenders a platform for her own ideas.

The last two parts of the extract suggest that whilst she is using force and energy interchangeably she actually has two separate meanings for the term force. To 'force force' into water in order to make steam, points to
a notion of deliberately infusing the water with a potency so as to raise its temperature. There is evidence here for a range of frameworks: that natural energy is inherent within objects (D-E), that 'forced' energy is a man-made device (F-E) and that is generated when catalysed by some other activity (I-E). Moreover force/energy is something that can be transmitted from place to place (T-E; S-F) and undergoes changes.

The tables in figure 47 are an expansion of 3E and 3F, 4E and 4F and 6E and 6F columns in the table in figure 46.
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Figure 46
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<td>ENERGY: A-E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FORCE: C-F</td>
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<tr>
<td>SEPARATE AND DISTINCT</td>
<td>4</td>
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<td>7</td>
<td>D-F/D-E; D-F/O-E; O-E/D-F; A-F/D-E; O-E/M-F; C-F/D-E; E-F/O-E</td>
</tr>
<tr>
<td>SEPARATE AND RELATED</td>
<td>29</td>
<td>T-E+M-F; A-E+M-F; O-E+I-F; T-E+A-F</td>
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<td></td>
<td></td>
<td>M-F+D-E; C-F+T-E; D-F+O-E(2); E-F+P-E</td>
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<td></td>
<td></td>
<td>C-F+O-E(3); I-F+T-E; D-F+D-E; E-F+T-E(4); O-F+O-E</td>
</tr>
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<td></td>
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<td>M-F+D-E(2); M-F+O-E(3); D-E+A-F; D-E+I-F(2); M-F+T-E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OTHERS</td>
</tr>
</tbody>
</table>

Figure 47

5.69
In table 3E + 3F, thirteen students make no comment about the other concept in the interview and, as has already been suggested, make use instead of words like power, strength, push, pull, speed and so on. In the remaining twelve interviews in this third year group, force and energy are co-discussed some seventeen separate times. On five occasions they are separate and unrelated. The responses offered as explanations of this are evidence for a wide range of (ten) different frameworks. On seven occasions the two terms are used synonymously so that they are interchangeable between the pairs of frameworks indicated. These are along the lines 'well force and energy are the same... it's what's inside you to let you do things'.

Where a relationship is delineated it is either in terms of energy being needed to produce or generate a force (for example in humans pushing (E1)), or a force being required to produce energy (for example, a force in a battery being required to produce electrical energy (E2)). In 'other' cases the relationship is unclear (for example, where the force and energy of a golfball (F8) both 'get weaker' as it goes upwards).

Although the figures in the 4E + 4F table in figure 47 are different (with a considerable increase in responses, particularly in perceived relationships between force and energy) the shape of the table is the same, as is that for 6E + 6F. The 'others' group of relationships are ones often difficult to designate to particular frameworks. In the majority of cases where students use 'energy' in a force interview (for example) they discuss it in
sufficient length to allow a reasonably clear notion of how they intend it to be used at that particular instance. Where 'one-liners' occur they are much more difficult to assess. Some examples are given below, all from the 6E and 6F table.

Extract 108
A. ... force... that's what energy **does**
   (A, 6E)

Extract 109
P. well... energy is proportional to force
   (P, 6F)

Extract 110
A3. ... force is... the energy you need to do something
    (A3, 6F)

Extract 111
T. I think energy is the **measure** of force
   (T, 6F)

These rather clipped extracts indicate some of the levels of response. It needs to be said here, to be commented upon later, that (not included in the 6E + 6F table) of the seventy-seven interviews, two responses are what might be termed orthodox physics answers in terms of **work**.

These both occur in the 6th year group, 6F.

The overall impression of the three tables in figure 47 is of the wide variety of frameworks that are evoked in
the joint consideration of force and energy. The most common rejoinder from a student is 'well in this case...' or 'here it's different because...' The two terms are used generously and with differing levels of meaning and implication in order to account for features in the pictures. The most popular sequence in the 6th year group is where energy is treated as a force. It is described as a force in 'counterbalancing' other forces (like gravity or friction). In doing so it changes into other forms and 'becomes' gravitational potential force (or energy) or produces heat, and so on. This is reflected in sequence E-F → T-E in the 6E + 6F table.

B. Energy ↔ Heat Overlaps

There are 34 energy interviews and 29 heat ones making a total of 63 in this combination. They can be seen in terms of year groups in the table in figure 48, and in more detail in figure 49.

<table>
<thead>
<tr>
<th>ENERGY</th>
<th>HEAT</th>
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<td>10</td>
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<tr>
<td>34</td>
<td>29</td>
<td>63</td>
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<td></td>
</tr>
</tbody>
</table>

Figure 48

The extract used to introduce this set of interviews is taken from a discussion with C2, from group 4H, where she is talking about human body heat and the blood's circulatory system (card H15, the runner).
<table>
<thead>
<tr>
<th></th>
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<td>SEPARATE AND RELATED</td>
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<td>51</td>
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<td>NO. OF RESPONSES</td>
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<td>37</td>
<td>64</td>
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</table>

**Figure 49**

5.73
Extract 112

C. we have oxygen... carbon dioxide... glucose or starch.. proteins and they're all made out of carbon and hydrogen and nitrogen and stuff

I. aha

C. and they use the oxygen... and they're oxydised and when you oxydise something it gives off heat and our circulatory system carries the heat round and if there's too much heat we get rid of it by sweating and give off the heat

I. why would there be too much heat?

C. well when we're running we take in too much oxygen and we're making too much energy and there's too much energy and there's too much heat and that means we sweat... we get hot and our veins go to the surface and we look red

I. and energy... what's energy?

C. umh.. it's a type of force I suppose.. its like a fuel... when your face goes red and things like that it's probably because you've used so much energy

I. and what does it do?

C. with the oxygen... you need red cells in you and they need energy... I would think they're using the energy to get round in your blood (C2,4H)

This level of response is the norm in the interviews. The student is trying to make sense of aspects of physics lessons as well as parts of chemistry and biology. If, as she supposes, heat is produced as part of chemical reaction in the body then she must turn to what she knows of such reactions in order to structure her response. Energy is seen to be part of physics and so when the interviewer picks up on that word in her account she makes sense in her answer by organising her ideas in physics. The red blood cells are then described as using up the energy in the body in order to circulate within the blood. It is a theme
she returns to several times in the interview, when a person is standing in snow (in relation to the dustbin card H10) and when they fall ill (H1). The energy is seen as related to the heat in the sense that it is required to mobilise the red blood cells in order that heat might be 'given off' through sweating.

As previously for force and energy, the analysis is taken a step further by expanding the \( E + H \) column of figure 50 so as to indicate the most popular frameworks involved. Again, as with force and energy, there is an increase with age-group of the numbers of responses where there is a perceived relationship between heat and energy. A number of interesting points can be made from the tables. First the number of responses where heat and energy are seen as separate and distinct (unrelated) decreases after year three. Of the 25 responses in the year 3 interviews, 5 suggest that the two are distinct - some 20\%. In year 4 this is 9 out of 66 responses (about 14\%) and in year 6 about 14\%. Although it is not possible to make strong comparative statements from the small numbers involved, it is tempting to look for some indicators. One might expect the two concepts to be seen to be related more by the 6th year group, given their longer exposure to physics and their greater homogeneity of achievement in physics. This is not immediately borne out, however, by any marked increase in the use of the aphorism 'heat is a form of energy'. One particular distinction made between heat and energy is worth noting. It centres around the card depicting some hot water in a beaker (E4). The notion is that hot objects - or in
<table>
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<th>FRAMEWORKS</th>
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<td></td>
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<td></td>
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<td>(heat is a form of energy)</td>
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<table>
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<td>OTHERS - 4.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(heat is a 'form' of energy)</td>
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(only the most popular of all the combinations are shown)
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<tr>
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<td>9</td>
<td>ENERGY: O-E(4); D-E(1); A-E(2)</td>
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<tr>
<td></td>
<td></td>
<td>HEAT: N-H(4), C-H(4); R-H</td>
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<td>R-H/P-E; C-H/P-E; G-H/I-E; N-H/I-E; T-E/M-H</td>
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<td>OTHERS 7 (heat is a form of energy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(only the most popular of all the combinations are shown)</td>
</tr>
</tbody>
</table>

Figure 50
this case, a beaker of hot water - does not have any energy. That is, in that situation, energy and heat are separate, distinct and unrelated. The commonly presented reason is that the water has no energy within it to be able to do anything. This is represented in the tables as a distinction between conspicuously hot bodies (C-H) and internally activated ones (D-E). This distinction appears in table 3E+3H, and is the most popular in both tables 4E+4H and 6E+6H. Some extracts below, one from each year group, are intended to illustrate this distinction.

Extract 113
C. well water's got energy and that... when it keeps you alive... but that's /the picture/ not showing that...
I. what do you think the picture's showing?
C. well not the energy... that's just showing the heat of the water... I don't think it's really energy of water
I. is there any connection between heat and energy?
C. ... heat.... energy... well this /the water/ is heated but it isn't heat...... it's not really hot... the heater had the energy but this hasn't. (C2,3E)

Extract 114
H. no
I. no?
H. I mean things have got energy or they haven't and that hasn't...
I. why do you say that?
H. well it can't do anything.. it can't make itself to go anywhere... it hasn't anything in it to move anything... it's just hot water... (H,4E)
Extract 115

G. ... hmm... heat energy... heat energy I would have thought was when it gets really hot... I mean okay that's hot... but if the water was boiling, then you would say there's a sort of energy there ... but I wouldn't have thought that was really hot enough to be described as heat energy... if it's boiling it's got some power to do something but not as it is now (G2,6E)

In these three extracts the energy within the water ranges from being that which can keep us alive, to that which can make things go, and finally to some power that can do something. In each case it is contrasted with water that is static and simply hot (and, according to G2, not hot enough).

A second point to be drawn from the tables is the large number of responses that can be grouped under the heading 'energy produces heat'. Rather than seeing heat as one amongst a variety of 'forms' or 'kinds' of energy, heat is separate from energy (is not an energy) but is produced by it. It occurs as a result of some energy being expended. This response is similar in both the macroscopic discussion (in terms of human bodies, car engines, blocks of ice or whatever) to the microscopic (in terms of molecules, atoms, particles or electrons). An element of this can be seen in C's (C2,3E) extract 113 above. The water is heated by some source external to the beaker of water. It is the heater that has the energy in order to produce the heat which in itself is not energy.

A later extract from the interview with G2 illustrates similar expectations of heat and energy at a microscopic
level. Whilst the initial focus to this part of the conversation is the block of ice (E8), G2 returns to the hot water card during the discussion.

Extract 116

G. it's interesting isn't it... I hadn't thought of it /the hot water/ like that /in terms of 'molecular' activity/ ... well I suppose the water molecules being the hot water must be moving... so therefore .. they will have some sort of energy... I suppose as they're moving... they must be getting hot... which I suppose is because they are being heated (laughs) but that isn't real energy I wouldn't have said.. it's not what you'd call actual real energy there..

At this point G is still maintaining a distinction and separation between the two although he now perceives some link (they must have 'some sort of energy'). He goes on to talk about electricity generated by steam driven turbines and then about nuclear reactors.

I. and when you talk about nuclear fuel what do you mean?

G. well it's radio-active decay.. the way it works is you get the neutron emission from.. like uranium 238 which collides with other uranium atoms and produces a lot of heat.. but basically the heat is produced when the atoms and that collide..

I. what do you mean when you say produced?

G. when the neutrons collide they must sort of react together to give the reaction and part of that must come off as heat.. which goes to the water until it boils... it gives steam... steam drives the turbine and so on..

(G2,6E)

By taking this longer look at G's conception of heat and energy, the intention is to illustrate and exemplify one of the many combinations of frameworks that are included in the tables. It would clearly be an unduly lengthy
process to detail all of them. These extracts, though, do highlight the points to be made. The separation and distinction between heat and energy, and in the latter part a perceived relationship between the two, is continued from the macroscopic into the microscopic level. This is seen, too, in the extract 112 from (C2,4H) which was used to introduce this area of overlap. The energy a person needs is a 'kind of fuel' and this undergoes a mechanism ('oxydisa- tion') which in turn 'gives off' heat. It is a by-product of the process, the energy being required (at the microscopic level) in order to move red cells in the blood stream.

From the extract 116 by G2, a subsidiary point can be made. Both the separation of heat and energy (as unrelated) and the eventual relationship (of energy producing heat in the nuclear 'reaction') are both present within the same interview. The term 'produced' is still a vague mechanism (although perhaps not to G2) even when explained: heat is 'some part' of a collision that 'comes off' and which then 'goes' into water. Some aspects are reminiscent of the 'hot molecule model' already intimated and which is discussed further in the next chapter.

C. **Energy↔Light Overlaps**

In these interviews there are 28 light ones to be added to the 34 energy interviews, a total of 62 in all. This is shown in the table in figure 51 below.
The opening extract in this set of combined interviews is from Y in group 4L, who is relating energy to the production of light. He discusses this by considering the battery and bulb circuit (L10) although he then generates his own example in terms of a hypothetical chemical reaction.

**Extract 117**

Y. well... let's say that you have a chemical reaction ... it's the same kind of thing as what's happening inside the battery or something... it's two things reacting together /he extends his arm as if holding an imaginary test tube between index finger and thumb/... and producing energy... because its bubbling away quite happily there so it must be producing some kind of energy which is.... moving it about

I. and what has light got to do with energy?

Y. there could be... if it's something that produces light when it reacts with something else

I. what are you thinking of?

Y. well... if you put... let's see.. put lithium into water you should get it.. it starts to sort of it melts and then it bursts into light.. it burns to produce light (Y,4L)

This extract represents an example of where some

5.82
relationship is expected between energy and light although it is not explored in depth and remains quite vague. Energy is suggested as being present in a test tube of bubbling chemicals (because they are bubbling and moving about), and some chemical reactions are capable of generating light. This particular relationship is not expanded upon any further in the interview although he does argue at some points that light produces energy (inside the chloroplasts in leaves and in solar panels).

The summary tables for these interviews are shown in figure 52, and as in the previous cases, the more detailed breakdown of the E+F column is shown separately (figure 53). A similar trend is notable as in the previous ones; there is a greater number of responses showing perception of some relationship between the two after year three. As before, there are some points of interest to be drawn from the tables. To begin with, since so many cards in both decks would seem to be 'obvious' examples of light and energy, the incidence of no-responses needs to be examined. How is it possible to discuss the battery and bulb circuit (E2;L10); the hand lens (E6;L9); the flower (E14;L11) or the stars (E15;L13) without some mention of light - if only to make some kind of distinction between it and energy? Three different reasons are apparent in the transcripts.

Firstly, the students make no attempt at an explanation and might offer variously that they simply do not know; they have not yet 'done' this in lessons yet; that this is biology and they no longer do biology; they have covered it in lessons but they no longer remember and so on.
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**Figure 52**

5.84
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</tr>
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<td></td>
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</tr>
<tr>
<td></td>
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<td>LIGHT PRODUCES ENERGY 4 -</td>
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</tr>
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<tr>
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<td>I-L/F-E</td>
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<td>SEPARATE AND RELATED</td>
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<td>D-E+P-L(5); T-E+D-L(5); D-E+O-L(6); F-E+O-L(2); T-E+P-L(2); P-E+P-L(3); F-E+M-L(2) O-L+P-E(5); P-L+D-E(2)</td>
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continued...
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<th>CATEGORY</th>
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<td>P-E/P-L(2); C-L/T-E</td>
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<td>SEPARATE AND RELATED</td>
<td>39 ENERGY 'PRODUCES' LIGHT 24</td>
<td>T-E→M-L(3); T-E→P-L(3); D-E→P-L(4);</td>
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<tr>
<td></td>
<td></td>
<td>T-E→O-L(2); D-E→M-L(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M-L→P-E(3); O-L→P-E(3); P-L→T-E;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P-L→A-E; O-L→D-E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(only the most popular are shown)</td>
</tr>
</tbody>
</table>

Figure 53
Secondly, the conception has developed a particularly strong line so that the thrust of the argument does not encompass light (in an energy interview, say) and so it passes without comment. An example of this might be where a student has developed a strongly anthropocentric conception of energy and is judging each situation on whether the energy 'does anything for us'. In this context 'stars' (E15) might be classified as a non-example on the basis that they serve no practical human purpose, so that their light is not even considered. In contrast, the hand lens would have energy because it 'lets us see things better' but again without light being mentioned as somehow necessarily involved.

Thirdly, although one specific conception might not dominate the discussion, within the range that is offered none is brought to bear on the other concept. So, for example, even though a flower might be discussed in terms of energy, it would be energy from water, the soil, nutrients, its leaves and so on. Energy from the sun might be considered in terms of heat, or just as 'the sun's energy' but without light featuring in the response. The battery and bulb are sometimes spoken of as 'electrical energy', or the 'power' from the battery 'making the bulb work' etcetera.

In terms of the year groups, the two 'no-responses' in the 6th year table (6E+6L) shown in figure 53 fall one each into these last two categories. One is a strong argument in favour of 'deposits of energy', the second a widely ranged set of explanations that feature no comment on light.
The first category of no-response - the 'I don't knows' - is more common in the year groups 3 and 4. There, the spread is more often between these three kinds of no-response category.

The number of distinctions between light and energy is worth noting, too. It prompts the question that if light is not energy, then how is it described? A popular distinction - occurring a number of times within each year group - is between energy seen as deposited within objects (like lumps of coal, or vitamins in food), and the happenstance of being an observer to a scene or view. That is, between a D-E and a D-L framework. In this case, the watching of other youngsters through a window as they walk past outside the room is not related to a specific light source. In the event, light is needed (so that they are not in the dark) but the onus is on the observer to look in that direction and 'see', rather than for light energy to be reflected into the observer's eye. 'Looking at' is an activity that does not involve any fuel or power source, there is no 'battery' to make us see, and so 'energy deposits' and 'watching an activity' are seen as separate and distinctly unrelated. An example extract helps to make the point:

Extract 118
/the hand lens E6/

C. ... well energy was probably needed to make it... you know to mould the glass and the plastic but I don't think it has any energy in itself... I mean it doesn't produce any... the piece of glass stays a piece of glass... the plastic stays a piece of plastic... there's no energy in it to come out of it

I. you mentioned before that it might be a powerful lens

5.88
C. (laughs) ah yes but I didn't mean it that way
I. how did you mean it?
C. no.. the shape of the glass... the letters are always the same it's just the shape of the lens is magnifying them so we can see them better... we just look through it and see them bigger.. it doesn't have energy there to do that... (C2,3E)

Argued in this way, C's distinction seems reasonable and self contained; there is no 'obvious' power source to a lens (unlike, say, an electrically illuminated microscope) and the seeing of the magnified image is simply a property of the lens. Similar arguments occur in the 4th and 6th year interviews.

Interestingly, light being synonymous with energy occurs in the older year groups, although (in comparison with synonymity between force and energy) quite infrequently. The P-E/P-L combination of frameworks shown in the tables can be illustrated from a 6L interview where photons are discussed:

**Extract 119**
/D is discussing the candle (L6)/

D. light is being emitted by the candle but (laughs) what is a flame.... I don't really know... burning material I suppose (laughs)
I. (laughs) yes but what does that mean?
D. hmmm... a good one... well light is made up of photons.. that can be described as elementary particles which .. okay.. are a unit of energy and .. since this material is being destroyed or whatever... and then from E=mc² the energy is given out and that's the light... energy and light are the same thing... it's being produced in the flame and then given out into space...
(D,6L)
In one sense this extract can be clearly earmarked as coming from a 6th year transcript about light. Expressions like 'emitted'; 'photons'; 'elementary particles'; 'units of energy'; 'E=mc^2', and so on are not commonly part of, say, a year three transcript (although there are one or two). However, the general organisation of such elements of explanation, the confabulation of the features being described that produces a coherent yet unorthodox conception is similar across all year groups. Moreover, the themes are still present - energy is produced (P-E) by a mechanism (the destruction of material) and projected - as photons - out into space (P-L).

As can be seen from the tables the relationships between light and energy are very varied and, given the flavour of the extracts used so far, can each be seen in its own right as cogent and coherent. Of these many relationships one is selected here for comment. It occurs once in each of the year group interviews and is shown as P-L → A-E. It does not appear in the table 4E+4L in figure 53, because it is not one of the most popular. However it does serve to highlight the diversity within the accounts being put forward. The relationship is one between a Projected Light framework (beams or rays of light being directed to hit objects to some effect) allied to an Anthropocentric Energy framework. It is an alliance, too, that is included with others where light is considered to be producing energy. That is, human beings derive energy for themselves from incident light. In many school classrooms, such an unorthodox combination of arguments - in that unadorned style -
might probably be greeted with frank disbelief, if not derision. In the more discursive and open atmosphere generated in the interviews they transpire as follows:

**Extract 120**

/sunbathing (L8)/

C. ... I don't know... you always feel better... you know if you're suntanned... you always feel well it just feels better... obviously if its ultraviolet rays it could be sort of re-charging your body and doing something to your body cells... /a moment later/... I mean if you go somewhere really hot for a month... a month every year. then it'd keep you sort of in trim... I don't know... its a difficult thing thinking about a suntan... I mean you can't get a tan from an electric light... but you can now buy sun ray lamps... they're giving off ultra violet rays and that does brown you and make you feel more energetic.. (Cl,4L)

Within the context of the interview, this particular discussion was sandwiched between C's personal debate as to why white European people should ever get a suntan - on the basis that white objects reflect all light.

The next three of the areas of overlap receive rather shorter and more cursory treatment than these other, more direct, overlaps. In designing the IAI cards, the exploration of the interrelationship between the concepts was envisaged with respect of the areas of overlap already discussed. With the introduction of each new target concept deck of cards the possible combinations multiply rapidly and so for pragmatic reasons the analysis of overlap is restricted. There are however, one or two interesting points to be drawn out of these remaining, minor, boundaries
between frameworks and so they are mentioned here briefly.

D. **Heat ↔ Light Overlap**

This discussion begins with an extract taken from an interview with Y (4L). He has been talking about light and energy when he introduces the notion of heat, in relation to the sunbathing card (L8). Like C(4L), at the end of the last extract (Extract 120), Y is puzzled by the action of heat and light.

**Extract 121**

**Y.** ... the person will absorb all the... well a white person will absorb all the light... but that's a funny thing because when you go out and sunbathe you should reflect the light but you don't you turn dark and then that absorbs the light not reflects it... and the brown is meant to protect you (laughs)

**I.** yes.. how do you think it works?

**Y.** I don't know.. perhaps if you want protection you should go shiny... tin-foil people (laughs).. but perhaps its the heat that does it not the light

**I.** and how would that work?

**Y** umh... light is sort of different... I know light travels in waves... I don't think heat travels in waves. I think it sort of.. you can get rays which produce heat.. but heat is different, because it's actually in things.

**I.** can you tell me anymore about heat and light?

**Y.** well light is little waves radiating and I think heat can get radiated if you put something cold on something hot... the sort of wiggling particles in the hot thing will start moving.. start exciting the ones in the cold thing

**I.** and what does it do here? /in the sunbathing instance/

**Y.** well that's the little rays which come from the sun ... they must be sending things with them as well I suppose

5.92
I. what sort of things?
Y. ultra violets... yes that's it... ultra violets... (Y,4L)

There is much to comment on in an extract like this - which makes it so useful as an illustration. It is illustrative of a range of points and comments already made. There are elements in Y's explanation (which continues for much longer than this extract - or this study - permits) that are clearly recogniseable as features in school science: reflect; absorb; waves; radiating; wiggling particles; exciting; rays; ultra violet and so on, which are all terms to be found commonly in descriptions in lessons and school texts. They are synthesised here, however, to serve a different - personalised - purpose. In retrospect and with the benefit of hindsight it is more easy to see what Y's conflicts are. Having focused upon a dilemma concerning sunbathing he decides that heat is the agent responsible and not light. However he has a conception of heat that is local to objects (is in things) and is transmitted by wiggling particles when objects are in contact. He is aware here of another conflict: how then is heat from the sun responsible for a suntan? He has a notion that rays can produce heat and eventually argues that light rays must then carry something - if not heat itself then something else.

This particular synthesis of ideas may not have occurred to Y before and might have been instigated by his own personal questioning of phenomena in the context of the interview, along with the interviewer's questions.
It is an example of an interview where Y entered into the discussion wholeheartedly (the transcript runs to forty six pages of typescript in a way similar to that shown in appendix III and quite often Y's contribution to any one card is many pages long - with only minimal intervention by the interviewer. In the course of it he discusses his own ideas (like tin-foil people); parts of science he says he 'knows', and those parts where he is puzzled by apparent contradictions.

In this immediate context, concerning the overlap between heat and light, Y's description shows that they are separate yet related. The relationship is not well established (beyond light acting as a carrier for heat), however they are not entirely independent. Whilst Y's description does not fall easily into evidence for any one framework, there are some facets that give some indications. In that heat is local to objects it suggests a Regional Heat (R-H) framework, whilst light is projected as a wave/ray (P-L).

The analysis of both the heat and light interviews enumerated below in figure 54, is shown (as before) in the tables in figure 55.

<table>
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<tr>
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Figure 54
<table>
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<tr>
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<th>3L (n=9)</th>
<th>3H+3L (n=18)</th>
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<td>11</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>SEPARATE AND RELATED</td>
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<td>8</td>
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<td>NO. OF RESPONSES</td>
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<td>22</td>
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<tr>
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<tr>
<td>NO. OF RESPONSES</td>
<td>11</td>
<td>11</td>
<td>22</td>
</tr>
</tbody>
</table>

*Figure 55*
The overall pattern of responses is less even than has previously been the case and this in itself requires comment. There is a clear indication that the two decks are not even in that there is more discussion about the relatedness of heat and light within light interviews than in heat ones. This is certainly the case in the third and fourth year interviews. Here, two possible reasons are suggested for this. Firstly, the two decks are uneven in that the cards used for light favour a discussion of heat more than the heat cards do for light. It is to be remembered that the two decks were not designed to give equal facility to the other concept; they are ones that 'work' for their target concept. With this in mind, the light cards most likely to encourage talk of heat have been:

- Candle (L6)
- Battery Circuit (L10)
- Sunbathing (L8)
- Flower (L11)
- Lens (L9)

In addition, once heat has become a topic of debate in relation to these cards, the slide-projector (L2) and television set (L3) are also included (as 'warming up'; 'needs a fan cooler' and so on). In the heat deck the 'light orientated' cards are mainly:

- Flower (H7)
- House (H9)
- Astronaut (H13)

In some cases, reference is made to a relationship between colour (i.e., red) and heat although this is left for separate comment.

A second, allied, reason is that whereas heat and light are seen as related, like that of Y(4L) in the initial
extract, the relationship is often vague. The most often quoted aphorism is that 'where you've got light you've got heat, but where you've got heat you don't always get light'. There are some examples of this being overturned - one student talks about the 'cold light of day'; another of being able to see a street light but not being able to feel its heat. The majority, however associate heat with very light objects, but not light with hot ones. 'You wouldn't expect boiling water to glow would you?' is one rationale. In this sense the two most widely used heat frameworks (N-H and R-H) militate against an easy union with the light frameworks. Heat is in and around things, it is what you feel and not what you see. Given this, it is to be expected that the sunbathing (L8) and lens (L9) cards provoked much discussion.

An example of a distinction being made between the two is given in extract 122. Extracts 123 and 124 show an example of synonymity and of a relationship, in that order.

Extract 122

D. no they're /heat and light/ different
I. what makes you say that?
D. well this /battery card, L10/ does I suppose I mean if you had a car and you put your headlights on your lights won't get any heat.... your battery might start getting heat up. and things like the plug and the fuse what gets hot really... like a battery if you keep on driving in a car sometimes you got to stop because of the heat and everything because it starts smoking... but that's not light (D,3H)
I. what about this one
A. I think if he's out in space it would be cold really
I. why do you say that?
A. because space is lonely and cold... I don't actually know what it's like (laughs)
I. (laughs) uha
A. it's the darkness really... I think of light as warm... and associate darkness with cold... I mean it's never actually warm at night is it? (A,4H)

Extract 124
I. what I wanted to ask you then was what has heat got to do with light?
P. they're both forms of energy. light and heat and energy can be intra... inter converted into the two forms... and there is an equation relating the two together... light and heat
I. so when you talk here /the lens card L9/ about a principal focus... what is being focussed?
P. it's the light... you are actually focussing the light rays and when they intricate here you get destructive interference and they produce heat (P,6L)

This last extract is a useful example of the interviewer having the facility (in comparison to some other data collecting methods) of 'picking under the surface' of a response. That is, of being able to press for a further explanation after an initial response has been made. What some might consider as an adequate and acceptably 'scientific' explanation of heat and light being forms of energy, is just one facet of a more elaborate and less orthodox explanation. P argues that the heat produced at the focus of a lens is 5.98
caused by rays of light in destructive interference (allowing that this is encompassed in her use of intricate as a verb).

E. Heat ↔ Force Overlaps

Of the seventy two interviews shown in figure 56, very few made any comment about the juxtaposition of the concepts heat and force. Those that did can be grouped into two main categories of response: where forces (like friction) 'produce' heat; and where heat is described as a force.

<table>
<thead>
<tr>
<th>HEAT</th>
<th>FORCE</th>
<th>TOTAL</th>
<th>YEAR GROUP</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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</tr>
<tr>
<td>9</td>
<td>14</td>
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</tr>
<tr>
<td>29</td>
<td>43</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

Figure 56

By far the greatest majority of responses fall into the first category where heat is treated as a by-product of some activity that involves forces and movement. Friction itself is not always treated as a force (sometimes as a kind of 'rubbing energy') and quite why such an activity should produce heat is not always clear (except that 'if you really rub your hands together it really gets warm'). An interesting example of this kind of argument is given in extract 125, whilst the following one (Extract 126) is an example of heat described as a force.
Extract 125
/the stone thrown off a cliff card, H11/

C. there's no heat... except. if we're talking about friction or something like that...I mean the stone falling through the air

I. you mentioned friction before.. didn't you what has that got to do with it?

C. oh.. as the stone is falling. its sort of making a hole in the air as its cutting through it. and as its cutting through it it's sort of going each side of the stone and its rubbing against it.. that's what makes things like the shuttle red

I. what about the shuttle?

C. the space shuttle.... its going quite a bit faster (laughs) and its coming through the atmosphere.. coming from miles up in space and its got further to fall and its bigger /than the stone/.. and more speed and its tearing through quicker and rubbing past quicker... cos if you strike a match along a box and strike slowly it won't work but if you go like that /he demonstrates a quick match-striking movement/ then it will...

(C3,4H)

This is interesting because of the analogies he uses in order to make his point about friction and yet still leave the action of rubbing (and the consequent production of heat) quite vague. It is interesting, too, how he draws on two other pieces, of information and experience, in order to structure his response.

Extract 126

I. what would you say heat is?

C. ... I suppose you could say.. if you light a candle and put your hand over it.. you feel pain in your hand and this is exerted by the candle's heat.. .. it's an energy-force...

(C,6H)
In some circumstances - for example, for the beaker of hot water (E4), or the iron bar (H5) - the heat is sometimes described as a force in that it 'forces' the mercury up a thermometer, or forces the iron bar to expand. In another example a student, talking about a very large bonfire, spoke about being 'hit by the force of the heat' as she walked nearby, and of the 'force' of the flames as the wood burnt 'fiercely'.

F. Light Force Overlaps

Even fewer responses make any link, distinct or otherwise, between light and force. In a sense this area of overlap is included partly for the sake of completeness and partly for the few interviews (out of 71; figure 57) where an overlap does occur.

<table>
<thead>
<tr>
<th>HEAT</th>
<th>FORCE</th>
<th>TOTAL</th>
<th>YEAR</th>
<th>GROUP</th>
</tr>
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<tbody>
<tr>
<td>9</td>
<td>15</td>
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<tr>
<td>28</td>
<td>43</td>
<td>71</td>
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</table>

Figure 57

Commonly, such overlaps occur at the torches card (F15). Although this card focuses upon differences in force on the lit and unlit torch, this is clearly an invitation to discuss light in the context of force. As is the case with heat, already mentioned, some students talk about light having to force its way through air in order to project.
An example of this is given in extract 127. Only one student discusses light as a force, but does so in a manner so graphic as to merit inclusion (extract 128). In relation to the torches card, for example S2(6F) says:

Extract 127

S2. ... well I don't know if there's any difference ... gravity is the same on both of them except this one /the lit one/ will need force to get it through the air

I. why do you say that?

S. well it /the light/ is moving so there must be a force there somewhere and then it has to push its way through at the air molecules...

(S2,6F)

In this sense the light needs a force in order to be moving (M-F) and this acts to clear a path for it through the air. For T, light is perhaps even more tangible:

Extract 128

T. .. the force is really in' the batteries and the bulb

I. is it the same as before? /T had previously been arguing that forces are things that one can feel/

T. well if you put your hand over the light you could feel it. pushing forcing... (6)... well you could see the light forcing itself through your hand.. your fingers

I. uha

T. well it's not like the force where you're pulling something it's a force where its... umh.. how shall I say.. light in fact does move things if you have it.. strong enough.. it's like putting your hand over it. it tries to get through

5.102
I. how do you mean?

T. sometimes. say for instance you shake up a bottle of coke and put your finger over the top.. well that's a force upwards. so it's the same sort of thing well sort of..

(T,3F)

This section on the areas of overlap between the four main target concepts is rounded off here with a final quote. As with some of the previous ones, it centres on a particular dilemma, or paradox that has occurred to the student. It is part of a light interview when R(6L) is talking about the rainbow card (L4). He describes the light as 'splitting up':

Extract 129

I. how does it do that?

R. well the light has different wavelengths and as it goes through they're each slowed down different amounts. and bent different amounts by the changing .. as it goes from air into water.. and I think it's slowed down going into the water and it speeds up coming out again.. so when it comes out it's split

I. how does it speed up when it comes out?

R. I don't know. it really puzzled me and we did get into a massive great argument once /in class/ about where it gets the energy from.. where it gets the force to accelerate and speed up again

I. and?

R. (laughs) it was never explained to us... I don't think he /the teacher/ wants us to bring it up again..

(R,6L)
5.4: The Incidence of Frameworks

The purpose of this section is to review and recast some of the major points made in relation to the overall distribution of frameworks. Since this is not a straightforward and direct exercise, a number of other pointers are used in order to discern trends and patterns in the use of frameworks. These trends are discussed in particular as they relate to the three age groups of the students interviewed. It has already been said that the three age groups are very different in terms of their composition. The students in the year three age group are heterogeneous in terms of both their motivation towards matters physics, and their level of achievement. In contrast, the sixth year group is quite homogeneous (being mostly A level candidates in physics). Whilst the year four group lies somewhere in between.

It needs to be said that, as a normative evaluation of the responses made, there is a clear trend towards 'acceptable school science' with an increase in the age group. Given what has already been said this should not be surprising. It would be more surprising if there was no movement towards an inculcation and interpretation of orthodox school science with age, motivation, achievement - or simply with greater exposure to physics. However, this is not a normative study and is instead, more concerned with the incidence - and therefore the durability - of 'sets' of ideas, in the three groups. Given the greater maturity, fluency, scientific literacy and so on, with year...
group, the question is one of how to document the changes and the spreads of frameworks that do occur.

An initial feature is the designation of instances as non-examples. The design of the cards allows for clear non-examples (in the physics sense) clear examples and 'borderline' cases. Figures 21, 27, 31 and 39 show how some of these fare. Given the composition of the year groups as described, the expectation might be that the clear non-examples in each deck would increasingly be recognised as such (in comparison with an orthodox school response) and so grow in number with age. Moreover, the borderline cases might decline for the same reason. This can in fact be seen to be the case; in energy, the ghost (E3) increases as a non-example from 5 (year group 3) to 8 (year group 6). In the force deck 'told' (F3) and 'robber' (F10) also show this increase. It is worth noting that if in eight of the 6E interviews the ghost is treated as a non-example, this still leaves two students who treat it as an example. Similarly, thirteen out of the fourteen interviewees treated the 'told' card (F3) in the force interviews as a non-example, leaving one student who thinks it an example. Along the same lines two sixth year students see 'thinking' (F6) as involving force. It is less obvious (almost by definition) as to what constitutes a borderline situation. There are cards which show a decline in being classified as non-examples. These are:

**energy:** hot water (E4)  ice (E8)
sledge (E9)  clock (E11)

**force:** book (F11)  balloon (F12)
moon (F14)
However, it is difficult to argue that these in themselves illustrate a general inclination towards a greater appreciation of school science. The example of the ice cube—used as an illustration of categories of response in chapter 4—indicates how the classification of a situation as a non-example can occur for a variety of unorthodox reasons. Interestingly, too, some of the 'borderline' cases remain fairly constant over the three age groups. These are:

**energy:** lens (E6) meal (E7) snow (E10) smell (E13)  
**force:** astronaut (F13) torches (F15)  
**heat:** flower (H7)

Again, the inclusion of the astronaut (for instance) as an example or a non-example of force is for a variety of reasons that do not suggest evidence for any overall pattern of changing frameworks.

Along these same lines, it is interesting to note which are the cards in each set that are not considered as non-examples at all. That is, that might be seen as stereotypical examples of the concept (for any reason). These are:

**force:** stone (F1) tree (F5) golfer (F8)  
**heat:** ill (H1) pies (H3) iron bar (H5) runner (H11)  
**energy:** box (E1) battery (E2)
reaction (E5)

light:  projector (L2)  candle (L6)

flower (L11)

Three of these cards have generally been (but not on all occasions) the first card to be responded to in the pack. They were chosen during the pilot study as 'good examples' as an attempt to provide an easy entry into the task of the interview and to establish an early basis for discussion and questioning. What is surprising in this case is that the mirror card (L1) should have been seen as a non-example, on five of the twenty-four times used. On each of these occasions it is rejected on the basis of a D-L framework: it is not an example of light but of 'seeing' an image on the mirror.

The other cards all seem to fit the bill as stereotypical examples of energy, force, heat and light with the possible exception of the chemical reaction as an example of energy. There is perhaps a suggestion here of chemical reactions being stereotypical examples of matters 'scientific' and therefore of expecting energy to be involved somewhere. The most popular frameworks involved see energy as being generated at the point when the two chemicals mix (I-E), and of it being produced as a side effect of a rather longer and more drawn out process (P-E).

A second major feature of the data shown in this chapter is that indicated in figures 46, 49, 52 and 55: in the areas of overlap between concepts. There is generally a greater willingness, with age, to entertain the possibility of a wider web of concepts within a particular construction
and explanation. That is, to provide responses that construe relationships between the target concept and others. This is less so with the relationship between heat and light. This feature too, needs interpreting with some caution. It has already been pointed out that, although the year three students did not tend to explanations of energy which overlap with force, they did use a variety of other expressions which have not been examined in detail. For example, the word power is one that pervades each of the concept areas and the year groups. Just as one may have a powerful burner or furnace (in terms of heat) so one might have powerful lights, a powerful force and the energy or power to do something. 'Strong' is another such term.

A third feature to note is the smaller amount of evidence for anthropomorphic/anthropocentric frameworks in the sixth year group. There is strong evidence there for anthropomorphism at all ages, and in force (A-F) the decline is not noticeable at all. However, a strong point to be developed in the next chapter is that there is considerable variation within the year groups. It would seem quite often to be the case that anthropomorphism and anthropocentrism is an individualised, personalised approach.

A fourth feature is one that is possible to detect within frameworks. The frameworks themselves are useful as a way of epitomising similarities in responses. It is possible to notice some variations in these similarities with age. The analogy used before was that the framework is a 'family' of elements. For example, the Depository Framework (D-E) is evidenced extensively from each of the
three age groups and for a wide variety of situations. Previous extracts have noted the tendency to see energy as deposited inside certain substances. These substances are shown in the table below, in figure 59.

<table>
<thead>
<tr>
<th>D-E YEAR 3</th>
<th>D-E YEAR 4</th>
<th>D-E YEAR 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxygen, water, food, soil, people, petrol, sleep, cars, fire, animals.</td>
<td>turbines, chemicals, glucose, carbohydrates, electricity, food, light, people, batteries, plants, hills, atoms.</td>
<td>vitamins, people, radioactivity, electrons, molecules, bonds.</td>
</tr>
</tbody>
</table>

Figure 59
That is, the range of convenience of the framework might alter in order to encompass new instances whilst the focus of convenience remains the same.
CHAPTER 6

6.0: Introduction to the chapter
6.1: Colin's Interviews
6.2: Cushla's Interviews
6.3: Petina's Interviews
6.4 Susie's Interviews
6.5: Summary
6.0: Introduction

The forty or so extracts used in the last chapter are intended to serve a number of purposes. Central to these has been the mapping of the alternative frameworks in the four target areas, first by arguing for intra-concept differences, then for similarities across areas, and then finally, for overlaps between them. A subsidiary but increasingly important role for the extracts has been to emphasise the variety and diversity of the responses to the IAI cards. The frameworks, in representing a broad complex of responses, are a way of handling disparate conceptions of the situations in the IAI cards. They provide a common link so that the responses can be accounted for as analyzable wholes. Constructing frameworks is a process of synthesis that runs the risk of obscuring the spirit, breadth and forthrightness of the answers. It was pointed out at the end of the last chapter that the thrust of this study is not to focus on success or failure in physics per se, but on the interplay between individual and multiple accounts of the phenomena portrayed in the pictures. The frameworks are clearly an important interpretative basis by which to infer the boundaries of such multiple accounts. But they obviously do not suffice to explain all facets of the responses given. This chapter approaches some of those facets in more detail.

The major part of the chapter is taken up with an examination of the conceptions of four students. Each one has been interviewed on all four of the concept areas -
a total of sixteen interviews. One of the original intentions of the study - at the outset - was to have a much larger sample of students interviewed in this way. The purpose behind this was to explore the overlaps between concepts with the benefits of generaliseability of a large sample. However, for the reasons already outlined in chapter 2, this has not been possible and so use is made of the benefits of detail and insight that can occur from a smaller sample. Although these four case studies lack generaliseability in a strong sense, if viewed within the context of the larger samples in chapter 5 some valuable general points can still be made.

The four students (one male, three female) are Colin, Cushla, Petina and Susie. They are identifiable as before, in terms of their initial, year group and concept interview. For the sake of this chapter Colin and Cushla will be known as Co and Cu respectively. Some extracts have already been used from these transcripts and the four students have been identified (and appear in tables in appendix II) as shown in figure 60.

Colin (Co): (C2,3E); (C1,4F); (C3,4H);(C1,4L).
Cushla (Cu): (C,4E); (C2,4F); (C2,4L); (C,6H)
Petina (P): (P1,4E); (P2,4F); (P,4L); (P,6H)
Susie (S): (S4,4F); (S,4E); (S,4L); (S,6H)

Figure 60

The timetable of the interviews adds something to the biographical detail of the four students. This is illustrated in figure 61. Two of the students (Cu and P) were interviewed in the September shortly after having

6.2
moved into the 5th year. These are counted in the year 4 group for the sake of this study. The three sixth year interviews were recorded in the period December/March of their first year of A-level work. This means that the longest span of time between any one student's first and last interview (for Cushla) was about thirty months. The longest time between any two interviews was for Susie (4L and 6H) - about sixteen months. The interviews closest in time are those of Colin's, who underwent all four interviews within a period of about ten months.

The first four parts of the chapter deal with each one of the students in turn - in the temporal order shown in figure 61. Thus Colin's are taken first, Susie's last. Colin's energy interview is one of the first interviews to have been conducted at the beginning of the study. It is such a rich and varied discussion of energy that, although the decision to re-interview a sample of students had already been taken, this interview spurred that policy into action. Colin is willing - and able - to talk about his ideas and also ventures opinions on force, heat and light (along with power, weight, and so on). This makes him an ideal candidate for further interviews.

During the interviews a number of features are sought and emphasised. These are as follows:

a) evidence from these conceptions to illustrate particular frameworks;
b) indications of the kinds of overlaps discussed in the last chapter. Whilst these will be mostly for the target concepts, some other, persistent, concept-overlaps are noted too;
<table>
<thead>
<tr>
<th>STUDENT</th>
<th>SCHOOL YEAR 3</th>
<th>SCHOOL YEAR 4</th>
<th>SCHOOL YEAR 5</th>
<th>A-LEVEL PHYSICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLIN (Co) (all boys school)</td>
<td>3E (General science group)</td>
<td>4F (after entry to mixed o/cse physics group)</td>
<td>4H</td>
<td>6H (after beginning A-level physics)</td>
</tr>
<tr>
<td>CUSHLA (Cu) (all girls school)</td>
<td>4E (after entry to o-level group)</td>
<td>4L (becomes prospective o-level candidate)</td>
<td>6H (after entry to A-level physics)</td>
<td></td>
</tr>
<tr>
<td>PETINA (P) (all girls school)</td>
<td>4E (after entry to o-level group)</td>
<td>4L (becomes prospective o-level candidate)</td>
<td>6H (after beginning A-level physics)</td>
<td></td>
</tr>
<tr>
<td>SUSIE (S) (Co-Ed. school)</td>
<td>4F (after entry to o/cse group)</td>
<td>4E</td>
<td>6H (after beginning A-level physics)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 61
c) the development of specific conceptions through the accounts - both within a single interview, and between the interviews with the same student;

d) attempts by the student to confirm or substantiate an aspect of their conception. This can happen within the interview (in terms of logical contingency, other cards, force of argument etcetera), or 'outside' of it by recourse to personal experience, what they have been told and so on. These pointers are considered during each of the student's four interviews. The final part of the chapter comments on all sixteen interviews, as a summary.

6.1: Colin's Interviews

a) The Energy Interview (C2,3E)

The outline of Colin's responses in terms of frameworks, overlaps, and supplementary comments, is shown in the table in figure 62. The arrows are an attempt to illustrate some of the many connections he makes during the course of the discussion.

He begins by making a strong case for an anthropocentric framework: he conceptualises energy as being at the person pushing the box (E1) up the hill, who needs energy in his legs because the hill 'makes it hard to push the box'. Colin suggests the person has energy whilst the box has force (because 'it has no energy in it'). The battery, in card E2, he says, is energy, which then 'runs' through the wires. The bulb needs the energy to 'get electrified'. The battery will 'run down' when the reaction (the 'bubbling'
<table>
<thead>
<tr>
<th>IAI CARD</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box (E1)</td>
<td>A-E; D-E</td>
<td>distinction A-E and D-E; power; force</td>
<td>The person has energy; the box has force but not energy</td>
</tr>
<tr>
<td>Battery (E2)</td>
<td>D-E; T-E</td>
<td>synonymy between energy and electricity</td>
<td>The battery is energy; the bulb needs energy for the filament to 'get electrified'</td>
</tr>
<tr>
<td>Ghost (E3)</td>
<td>A-E noneg</td>
<td></td>
<td>People-energy to dig the grave</td>
</tr>
<tr>
<td>Reaction (E5)</td>
<td>D-E; I-E; O-E</td>
<td></td>
<td>Chemicals are energy, and react together to produce more. The bubbling and gas are also energy</td>
</tr>
<tr>
<td>Hot Water (E4)</td>
<td>T-E; F-E</td>
<td>distinction F-E and R-H; force</td>
<td>Gas or electric is energy; heat is energy but the water is not heat - it is heated. Heat forces the mercury up the thermometer.</td>
</tr>
<tr>
<td>Meal (E7)</td>
<td>D-E; F-E; A-E</td>
<td>distinction between F-E and D-E ≠ man-made and natural energy</td>
<td>People need energy to eat, and food gives them energy. It's in glucose, vitamins, etc. It makes you feel lively and good.</td>
</tr>
<tr>
<td>Ice (E8)</td>
<td>T-E; F-E; noneg</td>
<td>Continues</td>
<td>There must have been energy (natural or man-made) to make the ice, but no energy in it.</td>
</tr>
<tr>
<td>Sledge (E9)</td>
<td>A-E; F-E; noneg</td>
<td>Distinction - force not energy</td>
<td>See Extract 3, force is downhill, energy is the person enjoying the ride and pushing it back up</td>
</tr>
</tbody>
</table>

continued...
<table>
<thead>
<tr>
<th>IAI CARD</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flower (14)</td>
<td>T-E; D-E; A-E</td>
<td>Continues with natural energy</td>
<td>Energy is in the vitamins and minerals in the soil, in UV rays and oxygen. Plants are like humans they move (open and close) and feed and breathe.</td>
</tr>
<tr>
<td>Snow (10)</td>
<td>A-E; O-E; D-E</td>
<td>Continues</td>
<td>The person is losing energy - the cold 'doesn't do you any good.' Weather is energy; and heat is energy.</td>
</tr>
<tr>
<td>Clock (11)</td>
<td>D-E; F-E noneg</td>
<td>Distinction between D-E and O-L. Continues manmade natural distinction</td>
<td>Energy must be controlled to be of use. The clock is manmade (and controlled) and so must the winding-up be.</td>
</tr>
<tr>
<td>Smell (13)</td>
<td>A-E; D-E noneg</td>
<td>Power. Distinction above continued</td>
<td>A smell is not to do with people, nor is it powered so it must be natural energy in the wind and not the smell.</td>
</tr>
</tbody>
</table>

Figure 62
inside) stops. The ghost (E3) is designated a non-example because he does not believe in such things. He decides, however, that energy must have been used by the people who had to dig the grave.

The chemicals in the reaction (E5) are deemed to be energy which, when joined together (I-E), react and cause even more to be produced. Again, as with the battery, the assumed activity (O-E) of the reaction is also energy (in terms of bubbles in the liquid and the gasses 'coming out'). The energy 'is no longer' when the 'bubbles have stopped and it's all brown and nasty'. The 'beaker of hot water' card (E4) is more problematic. The only possible activity in the situation is the mercury rising in the thermometer. This is a good example of the operation of a change of conception (and in multiple cases, of a framework). During the first few cards of the interview a number of conceptions are voiced - for example, energy is in substances; energy is activity, energy is made in reactions. Over two or three cards one of these is seen as more successful and is the first to be considered when a new instance is discussed.

Colin's transcript, for the 'hot water' card is difficult to explain without this interpretative gloss. He appears to look for activity (mercury moving up the thermometer) and decides that such movement is insufficient to account for the energy present. He says, then, that the heat is forcing the mercury to move and suggests that the 'water is creating energy to push the mercury up the thermometer'. Being asked to explain that, Colin's then in an uncomfortable position. The range of convenience of his
'activity' conception of energy is insufficient to cope with a stationary beaker of hot water. There are a number of broken pauses, anacolutha and stray phrases. One of these is that 'heat is a form of energy' which is clearly difficult to reconcile with his prevailing conception. At this point, he makes a distinction. Heat is energy, he says, but the water is not heat - it is heated. The heat is the gas or electricity external to the situation, which is energy. The water and the thermometer 'get heated up', an action that pushes the mercury along the thermometer.

Over the next three cards, Colin forges a second distinction that flavours the remainder of the interview. It is one between man-made, or manufactured energy, and 'natural' energy. The former is energy generated in some process that has a function; the latter is energy deposited inside objects, 'naturally'. In this sense the lens (E6) is a non-example. Energy was required at one time to make the glass and plastic but the lens has no energy in it. Moreover, a person needs energy to look through the lens - which is a good example of a Decoupled Light framework (D-L). The meal (E7) is 'natural' energy, it being located in vitamins, minerals, glucose, sugar and in oxygen. There are three interesting features in this argument. Firstly he supports his arguments by some 'self-evident' statements. Food must have energy 'otherwise people wouldn't buy it'; if you are hungry, you 'don't really move a lot.. you just sit around'. Oxygen is energy, he says, because:

Co. well, oxygen's energy I mean.. liquid oxygen burns. that's a fuel.. they're using it in space rockets at the moment..in the space shuttle.
Secondly, man-made energy is re-chargeable whilst natural energy is not. Once the 'goodness' is taken out of the food by the 'acids' inside you, it cannot be recovered. The man-made batteries can be re-charged. Thirdly, Co. introduces an element of human well-being into the discussion. Energy makes one feel good.

The remaining cards in the interview are discussed very much in these terms. A refrigerator is man-made energy, a winter's day is natural energy, so it would depend on how an ice cube (E8) was made for a proper answer to be given. The sledge itself coming down the hill is an example of force (not energy) - the energy involved is at the person who finds it 'exhilarating coming down the hill fast so he's enjoying it'. The flower (E14) is natural energy, from the vitamins and minerals from the soil in the pot, and the oxygen in the air. A person standing in the snow (E10) has natural energy. Also, 'the weather is energy and the snow is part of the weather so it must have natural energy'.

When asked for his definition of energy Colin develops these themes and invokes his own example of a power station - particularly a nuclear power station.

Co. obviously there's a lot of energy coming from there /a power station/... its being made... its man-made energy... most of them burn coal to turn turbines to drive a dynamo to produce electricity... and burning coal is energy... the turbine turning is obviously creating energy... I mean they're starting to close down power stations now because they're too wasteful starting to use other things

I. what sort of things?

C. nuclear power obviously... now that really comes into energy... its full of everything... its so dangerous.

6.10
... its full of energy... I mean the energy is so strong it kills you... well it would kill you from radiation sickness. its like a bomb let off

I. I see

Co. and it doesn't stop.. I mean oil is energy but as soon as its burnt its burnt.. the same with coal. when the energy's used it turns into something that's no good.. coal turns into ash and oil just burns away

I. and what happens with nuclear power?

Co. well even a little piece of nuclear energy I mean just keeps going on it doesn't stop. I don't think we'll run out of it.. it keeps going for millions of years and then we have to store the waste.

These three central conceptions, of manufactured, natural and human centred energy remain throughout the interview and are developed along the way. The final cards, the clock (El1) and a collision (El2) see the three co-exist as distinct but compatible conceptions. The clock is man-made energy (in the spring and the luminous dial) which needs natural (human) energy to wind it up. Colin spends almost seven minutes discussing the collision (with very few interjections from the interviewer). It is a very human-energy conception and can be paraphrased as:
- running is energy
- a collision can be painful, and pain can induce shock
- shock can drain you of energy
- energy is a mental thing
- if people can control their minds to overcome shock they can regain their energy
- energy is 'mind over matter'

His justification comes in a section as follows:
Co. if they're in pain they'll be down but if they think like 'its only a bump I'll be alright' and carry on running then they'll be alright and have energy again... I mean obviously if you're ill. if you've got a germ.. that's different.. but if you've got enough control over your body you think to yourself. I mean I do quite a lot of rowing in my spare time and when you're rowing it hurts and I mean if it doesn't hurt you're not rowing hard enough. and you make it hurt and you think to yourself. 'it hurts but I'm not going to let it make me stop.. I've got to keep on going if I want to win this race'. and I'll be collecting a medal in house assembly on Tuesday. but you've got to control your energy if you're going to win... its mind over matter isn't it?

This feature of 'controlling energy' he develops a little further. Natural energy needs be controlled so that we do not run out of oil and coal resources; or (in terms of food) because 'if we get too many vitamins, minerals sugars and calories we get fat.' Man-made energy needs to be controlled for our benefit ('we wouldn't want it to be out of control') and people-energy needs to be controlled so that we feel good.

The gloss of interpretation used here, is, of course, just one of a number of possible interpretations. Colin would seem to use the early cards of the interview to voice some conceptions and to become familiar with the task and the 'rules of the game'. One such rule is that he is likely to be asked 'why' questions, or be asked to explain his words, at various intervals. Another 'rule' is that he is pretty much free to shape what he says and to move backwards and forwards between the pictures. The upshot of this, is that he becomes aware of the possibility that future cards and questions are going to test his commitment.
to previous statements. The possibility of the interviewer saying 'ah, but a moment ago you said...' looms large. In this case, he picks his words - and his conceptions of energy - with an element of care and develops successful ones he can substantiate to some degree.

One interpretation - that this leads to him voicing his most safe, most anodyne and least controversial of answers - is clearly not the case. One reason is that he becomes involved both with the issue (in identifying and describing energy) and with the task (in discussing such issues, and developing ideas at length with an attentive adult). In addition, there is evidence of his discussing and then rejecting, or amending, specific conceptions in the face of new instances. So whilst he is exploring conceptions along lines that look 'profitable' he is not afraid to stay, or to change them. An example of this comes when he is considering, towards the end of the interview, the 'smell' card (E13) of a dead fish:

Co. I don't really know... I mean odour.. it could be about us. I mean if you didn't have a nose it wouldn't bother you. But we've got noses and we smell these things. No its not that.. I don't really know I suppose a smell is energy. its got it in it... no there's no real energy or power of a smell. well it can be a powerful smell but that's not its energy. no its just natural energy. its blown along in the wind and hits into our noses. I don't really know about smells.

This is taken as evidence of his first testing, and then rejecting, an anthropocentric and a 'manufactured' conception in favour of a 'natural' energy conception.
PAGE NUMBERING AS ORIGINAL
Colin's Force Interview (C1,4F)

Some similar patterns emerge in this interview even though it was recorded some three months after the energy one. The early cards establish a backdrop and by the fourth one he begins to make some distinctions that form the bases for many of the arguments he puts forward in the middle and later parts of the discussion. The outline of the interview is shown in the table in figure 63.

Colin begins by discussing objects in terms of force, very much as a Designated Framework (D-F). The stone (F1) has force, as does the rocket (F2). He mentions gravity (as he did at one point in the energy interview) as being 'like a magnet'. However, it is in addition to the force of the objects themselves, so that, for example, he says:

Co. the stone has got a force in itself... a force onto the ground... and its being held there by gravity..

For the rocket, the 'ignition' is treated as a force which pushes against the ground and which is forcing the rocket into the air. He includes another force which holds it upright on the ground and keeps it 'straight' as it moves upwards through the air, so that it does not 'topple over' (C-F).

In card F3, (being told to do something) he makes a distinction between force and power. So far, he says, all of the cards have been examples of force (including F3) but only the first two have had power. In this instance, the person is being 'forced to do something' but there is 'no power going into it'. In the tree card (F5) he makes another distinction, between man-made and natural forces -
<table>
<thead>
<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
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<tr>
<td>Stone (F1)</td>
<td>D-F; C-F</td>
<td>Gravity synonymous with force</td>
<td>The stone is force, there's force in the men's legs; gravity is like a magnet.</td>
</tr>
<tr>
<td>Rocket (F2)</td>
<td>E-F; D-F; C-F</td>
<td></td>
<td>The force of 'ignition' pushing the floor; there's a force in the rocket, also a force holding it upright.</td>
</tr>
<tr>
<td>Told (F3)</td>
<td>A-F</td>
<td>Distinction between force and power</td>
<td>Person is forced to do something but there is no 'power' going in to it.</td>
</tr>
<tr>
<td>Tree (F5)</td>
<td>O-F; C-F; A-F</td>
<td>Overlaps between pressure; elasticity; distinction between natural and manmade force.</td>
<td>The blowing of the wind is a force; as is the tree being held upright in the ground. The tree is alive, but it has no choice (natural) it must bend or snap.</td>
</tr>
<tr>
<td>Diver (F4)</td>
<td>I-F; C-F; A-F</td>
<td>Elasticity</td>
<td>A force holds the boards in position (like the tree); man uses muscles and forces himself upwards to dive.</td>
</tr>
<tr>
<td>Robber (F10)</td>
<td>A-x; D-F</td>
<td>Distinction: A-F / D-F manmade force has power; natural does not.</td>
<td>The bank clerk is forced to hand over the money; manmade force is 'doing what is forced' (eg., rocket, gun, diving board).</td>
</tr>
<tr>
<td>Golfer (F8)</td>
<td>D-F; M-F</td>
<td></td>
<td>Manmade force is put into the ball to make it go</td>
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<tbody>
<tr>
<td>Green (F9)</td>
<td>D-F; I-F; M-F</td>
<td>Synonymy between power and force, and electricity and force</td>
<td>Ball loses power in flight and as it lands. The ground absorbs some force.</td>
</tr>
<tr>
<td>Sledge (F7)</td>
<td>D-F; I-F; M-F</td>
<td>Distinction between moving force (fares away) and static force (remains).</td>
<td>The sledge has the force of coming down. The ground pulls it down and slows it down. Snow is a force, like rain, in a tornado.</td>
</tr>
<tr>
<td>Thinker (F6)</td>
<td>A-F</td>
<td>Power. For manmade there is no choice.</td>
<td>Manmade forces in people are allowed a choice. In objects, it is not. Natural forces have no choice at all.</td>
</tr>
<tr>
<td>Book (F11)</td>
<td>A-F; C-F; D-F</td>
<td>Gravity</td>
<td>Table and legs are a force, so is book. Also the person who put it there.</td>
</tr>
<tr>
<td>Balloon (F12)</td>
<td>A-F; O-F; D-F</td>
<td>Pressure, density</td>
<td>There is force in the boy's arm and in the balloon. Pressure in atmosphere increases with height (continuously).</td>
</tr>
<tr>
<td>Astronaut (F13)</td>
<td>M-F; E-F</td>
<td>Pressure; strain; gravity.</td>
<td>The strain in the astronaut's line is a force. Pressure is still present and 'high' in space</td>
</tr>
<tr>
<td>Moon (F14)</td>
<td>A-F</td>
<td>Pressure</td>
<td>Little force so the astronaut would not get hurt falling. Pressure model continues.</td>
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**Figure 63**

6.17
one similar to that in the energy interview. The wind
is a natural force, whilst the others show something being
made 'to do something' by people. The wind's force is
derived from pressure; the tree has force (to keep it
upright) and a lot of elasticity (not force) to return it
to its own position should the wind stop. Also, within
this discussion, he says of the tree that:

Co. it's alive.. sucking water from the earth.. vitamins
and minerals.. that gives it strength.. I mean if it
was dead.. if it was a dead tree it'd just snap

Over the middle selection of cards he develops the
classifications he has been making, between natural and man-
made forces. The latter he subdivides into those that
have power and those that do not. Those with power have
no choice and are made to do something, those without,
have a choice and can resist or 'out-power' things. Power
in this sense is a gas, electricity or fuel of some kind.
When the golfball (F8) arrives at the green (F9) it is
because the power (from the golfer) has gone out of the
ball. He argues his point as follows:

Co. the power goes out of the ball and it comes down
and hits and it obviously won't go as high as the
first one and then on the second one /bounce/ it'll
only go a little bit. then a little bit and eventually
it'll roll

I. when you say the power goes.. where does it go to?

Co. well its got to slow down sometime hasn't it as it
comes down.. I mean any ball if you bounce it once
the second time it'll bounce again but it won't go
so high. and it'll get lower as it loses power..
every time it bounces it loses a bit of power.. like
a car will slow down if you take your foot off the
accelerator... and I think the ground absorbs a bit
of it as it hits. the ground gives a little bit and
takes the force. like if a cricket ball's hit towards
you you don't just catch it because you sting your hands up.. you have to cushion it.. slow it down a bit before you actually stop it

He uses the distinctions he has established to reorganise the cards and he sorts them according to the divisions he has made. One or two prove difficult; the sledge (F7) is force sliding down, but he cannot decide whether snow is or not. Like rain, it is a force if it is 'coming down' hard or in a drift. A person thinking is a force because:

Co. .. he's using force. power from his brain .. thinking about physics

The book on the table is a force because, amongst other ones, someone must have used force to put it there.

The latter part of the interview takes a different line and introduces an unusual conception. In discussing just three cards, the conversation takes up some twelve minutes - over a quarter of the interview.

Colin's is a conception of air-pressure that increases with altitude. It begins in consideration of the forces on a helium balloon (F12). Where he suggests that the gas is a force, inside the balloon, to make it rise. If the balloon is released, he says, it will 'burst from a high altitude' because:

Co. I mean. as it goes up the air's getting slowly and slowly denser so the pressure's pushing in on it

A moment later, when he is asked to explain this he makes the following comparison:
it /the air/ gets slowly denser and denser I mean its like if you walk out now and just keep walking ... slowly it gets darker and darker as it gets into night or its quite foggy out there now so. slowly as you keep walking the fog's going to get thicker and thicker...

This description is particularly apt - the interview was being conducted just at the end of the school day on a dark and foggy January evening. The notion of walking away from the school lights into the gathering gloom is a graphic analogy of increasing atmospheric pressure and density.

The two following cards concern the astronaut in space (F13) and on the moon (F14). Whilst other forces (like 'strain' in the astronaut's line; in the rocket, and gravity) are mentioned, the conversation keeps returning to the pressure model. For example, an astronaut's suit is seen as preventing the pressure 'pushing in on you'. Asked about forces on the moon, he says:

Co. .. well again its the pressure on there.. pushing against his suit.. there's not much oxygen in it /the suit/.. its pushing him down

I. what kind of pressure is it?

Co. well its obviously a force. I mean it'd kill you.. it can kill you if you haven't got a proper suit.. it'd just burst through your suit... it's a very strong force I should think

He does not explain what causes the pressure except to return to the balloon and discuss its implosion. In this sense he presumably assumes that both space and the surface of the moon are subjected to high air pressure - much higher than that on the Earth's surface. The interviewer's rather inept question (above) to find out more about the pressure, only results in a description of what
it might do to an illclad astronaut.

This is an unusual conception - only one other interviewed student has hinted at anything similar. In that case it was based upon the notion that, if hot air continues to rise, then it must be 'much more dense up there than it is down here.' (J,4H). Colin's is a well developed and consistently used conception that is, to all intents and purposes, idiosyncratic. It is neither sufficiently general nor widespread, in the context of this study, to be called a framework.

Colin's Heat Interview (C3,4H)

In the context of the four interviews, this one on heat is Colin's most subdued and low-key. He does not display the same degree of involvement with the topic or the task and is less inclined to be as forthcoming as in the others. At one point, he comments that he does not 'see the problem' with heat - it is 'pretty obvious what it is'. He still retains the propensity to forge distinctions and then to follow these through, but in this interview they are less rigidly held and he treats them more flexibly than in the other cases (Figure 64).

As before, the first few cards can be seen as generating some opening arguments, as he appears to re-familiarise himself with the requirements of the task. For these instances he conceptualises heat very much in the mould of a Normal Heat (N-H) framework - heat is hotter than himself, cold is anything cooler than body temperature. Temperature itself he describes as a measure of heat.
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<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Ill (H1)</td>
<td>N-H; R-H</td>
<td>Temperature (is a measure of heat)</td>
<td>A thermometer tells you what the heat is, in a person's body.</td>
</tr>
<tr>
<td>Reaction (H2)</td>
<td>N-H</td>
<td></td>
<td>No special heat needed, just normal. Some reactions do need heat.</td>
</tr>
<tr>
<td>Pies (H3)</td>
<td>C-H; R-H</td>
<td>Relationship between temperature and mass.</td>
<td>There is steam so the pies must be hot. The bigger basin holds more heat. A bigger mass attracts more heat (depending on what it is).</td>
</tr>
<tr>
<td>Argument (H4)</td>
<td>Noneg; N-H</td>
<td>Distinction between heat (sense) and heat (emotion)</td>
<td>Sensory heat I feel means 'I'm sweating'. The other heat means a fierce dislike.</td>
</tr>
<tr>
<td>Iron-bar (H5)</td>
<td>R-H; M-H; N-H</td>
<td></td>
<td>The burner is the heat, the water is just wet. The bar heats only the first quarter - on the outside - cooler on the inside. Heat rises, some heat travels. Heat reacts with the iron: water + iron = rust heat + iron = a liquid (which turns to iron) water on iron = corrosion.</td>
</tr>
<tr>
<td>Ice (H6)</td>
<td>S-H; N-H</td>
<td>Distinction in temperature between hot, cold and freezing</td>
<td>Things can be hot or cold, very cold is 'freezing' - when things freeze - and crystallise.</td>
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<tr>
<td>Flower (H7)</td>
<td>Noneg</td>
<td>Distinction continued between sense and emotion; relationship between heat and energy heat and light</td>
<td>Does not need heat; would die without it</td>
</tr>
<tr>
<td>Pepper (H8)</td>
<td>Noneg</td>
<td>Friction produces heat</td>
<td>Not heat, just taste.</td>
</tr>
<tr>
<td>House (H9)</td>
<td>R-H; C-H; O-E</td>
<td></td>
<td>Heat is what we feel, not taste or smell; it's produced by friction, gas, electricity, etc., it is an off-shoot of some act. Can a house 'feel' warm.</td>
</tr>
<tr>
<td>Cliff (H11)</td>
<td>P-H</td>
<td></td>
<td>Extract 125. Friction produces measurable heat in the stone.</td>
</tr>
<tr>
<td>Astronaut (H13)</td>
<td>Noneg; C-H; N-H; R-H</td>
<td></td>
<td>Space is cold, heat rises. Is it hotter over the sun?</td>
</tr>
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**Figure 64**

6.23
He also treats heat as being quite local, to a person's head, for example, if they are ill (H1). The bigger pie (H3) can hold more heat because it has 'a bigger basin which holds heat'. In this instance he associates heat with mass and suggests that there might be different things in the pies that might 'attract' heat differently.

In the fourth card he begins a distinction, one part of which he develops further. The card shows an argument (H4) and Colin argues that heat is 'what you feel' (by one's senses) and not what you feel (in terms of 'feelings', or emotions). He seems to enjoy this ambiguity in the term 'feel' and says:

Co. I mean if you're having a fight or something like that then you don't feel warm but you do feel heat against the other person.. your whole body doesn't change I mean you're thinking about the person and you feel frightened and you probably don't like him much but it's a different kind of feel it doesn't mean the same. its only a connection

The sensory aspects of heat - feeling heat from a source of heat - are the ones he develops further.

The iron bar card (H5) evokes four interesting points. He suggests, firstly, that heat is retained very much at the burner end of the bar and that the other end is unheated and simply wet. Secondly, he maintains that the heat mostly rises off the bar (although some does travel along it) and thirdly, that the heat is 'reacting' with the iron. Lastly he suggests that the heat is very much on the exterior of the bar and that - if you were able - 'to touch the inside then you wouldn't get burnt'. He makes these points in the following way:
Co. well you're heating one end and making the other one wet... its going to be much hotter at this end than it is at that end because here it's reacting with the heat... but in an amount of time even this /tap/ end is going to feel warmth.

I. why do you say that?

Co. well first of all the heat's going to heat the end of the iron for only about a quarter of the way and then the heat's going to rise off the bar. but some heat's going to move along to this end....

I. go on

Co. well heat naturally rises I mean. once the thing gets hot.. past red hot or something then you just get waves of heat.. some of it goes fading down the bar to the end..

I. you said that it's reacting with the heat.. I wondered what you meant by that..

Co. oh there is a certain reaction between both of them .. I mean water and iron produces rust..... heat and iron produces a liquid.. which then turns into iron .. and then there's corrosion. water on iron produces corrosion.

These last three are quoted rather like memorised chemical formulae and reactions.

The remaining cards in the interview take up some of the points he has made so far, but without any one conception prevailing as dominant. Some lead him into paradoxes upon which he deliberates at length. For example, if heat is a (sensory) feeling then how can a house 'feel warm'. Or, put another way, does the word 'feel' refer to the object one is feeling or to the person engaged in the act: is it the house that feels warm or a person who feels the house warm?

He discusses friction, too, in a way that has already been described in extract 125 at the end of the last chapter.
When he is asked to define heat, he calls it an 'off shoot' of something:

Co. .. it's an off shoot of something.. like friction. you rub your fingers together and then there's heat generated...

This is separate and distinct from light, because:

Co. they don't always go together.. I mean you can't feel the heat of a match if it was over the other side of the room but you can still see the light.. I mean there are some places.. places like the arctic and that.. there's sunlight but there isn't much heat .. if there was heat you wouldn't have ice there would you?

Another paradox stems from the astronaut card (H13) where he returns to heat rising. He has said that space is cold ('well spacemen wear thermal clothes and special socks') but is then unsure if heat rises 'above' the sun to make it hotter there. He finishes by saying:

Co. well most heat rises but the sun generates heat all the way round. it's a big ball. but it's just a known fact it's colder in space and I don't know why (laughs)

Colin's Light Interview (Cl.4L)

If, whilst discussing heat, Colin is muted, in discussing light he is ebullient. It is a conversation of about an hour's duration when (comparatively) little is said by the interviewer. The full transcript is the sample transcript provided as appendixIII. The outline is shown in figure 65. Not only does he volunteer ideas, definitions, and distinctions, he also extrapolates on these to explore certain issues. He puts forward what he calls 'his theories'
and expands on these at some length. Moreover, he articulates a number of paradoxes - for which he can see both sides of a problem yet confesses to having few solutions. These occur in the transcript as questions he asks out loud and, although they might appear to be directed at the interviewer, they are mostly for his own benefit in that he leaves no space for a response but answers them himself.

He is clearly familiar with the routine of the interviews and, unprompted, refers many of the cards back to previous ones discussed in order to draw out parallels or distinctions. He shapes much of the conversation himself and makes considerable use of his own personal experiences to enhance conceptions he has previously adumbrated.

During the session, Colin makes two distinctions which form the major part of the discussion. The first is a distinction between 'natural' and artificial light. At the centre of this is an uncertainty as to whether light is a single pure substance, or is itself a composite entity. In order to account for various situations (for example, rainbows, X-rays, and suntans) he feels the need to postulate different kinds of light (daylight, sunlight, electric light and so on). The problem arises not so much with pure light as with impure: is it minus some vital ingredients or does it have added impurities? The first moves towards a composite view (C-L), whilst the other augers for different modes of light (M-L). He uses both at different times and eventually reaches an uneasy truce between the two.

The second distinction is between 'projected' and
<table>
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<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Projector (L2)</td>
<td>P-L; D-L</td>
<td>Distinction between mirror images and projector images</td>
<td>Light travels. It is projected (thrown onto a screen) but there's no light on the screen. A projected image is 'exact', a mirror image is opposite.</td>
</tr>
<tr>
<td>Television (L3)</td>
<td>O-L; D-L; M-L</td>
<td>Light and sound are separate and related</td>
<td>The aerial catches light waves and the T.V. reforms pictures. Similar (but bigger) to a projector: the screen 'throws' the image.</td>
</tr>
<tr>
<td>Flower (L11)</td>
<td>I-L; O-L; A-L</td>
<td>Both are waves</td>
<td>Flowers need light (and move towards it). Both light and sound are waves. Light lasts longer than sound.</td>
</tr>
<tr>
<td>Rainbow (L4)</td>
<td>O-L; P-L; C-L</td>
<td>Spectrum; sound waves and electrical waves are separate</td>
<td>Raindrops act as prisms. The sun hits and, because of angles, splits into colours. Sound waves cannot be received on a radio. Rainbow is similar to a projector.</td>
</tr>
<tr>
<td>Painting (L5)</td>
<td>I-L; D-L; Noneg</td>
<td>One can see in the dark; light brightens things up so they can be seen. A red painting is not an example unless it is luminous. Similar to the flower.</td>
<td></td>
</tr>
<tr>
<td>Shirts (L12)</td>
<td>A-L; P-H; D-L</td>
<td>Heat and light are related. A distinction between natural light and sunlight</td>
<td>One holds things up to the light. Heat and light connected, natural light is not the same as sunlight.</td>
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<tr>
<td>Mirror (L1)</td>
<td>A-L; I-L; D-L</td>
<td>Reaction</td>
<td>Similar to projector - light hits you and hits mirror to form a reflection. Difficult to explain why light reacts with mirror.</td>
</tr>
<tr>
<td>Lens (L9)</td>
<td>M-L; C-H; O-L</td>
<td>Distinction between pure sunlight and electric light. Heat produces light.</td>
<td>Similar to mirror - hard to explain. Pure sunlight can burn but electric light won't. Light is given off from heaters in both cases. Electric heaters give light and burning too produces light. Snow reflects light.</td>
</tr>
<tr>
<td>LIGHT IS...</td>
<td>P-L; D-L</td>
<td></td>
<td>Travels at the speed of light; is a wave; splits like an atom; is transparent; hits screens and slows (TV) or stops (projector); is reflected off mirrors and stretched by a lens.</td>
</tr>
<tr>
<td>X-Rays (L7)</td>
<td>M-L; O-L; C-L</td>
<td>Radiation; beam; ray</td>
<td>X-ray machine is like a camera; is sensitive to radiation. Radio active particles give off light. A beam is composed of rays (extract 75). X-rays are very sensitive light.</td>
</tr>
<tr>
<td>Sunbathing (L8)</td>
<td>M-L; I-L; C-H</td>
<td>Relationship between light and heat. Distinction between electric light and sunlight.</td>
<td>Light and heat given off by sun, but light causes suntan. Electric light is pure sunlight has additives (extract 81). Snow is like a mirror. Suntan makes you feel better (extract 120) which is why sunray lamps work.</td>
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Figure 65

6.29
'received' light. It is a distinction between sending out light and getting back pictures. He reconciles these two aspects of the cards by hypothesising a 'barrier' model of light. In this, light carries an 'image' and is 'thrown' against a screen, wall or some barrier. Here the light stops and leaves the image on the surface. It is a distinction between a projected Light framework (P-L) and a Decoupled one (D-L).

Needlesstosay, neither distinction is entirely tidy and he voices a number of difficulties (for example, in explaining what happens at a mirror). Some complications that contribute to his voiced difficulties are, firstly, that whilst we use light in order to see things, we can also see through light (it is 'transparent'). Secondly, he is entirely unsure why light should penetrate some surfaces (like skin) and yet be reflected off others (like snow).

He begins to forge these distinctions from the beginning of the interview with the projector card (L2) and the television set (L3). He suggests that the projector image is thrown from the projector onto the screen, and that for the T.V., it:

Co. .. comes down the aerial. the waves. and there /inside the T.V. set/ it's transferred to a picture..

I. is that an image?

Co. yes. its an image rather than just light or a picture .. its an image. a thrown image same as the projector really.. its just that its on a bigger scale. I mean the television company are throwing out more waves than a projector would.

Later he pursues the similarities between the projector and
a television. He is asked to say what light is, and begins a discussion around the speed of light. He suggests that the waves arriving at the T.V. set are light waves, traveling at the speed of light, and which are slowed by parts inside the television and then re-constituted to their 'original form'.

Co. I mean. this television set is. I mean obviously it's. the waves are travelling at the speed of light. .. I don't know. I suppose they're travelling at the speed of light because I mean it is light you could say. and its got to be travelling at the speed of light and then as it hits the aerial and gets into the circuitry it slows it down and puts it back into its original form /a moment later/

.. its like the screen I mean. the projector's throwing it out at the speed of light because obviously light will move at the speed of light and then... just sort of abruptly hitting this screen and stopping... throwing the image. and going back to its original image. its like a barrier I suppose... whereas the television just slows it down..

This is also part of the conversation about the constituents of light and in this description he has opted for a 'composite' view. Light is split up into various 'bits' like colours; parts of a picture, or is broken up 'like waves', and is then re-formed so that the image can be seen. This view is epitomised in extract 75 where he describes the composition of a 'ray'. In this manner he uses a 'composite' view for the television (L3); the projector (L2); the rainbow (L4) and in defining light. The 'modal' view surfaces when he is discussing sunlight - for example, in cards showing the flower (L11); clean and dirty shirts (L12); a lens (L9) and a sunbather (L8).

He begins by maintaining that natural light (ambient light (A-L)) whilst different, is quite similar to sunlight.
Although the latter is often shown to be yellow, if you look directly at it ('which you're not meant to do anyway') you see it is white. Later, when pressed, he finds it difficult to describe 'natural light'. Natural light is, in some senses, part of a Decoupled framework. It is the light which means we can see things. Yet is not due to any specific source. Consequently, in talking about a clean shirt (and holding it up to the light), one is holding it up to be seen and not towards a particular light source. When asked to explain it, he concludes that all light is artificial except sunlight ('I wouldn't call anything you know charged with electricity natural'). He finds this difficult to maintain, however, when talking about sun-bathing. Because one can not become suntanned under an electric light, he argues that it is 'electric light' that is pure and that sunlight is mixed with lots of other lights (like ultra-violet light and radio-active light - see extract 81).

A conception of light, like a Decoupled framework, is evident in the discussion about the painting (L5), the lens (L9) and the mirror (L1). For example, of the painting he says:

Co. if it's just a bright red painting. I shouldn't think that that's got anything to do with light at all.. oh I suppose the only reason its bright red is because there is actually light shining on it.. I mean if the lights were off you wouldn't probably notice that it's. exactly bright red.. he might be able to work out it's red but not bright red..

It is very similar to other descriptions where light is used to 'brighten things up' rather than for the image
to be transmitted to the eye.

This description of Colin's interview has inevitably left out a range of points he makes. Some are excellent examples of some of the difficulties he has in his understanding of light; of the paradoxes he perceives between what is said about it and the ways in which he believes that it operates. He draws on his own experience to substantiate conceptions (from skiing in Switzerland, operating a hand-warming device in cold weather, having X-rays of his arm and teeth, to burning the varnish off his desk with a hand lens).

He considers the meanings of a range of terms like image, heat, reflection, ray and wave, and introduces a number of logical contingencies to support his hypotheses and suppositions. As a final quote, an example of a debate with himself about waves in the wake of the flower (L11) card:

Co. light's more or less the same as sound I should imagine. with waves I mean.. I mean talking I'm transmitting sound waves and this light bulb's /he points to an overhead light/ transmitting light waves as well.... I'm just giving out sound waves while I'm speaking and that's giving out light waves as it's.... I don't know I suppose it /light/ goes on longer than sound waves. I mean. as soon as I stop talking you don't hear my voice but the light is sort of bouncing around all the time...

6.2: Cushla's Interviews

Cushla's interviews are both shorter and less expansive than Colin's: the average length of the sessions is about twenty five minutes. A period of about thirty months elapsed between the first and last interviews. The sequence
of interviews is different to that of Colin's, for Cushla it is energy, force, light and then heat. As with all the interviews, the sequence results more from circumstances than from deliberate planning.

In the organisation of the study, Cushla was not originally a student singled out to be re-interviewed. Her responses in the interviews, particularly the first energy one are fairly perfunctory - jejune in some instances. She closes responses quickly and in only a few cases does she link together arguments across the cards. The decision to re-interview came about more as a result of her interest in another session (as expressed to her teacher) and in her volunteering to another discussion. In the last two interviews she begins to detail her responses more than in energy and force.

One consequence of her numerous single clause answers is for the question style employed by the interviewer. In the case of Colin's responses, the basic questioning strategies are to re-arrange some of the words in his answer and, by inflection, to pose a question - or to simply reflect the last few clauses. This is not very successful with Cushla - to repeat her answer back to her leaves her simply saying 'yes' or 'no' without further elaboration. In one or two instances, it seems to cause her considerable doubt and as she becomes uncomfortable, she enters into several reversals, retracting what she has said. She appears to interpret reflected questions as stark incredulity on the interviewer's part. More successful are direct questions and, on one or two occasions, for the interviewer to act as
'devil's advocate'. Because of this, her transcript allows for a more direct relationship to be established between conception and question-type.

Cushla's Energy Interview (C,4E)

Her dominant conception here is typified by an Osten­sive Energy framework: in most instances she recognises energy because something is happening. Where she fails to find anything, she regards it as a non-example. Her comments introduce a number of terms like heat, light, sound, kinetic, potential and work although largely she is reluctant to talk through any of these. She likens potential energy to an elastic band and kinetic to movement of any kind. However, this represents her only attempt to extend her ideas. The interview is quite short (the outline is given in figure 66) and of the fifteen cards that she responds to, she considers five of these to be non-examples.

Cushla's Force Interview (C2,4F)

In this interview, she is considerably more forth­coming, volunteering both detail towards the conceptions she suggests and (once) in personal detail about herself. She does not comment about the previous interview although it had been only about six weeks earlier. The outline is shown in figure 67. At this stage, it is difficult to know if her more forthright approach to the interview is because she identifies more with the task or with the issue, in that she finds force easier to discuss than energy.

She makes clear three particular conceptions, which
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<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Box (E1)</td>
<td>D-E</td>
<td>Potential</td>
<td>There is energy in the box and in the person.</td>
</tr>
<tr>
<td>Battery (E2)</td>
<td>I-E</td>
<td>Potential; work; synonymy between energy, heat and light.</td>
<td>Heat and light are energy; the point of the battery is to make the light work.</td>
</tr>
<tr>
<td>Hot water (E4)</td>
<td>O-E; Noneg</td>
<td>Heat and energy are separate and distinct</td>
<td>There is energy if the mercury is moving. Hot water is not energy, it has heat but not energy.</td>
</tr>
<tr>
<td>Reaction (E5)</td>
<td>O-E; Noneg</td>
<td></td>
<td>Maybe there's energy in the putting of the chemicals together. Otherwise none.</td>
</tr>
<tr>
<td>ENERGY IS...</td>
<td>D-E; O-E</td>
<td>Kinetic, potential</td>
<td>Energy is in batteries and elastic bands, and mostly in movement which is kinetic energy. A large amount of energy is Concorde.</td>
</tr>
<tr>
<td>Lens (E6)</td>
<td>O-E; noneg</td>
<td></td>
<td>Because it isn't doing anything.</td>
</tr>
<tr>
<td>Meal (E7)</td>
<td>O-E; D-E</td>
<td></td>
<td>Energy is part of the food, and the person is moving.</td>
</tr>
<tr>
<td>Ice (E8)</td>
<td>O-E</td>
<td></td>
<td>The water is moving as it drips.</td>
</tr>
<tr>
<td>Sledge (E9)</td>
<td>D-E</td>
<td>Kinetic; potential</td>
<td>The hill has energy at the top. It gives this potential energy to the sledge which moves. continued...</td>
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6.36
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<th>IAI CARDS</th>
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<tbody>
<tr>
<td>Snow (E10)</td>
<td>O-E</td>
<td></td>
<td>There's energy because he's shivering.</td>
</tr>
<tr>
<td>Clock (E11)</td>
<td>O-E; F-E</td>
<td>Sound; light; work; A synonymy between energy and power.</td>
<td>There's energy in the ticking and the movement. Also in the light of the luminous dial. Energy is the power to make things work.</td>
</tr>
<tr>
<td>Collision (E12)</td>
<td>O-E</td>
<td>Sound</td>
<td>There's movement and they might cry out in pain. When they stop, the energy stops.</td>
</tr>
<tr>
<td>Smell (E13)</td>
<td>Noneg</td>
<td></td>
<td>No reason.</td>
</tr>
<tr>
<td>Flower (E14)</td>
<td>O-E</td>
<td></td>
<td>There's energy in the movement of it growing.</td>
</tr>
<tr>
<td>Stars (E15)</td>
<td>O-L</td>
<td>Light</td>
<td>Light is energy.</td>
</tr>
<tr>
<td>Clouds (E16)</td>
<td>F-E; noneg</td>
<td></td>
<td>Stars have no energy, energy is in cars and trains.</td>
</tr>
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**Figure 66**

6.37
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<th>IAI CARDS</th>
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<tbody>
<tr>
<td>Stone (F1)</td>
<td>E-F; A-F</td>
<td></td>
<td>The forces are at the ring where the ropes join. The stone is fighting back against the people.</td>
</tr>
<tr>
<td>Rocket (F2)</td>
<td>O-F; E-F</td>
<td>Synonymy between pressure and force</td>
<td>Forces are at the 'nose' of the rocket. Force is in the pushing up. Machines are stronger than people and can exert more pressure.</td>
</tr>
<tr>
<td>Told (F3)</td>
<td>O-F; A-F</td>
<td>A distinction between verbal force and the force of machines; radiation.</td>
<td>There is force in pushing, but a person is less forceful than a rocket. Verbal force is a force although there's no contact - like radiation there need not be contact for a force.</td>
</tr>
<tr>
<td>Tree (F5)</td>
<td>E-F; C-F</td>
<td>Gravity, energy</td>
<td>Similar to the rocket. The wind is not touching but is creating energy. The tree reverts to normal when wind stops. Gravity - and roots - hold the tree up.</td>
</tr>
<tr>
<td>Diver (F4)</td>
<td>E-F; C-F</td>
<td>Potential; gravity</td>
<td>The board has potential force. The board goes back to normal where it is kept by a force. The diver creates a force to dive. Gravity acts when he is up.</td>
</tr>
<tr>
<td>Robber (F10)</td>
<td>A-F</td>
<td></td>
<td>Similar to 'told'; it is a force of the mind. The person is 'forced by instinct' to hand over the money.</td>
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<tbody>
<tr>
<td>Golfer (F8)</td>
<td>A-F; M-F</td>
<td>Gravity</td>
<td>The force is the golfer's strength. The ball continues to travel with the 'force put on it'. At the top, the force finishes and gravity then pulls it down.</td>
</tr>
<tr>
<td>Green (F9)</td>
<td>I-F; M-F</td>
<td>Force and energy are separate yet related</td>
<td>The ball hits the ground and 'gets' energy to rebound. Both energy and force diminish as the ball goes along. Forces are given by energy and energy is what is produced by a force.</td>
</tr>
<tr>
<td>Thinker (F6)</td>
<td>A-F</td>
<td></td>
<td>There are different forces; the force of the mind, the force of giving energy; gravity force (large) and moon force (small).</td>
</tr>
<tr>
<td>Book (F11)</td>
<td>C-F; D-F</td>
<td>Gravity; weight</td>
<td>Forcing yourself to think.</td>
</tr>
<tr>
<td>Balloon (F12)</td>
<td>C-F; D-F</td>
<td>Gravity</td>
<td>The book has weight and gravity holds it down.</td>
</tr>
<tr>
<td>Astronaut (F13)</td>
<td>C-F; D-F</td>
<td></td>
<td>The person has force to hold it. Gravity doesn't effect it; it would if it weighed more.</td>
</tr>
<tr>
<td>Moon (F14)</td>
<td>O-F; D-F</td>
<td>Gravity</td>
<td>There are forces in the rocket and some holding him there.</td>
</tr>
</tbody>
</table>

*Figure 67*
bear similarities to the Affective (A-F), Configurative (C-F) and Encounter Force (E-F) frameworks. She tends to the view that gravity is something that 'holds things down' and yet (as far as projectiles are concerned) operates only on their downward path. In this sense she makes an interesting point where she distinguishes between two frameworks. In discussing the book on the table (F11) she argues that it has both a force 'holding it in place' and its own weight. That is, the book itself has a force (D-F) pressing down on the table and gravity also operates to prevent it floating away. This argument is continued into the balloon card (F12) where she decides that there may be gravity on the balloon but it does not affect it. Gravity would she says, if the balloon were heavier.

As in the energy interview, she introduces the term 'potential' a number of times, although here she refers to potential force. Other terms, like pressure, energy and radiation are also deemed to be forces. She also emphasises the humanity of the situations in some instances - so that all of the orthodox non-examples she considers to be examples. In these cases, she calls the force a 'verbal force', or a 'force of the mind', which (although it does not make contact) is still a force.

In this interview, as with the energy one, her responses are taken mostly to infer locative and descriptive frameworks. Certainly, her responses are given more readily to the somewhat limiting and closed nature of the locative question type ('where is there force?') and to descriptive questions ('what is (are) the force(s) doing?'). Most of
her explanations, then, can be seen as evidence for Affective (A-F), Designated (D-F) (both largely locative frameworks), and a Configurative (C-F) framework (a descriptive one).

Cushla's Light Interviews (C2,4L)

There are a number of similarities between Cushla's view of light and that of Colin. She, too, has a conception of light that is decoupled from the observer, particularly in the context of mirrors, lenses and television sets. She also moves between a composite and modal conception of the nature of light. She expresses particular difficulty in explaining the action of mirrors and lenses. The other expressions she emphasises within her accounts are also similar, colour, heat, image, reflection and radio-active.

The outline for this interview is shown in figure 68.

The D-L framework is the most clearly evidenced. For example, of the mirror (L1) she says:

Cu. well there has to be light for him to see himself in the mirror.. and the mirror acts as a sort of reflection of his image the light..... um portrays the image on the mirror and that's how he can see himself

I. and how does it do that. do you know?

Cu. I think its the light that picks up the colour of him and the shape of him...... no its not.. no... no I don't think that

I. why's that?

Cu. because it's the mirror that picks up the image not the light... I mean the light can give a sort of silhouette but it doesn't give an image.

This extract gives an example of one of Cushla's reversals - not only a contradiction of argument between
<table>
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<tr>
<th>IAI CARDS</th>
<th>FRAMEWORK</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Mirror (L1)</td>
<td>D-L</td>
<td>Colour; reflection</td>
<td>There must be light so that he can see his image on the mirror. Perhaps light picks up the person's colour - or light gives a silhouette and not an image.</td>
</tr>
<tr>
<td>Projector (L2)</td>
<td>O-L</td>
<td>Ray; a distinction between real and virtual images</td>
<td>The bulb in the projector shines a ray onto the screen. The screen captures the image (which is real). A virtual image cannot be caught on a screen.</td>
</tr>
<tr>
<td>Rainbow (L4)</td>
<td>M-L; C-L</td>
<td>Distinguishes between colours and images</td>
<td>Rainbow is either caused by light shining through different colours in the atmosphere or moisture breaking the light up. Must be the first since colours are different shades of light, it is not an image.</td>
</tr>
<tr>
<td>Lens (L9)</td>
<td>D-L; O-L; P-L</td>
<td>Heat is related to natural light and not artificial (electric) light;</td>
<td>Lens bends the light. It would work in the dark except that the person wouldn't be able to see it. Natural light is warm, electric light is not.</td>
</tr>
<tr>
<td>X-Ray (L7)</td>
<td>M-L; Noneg</td>
<td>Radioactive material</td>
<td>X-rays are very intense light that can't pass through bones. Or it is radio-active material and not light.</td>
</tr>
<tr>
<td>Battery (L10)</td>
<td>M-L; C-L; P-L</td>
<td>Distinction between natural and artificial light.</td>
<td>Circuit produces artificial light using chemicals. The intense white of the filament produces light.</td>
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<th>COMMENTARY</th>
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</thead>
<tbody>
<tr>
<td>LIGHT IS...</td>
<td>M-L</td>
<td>Energy, radio activity</td>
<td>Light is energy in the form of a ray. Some objects have so much energy they</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>produce light. The sun = light + radio-active rays.</td>
</tr>
<tr>
<td>Television (L3)</td>
<td>D-L; P-L; C-L</td>
<td>Image; distinction between</td>
<td>T.V. works by a light at the back that shines through an image on the screen.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>light and waves.</td>
<td>It is light plus radio-active material. T.V. studios send out waves which are</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>caught on the screen.</td>
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**Figure 68**
explanations but also a kind of 'shear' in the account.

Her discussion on the composition of light begins with the rainbow card (L4). She is unsure quite what a 'colour' is, whether it is a shade of light (that is, pure light subjected to some change) or a constituent of light. She concludes by moving towards the first because it is not just that moisture in the air, but also mirrors, that can cause rainbows. She takes this as an argument that light changes rather than 'splits up'. Like Colin, she describes the sun as 'natural' light whilst electrically produced light is artificial. She says of the battery card (L2):

Cu. ..this is a way of producing light artificially using chemicals

I. how does it work?

Cu. the electricity is in here /the battery/ and then when it gets into contact with the light /bulb/ it lights .. it heats the filament which becomes very hot and produces light..

This follows a discussion about heat where she had suggested that natural light is warm but electric light is not. When pressed here, she argues that although the filament gets so hot it 'turns an intense white'; this is only hot for filaments (as opposed to people) and that anyway it is only a little bulb.

A final similarity with Colin's ideas is that of the television 'catching' waves from a studio. In Cushla's case, they are not so much re-formed into a picture as 'shone through' to make an image.
Cushla's Heat Interview (C,6H)

At the time of this discussion, Cushla had entered sixth form and begun A-level work. She elaborates rather more on her constructions and so offers more than is asked for in the questions. She draws on a few inferences from what she herself says, sometimes quite creatively. One distinction (see figure 69) she makes throughout the interview that energy 'produces' heat. She says this of four instances, ill (H1), reaction (H2), house (H9) and the cake mixer (H12). In each case, it is produced from energy rather differently. In the first two it is caused by reactions - either by chemicals in food producing energy and then producing heat, or from chemicals reacting in a test tube to the same effect. Later on it is the sun's energy that produces heat (by its 'rays cutting through the atmosphere') and then by the mixer blades 'creating friction energy' which 'creates' heat.

She makes two other distinctions, one between 'heat' and 'being heated', the other (more unusually) between the 'air' and the 'atmosphere'. The first is a difference between the temperature of an object (it's heat) and the act of raising it's temperature (being heated). The latter she refers to as 'exerting actual heat'. The second comes in the discussion of ice melting (H6) - when she suggests that the sun warms the atmosphere and this then warms the air. The air is moved about as people move around so allowing a transfer of heat to the ice.

Two more points about the interview are worth noting. Firstly, she makes some comments about heat and particles


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<tbody>
<tr>
<td>Ill (H1)</td>
<td>N-H; P-H</td>
<td>Temperature; reaction; energy</td>
<td>Bedclothes produce heat; reactions occur in the body to produce heat - food produces energy and that produces heat.</td>
</tr>
<tr>
<td>Reaction (H2)</td>
<td>D-H; P-H; P-E; I-E</td>
<td>Distinguishes between reactions between chemicals and cells, energy</td>
<td>Heat is given off by chemicals - it could be violent. The energy is not in the chemicals but when they meet.</td>
</tr>
<tr>
<td>Argument (H4)</td>
<td>Noneg</td>
<td>Distinguishes between heat and emotional heat; temperature is a measure of heat.</td>
<td>Heat and emotional heat are different. There is no rise in temperature in the latter unless the person jumps about.</td>
</tr>
<tr>
<td>Pies (H3)</td>
<td>P-H; R-H</td>
<td>Density</td>
<td>Both pies produce heat. The small pie has the highest temperature because it would cook faster and heat up more quickly. In the same time it would be brown and burnt. The larger is more dense and would cool more slowly.</td>
</tr>
<tr>
<td>Iron bar (H5)</td>
<td>C-H; M-H; R-H; D-H</td>
<td>Particles</td>
<td>Heat is exerted on the bar, going in and out. It moves the particles through the bar though the heat doesn't move. (Extracts 68 and 98).</td>
</tr>
<tr>
<td>HEAT IS...</td>
<td>C-H; N-H; P-H</td>
<td>Synonymous with energy and force</td>
<td>Obvious heat sources and heat that is produced. You can feel it (extract 126).</td>
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<tbody>
<tr>
<td>House (H9)</td>
<td>C-H; D-E; M-H</td>
<td>Energy; rays; a distinction between heat and light.</td>
<td>Sun is an energy source - it sends out energy rays which cut through the atmosphere to produce heat and light. Tropical islands have heat. Iceland does not.</td>
</tr>
<tr>
<td>Ice (H6)</td>
<td>C-H; N-H</td>
<td>Distinguishes between atmosphere and air</td>
<td>Ice is cold - air (warmed by the atmosphere) is warm. It is not actual heat.</td>
</tr>
<tr>
<td>Astronaut (H13)</td>
<td>Noneg</td>
<td></td>
<td>No reason given.</td>
</tr>
<tr>
<td>Mixer (H12)</td>
<td>D-H; P-H; P-E</td>
<td>Friction; particles; energy produces heat</td>
<td>Mixer creates energy (friction) which in turn creates heat. Friction is caused by particles rubbing together.</td>
</tr>
<tr>
<td>Cliff (H8)</td>
<td>Noneg</td>
<td></td>
<td>No reason given.</td>
</tr>
<tr>
<td>Pepper (H8)</td>
<td>Noneg; P-H</td>
<td>Reaction</td>
<td>It is not an example because it does not produce heat. Like (H1) and (H4). It might react with body cells.</td>
</tr>
<tr>
<td>Flower (H7)</td>
<td>Noneg</td>
<td></td>
<td>No reason given.</td>
</tr>
<tr>
<td>Fridge (H14)</td>
<td>N-H</td>
<td></td>
<td>The fridge might cool the room down given time.</td>
</tr>
</tbody>
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Figure 69
used as evidence for a Dynamic Heat framework (D-H) and in particular for a 'hot molecule' model. This has been mentioned in previous chapters and can be seen as a subsidiary of a D-H framework. Not only is heat involved in producing movement - in this case on a molecular level - it also induces the microscopic particles to migrate along an object (commonly the iron bar (H5)). Here, Cushla is less certain than other students about this phenomena and at one point makes a distinction between hot particles that move and heat that 'saturates' into the material of the bar. This comment has already been described in extracts 68 and 98.

The general comments to be drawn from all four sets of interviews are left to the end of the chapter. It is worth noting here, however, some early differences between students. These are particularly marked between Colin and Cushla. For example, Colin uses a few minutes of each interview to orientate his thoughts and then begins to develop and pursue strong ideas. The conceptions he develops however, do not always carry over from interview to interview. He identifies closely with the issue in each case and uses the interview in order to explore his own confident explanations. His ideas are firmly in mind, he tests his own statements, uses his own personal experience, balances and assembles his conceptualising over each interview. Cushla, on the other hand, grows in involvement both with each task, and issue, and with every interview that takes place. Despite this, her ideas remain remarkably consistent - even though the interviews are spread over a
much longer period. For example, her account of a chemical reaction is very similar even after a period of some two and a half years. She rarely refers to personal experience and seldom overtly tests her own statements. More than Colin, she is apt to offer standard 'school science' aphorisms and when pressed, rather than weigh ideas and substantiate conclusions, makes statements she then recants. She entertains fewer borderline cases and designated a much larger number of non-examples (often without proffering a reason).

It is interesting now to compare these students with the next two.

6.3: Petina's Interviews

Petina's interviews are like Colin's. She warms to the task quickly and soon becomes involved with the task so that she takes advantage of the situation to expand her ideas. The order of the interviews is like that of Cushla's - energy, force, light and then heat. Each interview is almost exactly forty minutes long - within a minute or two, and in each session she manages to shape it very much her own way.

Petina's Energy Interview (P1,4E)  
She has one dominant conception throughout the interview. It might best be described by using the analogy of a cold water cistern. Like the water in the cistern she conceptualises energy as something that continuously builds up inside something to be then released.
rapidly (quickly flushed) and used. It is a continuous process so that even as the expenditure takes place the energy is continuing its slow build-up. She calls the build-up energy 'potential' and the release 'kinetic'. In the interview it is a conception that is discussed at length - she relates it to batteries; ghosts; food; sledges and it forms a central part of her own definition of energy. The interview outline is in figure 70. She describes it thus:

P. it *energy* changes things... I mean it makes them move and if things are still it keeps them still.... and if they're still then the energy builds up.... and as they move they sort of *use* the energy.... if they're staying still they're not really using the energy they've got.... they're using a *little* bit but they're not really using as much as if they're *doing* something...

I. when you say you *use* it. what are you thinking of?

P. well.... if you have a good sleep I think the energy's building up for the next day.. but the body's also using up energy to make sure everything's alright inside the body... the flow of blood.. the heart beat .. in the muscles.. but as *well* its building up for the next day.

It is a conception of energy as an inexorable (dripping) aggregation that is released in movement, but even as it is, the next accumulation is being began.

It is a conception of energy that lies to one side of the energy frameworks. It is 'depository' in that she sees it as deposited within objects and yet it is (continuously) refuelable. She indicates its outcome in terms of overt activity - D-E and O-E frameworks are the most straightforward to evidence from the transcript.

At various times in the interview she suggests that energy is synonymous with force, heat, electricity and power.
<table>
<thead>
<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box (E1)</td>
<td>D-E</td>
<td>Potential</td>
<td>The energy is in the men and is potential energy in the box.</td>
</tr>
<tr>
<td>Battery (E3)</td>
<td>D-E; O-E; F-E</td>
<td>Energy and electricity are synonymous, electrons, potential difference, force; heat; pressure</td>
<td>Energy travels round the circuit from the battery. The bulb uses up electrons which leaves less in the battery which then wears away. The resistor is a pressure-force against the electricity it becomes hot and gives off light. Energy is produced to do something. Ghost has energy inside it if it moves. If it is stationary then it is building energy ready for the next move.</td>
</tr>
<tr>
<td>Ghost (E3)</td>
<td>D-E</td>
<td>Distinguishes between static and moving objects</td>
<td></td>
</tr>
<tr>
<td>Hot water (E4)</td>
<td>D-E; P-E; C-H</td>
<td>Distinguishes between heated and hot; heat and energy are synonymous; molecules, particles.</td>
<td>There is energy in the water. It has been heated but it only gives off energy if its really hot. Particles or molecules are moving about because it is hot, they're still if it is cool, though water itself has energy.</td>
</tr>
<tr>
<td>Reaction (E5)</td>
<td>D-E; P-E; I-E</td>
<td>Reaction, chemical energy</td>
<td>Reactions are usually violent and then produce energy the more violence the more energy. Chemical energy comes from chemicals - this is similar to the battery (E2).</td>
</tr>
<tr>
<td>Lens (E6)</td>
<td>Noneg; D-E</td>
<td></td>
<td>There's no energy in it and it doesn't do anything. There maybe energy to enlarge the letters.</td>
</tr>
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<tr>
<th>IAI CARDS</th>
<th>FRAMEWORKS</th>
<th>OVERLAPS</th>
<th>COMMENTARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY IS</td>
<td></td>
<td>Synonymous with force</td>
<td>It changes things - makes them more and keeps them still. If still they build up energy ready for movement. This is true of people when they sleep.</td>
</tr>
<tr>
<td>Meal (E7)</td>
<td>I-E; D-E; T-E</td>
<td>Carbohydrates. Energy is synonymous with food.</td>
<td>Energy is used to eat, and produced by eating. Body sends energy in the blood to the parts that need it. Food is energy though some (mars bars) have more than others (lettuce).</td>
</tr>
<tr>
<td>Ice (E8)</td>
<td>T-E; D-E</td>
<td>Heat; light; temperature</td>
<td>The molecules are being broken down by energy in the ice and around it. Both heat and light are connected and come from the sun.</td>
</tr>
<tr>
<td>Sledge (E9)</td>
<td>O-E; D-E; T-E</td>
<td>Kinetic energy; potential energy; gravity is a force not energy. Weight and gravity are separate</td>
<td>It has downhill energy and some stored in the sledge. Potential energy is energy that builds up inside something. Both gravity and the weight of the man pull the sledge down. Energy is both a fuel and a force.</td>
</tr>
<tr>
<td>Clock (E11)</td>
<td>O-E; D-E; F-E</td>
<td>Light; work; radioactivity is separate yet related to light.</td>
<td>The bell is doing energy as is the ticking. There's energy inside to make it work. Luminous dial is radioactive and continuous. Energy is in the 'spring works.'</td>
</tr>
<tr>
<td>ENERGY IS</td>
<td>P-E; D-E</td>
<td>Power and energy synonymous</td>
<td>The power to make things work; power is a build up of large amounts of energy inside you.</td>
</tr>
</tbody>
</table>

**Figure 70**
6.52
Gravity, however, is a force and not energy and operates in addition to an object's weight. Both power and potential energy are 'build-ups' of energy, the former in particularly large amounts, the latter when objects are stationary – in preparation for action. Like Colin, she maintains that water itself is energy, like Cushla she presents her own version of kinetic theory in her account of water and ice.

**Petina's Force Interview (P2,4F)**

The interview outline is figure 71. There are three interesting points in the interview which are themes that run through it. The first is a distinction she draws between physical force and mental force. This latter is indeed a force and she uses it to include the three orthodox non-examples (told (F3), robber (F10) and thinker (F6)) as examples.

The second point is her separation of force and energy. Her conception of energy is very similar to that of her previous interview – it is deposited inside things and is refuelable. Force, on the other hand, is applied to things and lasts as long as is necessary. She establishes this conception of force (of 'physical' force) early on and argues that forces are not in things but are applied to them. Thus the stone (F1), tree (F5), diver (F4) and golfer (F8) are all examples of physical forces whilst the three cards already mentioned are mental ones. The rocket is a non-example because she cannot see anything pushing it. She introduces energy to account for the golfball landing on the green (F9) and explains it as follows:
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Stone (F1)</td>
<td>O-F</td>
<td></td>
<td>Obviously a force because you can see it being physically pulled by the men.</td>
</tr>
<tr>
<td>Rocket (F2)</td>
<td>Noneg</td>
<td></td>
<td>It's not obvious that there's any force there. Could be in the blast to push it up.</td>
</tr>
<tr>
<td>Told (F3)</td>
<td>A-F</td>
<td>Distinction between physical force and mental force</td>
<td>Person is being forced to do as he's told. Would be a physical force if the other person dragged him along the floor. Mental force is a force.</td>
</tr>
<tr>
<td>Tree (F5)</td>
<td>E-F</td>
<td>Kinetic energy</td>
<td>A good example of force because there is actually something pushing the tree. Wind is a force on the tree. The tree has no force - it has kinetic energy.</td>
</tr>
<tr>
<td>Diver (F4)</td>
<td>C-F; E-F</td>
<td></td>
<td>Force is from the person to the board. When released the board just springs back free to its 'normal' position. It doesn't have force but is a force on the diver.</td>
</tr>
<tr>
<td>Robber (F10)</td>
<td>A-F</td>
<td></td>
<td>A mental force - 'hand over the money or be killed'.</td>
</tr>
<tr>
<td>Golfer (F8)</td>
<td>M-F; I-F</td>
<td></td>
<td>The force is the 'hit'. There's also the force of movement as it goes - in the direction of movement.</td>
</tr>
</tbody>
</table>

continued...
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</thead>
<tbody>
<tr>
<td>Green (F9)</td>
<td>M-F; D-E; A-E Noneg</td>
<td>Power; gravity, a distinction between energy and force.</td>
<td>This is an example of energy not force. Gravity pulls the ball down until it runs out of energy. Energy runs out because it is powered by something - it must be refuelled. Force is applied to things and lasts as long as you like. Gravity is a force you can't avoid that tugs things down.</td>
</tr>
<tr>
<td>Sledge (F7)</td>
<td>I-F</td>
<td>Energy</td>
<td>This is force not energy since nothing is pushing it. Movement force might run out. There's no force at the bottom of the hill.</td>
</tr>
<tr>
<td>Thinker (F6)</td>
<td>A-F</td>
<td></td>
<td>It is a natural, mental force.</td>
</tr>
<tr>
<td>Book (F11)</td>
<td>C-F</td>
<td>Gravity</td>
<td>Gravity is holding book and table down, otherwise they'd float. Gravity is longlasting.</td>
</tr>
<tr>
<td>Balloon (F12)</td>
<td>C-F; D-F</td>
<td>Gravity</td>
<td>The man acts like gravity to hold the ball down. The balloon has a force inside it and would go upwards if released in space.</td>
</tr>
<tr>
<td>Astronaut (F13)</td>
<td>Noneg</td>
<td>Gravity</td>
<td>There is no gravity, nothing to push on or grip.</td>
</tr>
<tr>
<td>Moon (F14)</td>
<td>C-F; noneg</td>
<td>Gravity</td>
<td>There's no real force, gravity is very small. Gravity is to do with atmosphere.</td>
</tr>
</tbody>
</table>

**Figure 71**
you put force on something you could push it or pull it... tug at it. you could move it in a certain way... any way you want to. but energy has got to be. something that contains energy has got to be refuelled. it will run out of fuel eventually and so. it's something that only lasts certain times. whereas force can last as long as it wants to really.

For this reason she classifies the green card (F9) a non-example since it is energy and not force.

She then faces a difficulty on the next card showing the sledge coming down a hill (F7). It is not energy (because 'there is no energy pushing it') and yet it 'runs out of force'. She decides that maybe some 'moving' forces can run out and makes it a special case by putting it separate from the other pictures on the bench.

The third interesting point concerns gravity, and in particular in relation to the balloon. Gravity is her typical example of a durable non-refuelable force that 'holds things down'. The balloon, however, has a force in it so that it is able to 'overpower' gravity to escape - her one piece of evidence for a D-F framework. During the course of this discussion she develops a small 'thought-experiment' for herself: what would happen if an astronaut took a hydrogen balloon such as this into space and released it? If there is no gravity to overpower what would happen?

She decides:

well if it was up in space... I suppose the balloon'd go away just as soon as the man let go of the balloon... the balloon'd just go on up.

The reason being that the hydrogen would be a force in the balloon.
Petina's Light Interview (P,4L)

In a manner very similar to the other two light interviews, Petina's discussions are dominated by responses that fit a Decoupled framework. She discusses each card at length and categorises only one (the x-rays) as a non-example. The outline is provided in figure 72. Her 'decoupled' responses hinge on her conception of an image - something she returns to three or four times in the conversation. The session ends with her discussing the eye, when she re-introduces the notion of an image. She has previously said that an image is an exact replica that is 'planted' on a screen and when talking about the eye, says that an image is made on the retina. She then says:

P. at least I suppose it's an image... it's not the same sort of image /as previously/
I. why what are you thinking of?

P. ..... I'm not sure if the image in your eye is turned upside down or something isn't it.. the light crosses over... two rays of light cross over at the back and eventually join at the retina... whereas here /in a mirror/ you just get a straight reflection in the glass and that doesn't happen at the back of your eye... /a moment later/ the lens /in the eye/ causes light to come to a point at the back of your retina to a dot whereas here /the projector/ they're projected straight onto the screen..

An interpretation of this response is as follows: Petina has been taught the operation of the eye in physics using a (customary) ray diagram to show two lines converging on the retina - often part of a discussion about defects of the eye and so on. This stylised explanation is far removed from the dynamic, colour-full, 'living' image she experiences each time she opens her eyes (or that she sees in a mirror,
Light shines on the mirror so that the person can see himself. The light is the 'general' light in the room. It is said that the image is as far behind the mirror as the person is in front. This is not so, the image is on the mirror not in it. (Extract 72).

A beam of light is projected onto the screen and that light makes the image appear. It is not reflected back but just 'planted' on the screen.

Light is made of seven colours. The white light 'all around' separates when it shines on rain (or glass). This is not an image since it is not a replica of something.

Same as projector. Light projects onto the screen and allows you to see the picture. It's a screen and projector all in one.

Power passes down the wires and goes in circles. Light is projected from the bulb by the power. Electricity is made from chemicals.

It is not light but radioactive rays ($\alpha$, $\beta$ and $\gamma$) which penetrate the body.

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<table>
<thead>
<tr>
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<th>OVERLAPS</th>
<th>COMMENTARY</th>
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</thead>
<tbody>
<tr>
<td>Lens (L9)</td>
<td>D-L; C-H; N-H</td>
<td>Heat and light are separate yet related; power; colour; density.</td>
<td>Light going into the lens makes words appear larger. They would still be magnified in the dark - we just wouldn't be able to see them, unless you switch on a light. It is caused by the density of the glass. Bright spots of light produce heat. Power from the sun is hot.</td>
</tr>
<tr>
<td>Sunbathing (L8)</td>
<td>O-L; P-L; C-L</td>
<td>Ray</td>
<td>Both light and heat from the sun cause suntan. A ray is lots of pieces of light clustered together. Clouds make them break apart and separate. In a room they are all joined up to give just a lighted room.</td>
</tr>
<tr>
<td>LIGHT IS...</td>
<td>Image</td>
<td></td>
<td>Hard to define. Is natural and opposite to dark, causes reflection and images in the retina. This is unlike other images - it is an upside down dot.</td>
</tr>
</tbody>
</table>

**Figure 72**
or on a screen). She distinguishes, then between light rays and seeing 'exact' images. The action of light in terms of rays, reflections, focusing etcetera is decoupled from the action of looking and seeing.

Clearly there are other interpretations, and whether this description could be used for other students' 'decoupled' responses is doubtful. However, her discussion does offer a possibility of an explanation for this particular conception. She says at one point that 'if you let your eyes get used to it you can see in the dark'. This leads her to wonder if a hand lens will 'magnify a word' in the dark and she says:

P. in the dark it will still be magnified but you won't be able to see it... well you wouldn't be able to see it unless you switch on the light and then you would be able to see it

I. but in the dark

P. yes it would be magnified

Another point of interest is the 'planting' of the image on the screen by the projector. It resembles Colin's 'barrier' model: the light is projected from the projector but goes no further than the screen (she is quite clear that it is not reflected). Similarly the television is a kind of 'back-projection' so that the image travels to the screen, is lit, and then seen.

She describes a beam, too, as a composition of rays - all clustered together - and which break apart and separate when coming between clouds (for instance). On a number of occasions she says that it is difficult to explain light or to describe how it works. She says she despairs of ever
knowing about rainbows - and decides to ask her teacher at the end of the interview.

**Petina's Heat Interview (P,6H)**

Like the energy and light interviews, this heat one is dominated by a single conception. Each of the instances discussed is judged as to whether or not heat is 'given off' - five of the thirteen cards are categorised as non-examples on this basis. 'Given off' means transmitted to the immediate surroundings and is not just a property of hot objects but of chemical reactions, moving objects and electricity as well. The outline of the interview is figure 73.

In the interview, Petina is especially forthcoming and generates five separate debates with herself (with some assistance from the interviewer). The first of these - about temperature - she leaves unresolved, but the other four she brings to some conclusion. She develops each of these arguments at length throughout the interview, returning to them cards later, and tests her ideas both against her own personal experience and its logical consequences.

The first debate is the temperature one. It begins with the chemical reaction and continues with the card about two pies (H3) which follows. Temperature she says, is a measure of how 'high' the heat is:

P. .. temperature is how high the heat is.. sort of.. I'm searching for an example. heat given off at a hundred degrees has a higher temperature than heat given off at fifty degrees. that's what I think temperature is...

Of the pies, she decides that the larger pie is giving 6.61
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</thead>
<tbody>
<tr>
<td>Ill (H1)</td>
<td>M-H; N-H</td>
<td>Temperature</td>
<td>Heat is given off from objects. Temperature is a measure of the heat given off. Person gives off heat if they are above normal temperature.</td>
</tr>
<tr>
<td>Reaction (H2)</td>
<td>M-H; P-H</td>
<td>Temperature; reaction</td>
<td>Heat is given off in chemical reactions when chemicals combine. For example, ACID + ALKALI gives heat. Temperature is how high the heat is.</td>
</tr>
<tr>
<td>Pies (H3)</td>
<td>M-H</td>
<td>Temperature,</td>
<td>The larger pie has more heat given off yet both are at the same temperature. The smaller pie cools more quickly.</td>
</tr>
<tr>
<td>Argument (H4)</td>
<td>Noneg; M-H</td>
<td>D-H</td>
<td>No heat given off. You can get hot if you wave your arms, your blood rises and you go red.</td>
</tr>
<tr>
<td>Iron bar (H5)</td>
<td>M-H; R-H; P-H</td>
<td>Reaction</td>
<td>Heat given off by the burner moves along the bar because it is a conductor. The heat spreads and is cooled at the water end; it just reduces. It is similar to the reaction card - burner and iron produces heat.</td>
</tr>
<tr>
<td>Ice (H6)</td>
<td>Noneg; M-H</td>
<td>None</td>
<td>No heat given off. Some heat in the air from other 'given-off' heat.</td>
</tr>
<tr>
<td>Flower (H7)</td>
<td>Noneg; M-H</td>
<td>None</td>
<td>No heat given off.</td>
</tr>
<tr>
<td>Pepper (H8)</td>
<td>Noneg; M-H</td>
<td>None</td>
<td>No heat given off. Just a taste.</td>
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<th>OVERLAPS</th>
<th>COMMENTARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>House (H9)</td>
<td>N-H</td>
<td>Rays; light</td>
<td>The sun's rays heat the house - the tiles and bricks but not the glass. Heat and light come together from the sun.</td>
</tr>
<tr>
<td>Dustbin (H10)</td>
<td>M-H; R-H</td>
<td></td>
<td>No heat is given off. There is some heat in the bin and coat, they might retain some heat.</td>
</tr>
<tr>
<td>Cliff (H11)</td>
<td>Noneg; M-H</td>
<td></td>
<td>No heat is given off.</td>
</tr>
<tr>
<td>HEAT IS...</td>
<td>M-H; G-H; N-H</td>
<td>Energy</td>
<td>Energy given off by hot bodies. A lighted match is hot and gives off heat and burns your hand. Heat can accumulate in things.</td>
</tr>
<tr>
<td>Mixer (H12)</td>
<td>M-H; D-H</td>
<td>Electricity; insulator</td>
<td>Electricity is hot, bare live wires will show a rise in temperature. Wires are normally (heat) insulated. The mixer blades produce heat as they turn - fast rubbing makes heat be given off.</td>
</tr>
<tr>
<td>Astronaut (H13)</td>
<td>C-H; R-H</td>
<td>Energy; radiation</td>
<td>There is heat from the rocket motors. Also space is hot - rockets at the top of the atmosphere get hot. Silver space suits radiate heat less than black ones would. Black attracts heat which is why windows don't get hot.</td>
</tr>
</tbody>
</table>

Figure 73

6.63
off more heat and yet both pies are at the same temperature. A moment later, she decides that the smaller pie will cool most quickly since it loses its heat to the air 'more quicker'. She is aware of some of the ambiguities of what she has been saying, begins a rationale in terms of surface area and then asks to shelve the idea.

P. no I can't think about that... no. put it aside here and we'll go on..

She returns to it a little later as she sorts through the cards but again abandons it.

Her second debate centres on whether heat accumulates in things rather than staying at a constant level. A flame, she says, is hot because it gives off heat and:

P. a radiator is hot... if you put your hand on it long enough you get burnt.... well I remember that one because my aunt put something on a radiator to dry and it started burning eventually.. yes it did actually .. it started burning. that's what I associate with something getting hot

I. how does that happen?

P. I'm not sure.. I think it gets hotter up to a point. I'm not sure. I've tried it actually.. you put your hand on a radiator and I think it gets hotter and hotter and then after a while you don't really seem to feel any difference... I don't know but you might get burnt.. it does get hotter but then I think it stops after a certain amount of time..

She suggests that things have their own temperature and that when this is reached 'the temperature stops'.

The third debate concerns glass and whether it can heat up. When discussing the house card (H9) she thinks bricks and tiles will get hot but not windows:

P. when there's a really hot day and I've put my hand
on the glass I don't think I've ever really felt it being hot... whereas if you put your hand on slate or something, its hot.

She returns to this later and decides that it is because glass is silvery and does not attract heat.

P. that's probably why windows don't really get all that hot... probably because they're shiny and transparent ... the heat's not really attracted towards them. and that's why black slates are really hot with the summer ... it could be the property of glass I'm nor really sure....

The fourth is a discussion as to whether electricity itself is hot. Here, again, she designs for herself a small 'thought experiment':

P. I was thinking of an electrical appliance and.. umh .. does electricity have to be hot?

I. a good question

P. I'm not sure about that one. if. you know. when current is flowing it comes hot... it you actually parted the wires so they were bare and then stuck a thermometer in there between them...

I. what do you think?

P. I suppose they'd be hot. I've never tried it really... I guess it would go up. it would have to because an electric kettle.....yes it does because the filament in an electric kettle gets hotter and boils the water so it has to go up

I. and what about an ordinary wire carrying it /electricity/

P. its a higher temperature than the surroundings yes I think so

I. can you feel it?

P. no because its got an insulator around it.

The fifth debate is about heat is space. Unsure, she eventually decides that space is hot because she remembers
something about rockets getting hotter at the top of the atmosphere.

These (mostly) self-generated discussions illustrate clearly the level, and the quality, of the arguments she uses. As with Colin, they betoken an involvement with the issues at hand and a willingness to reflect openly - with little self-consciousness - about her own puzzles. They illustrate, too, the sources of some of the conceptions and the rationales for them. There is little in this last interview to indicate her most recent A-level work and many of her conceptions - about reactions, energy, force and so on, remain remarkably consistent over time.

6.4: Susie's Interviews

Susie's interviews develop in two distinct ways. She builds upon each one of the interviews in turn and continues to elaborate on themes across all four. In particular, she begins a distinction in the first between natural and unnatural ('forced' or 'deliberate') effects which she returns to and incorporates into each successive discussion. The essence of this conception of common phenomena - that the distinction exists and can be seen to operate in all things - changes little in the two years or so that separates the first and last interviews.

In contrast, her responses can be seen to develop in terms of school science orthodoxy - she incorporates more 'acceptable science' into her answers. This is particularly so at A-level where her discussions of heat show a marked difference in terms of quality of argument to (say) her fifth year discussion of energy, where she also discusses
heat. Nor is this 'A-level influence' simply at an aphoristic level - there is evidence for a change in a range of her conceptions. Susie's interviews are in the order force energy, light and heat.

Susie's Force Interview (S4,4F)

The outline of the interview is figure 74. She begins to delineate 'natural' and 'deliberate' forces in the fourth and fifth cards about the tree (F5) and the diving board (F4). For the tree, she makes the case that the wind is a force which 'pressurises' the tree over from its natural position. Similarly, when a diver walks out onto a diving board he is deliberately 'forcing' the board, which returns to its natural position after the diver leaves the board. It is at this point she wants to reserve the term 'natural' for the wind as a natural force and 'deliberate' forces for man-made occurrences. She then re-phrases her summary of the wind card (F5) to say that, should the wind stop, the tree returns to 'its usual position'.

This distinction carries over into the orthodox non-examples - told (F3) and robber (F10). In both cases she includes them as examples of deliberate force - forcing something to do something it would not otherwise do. This allows her to include a number of anthropomorphisms.

The other interesting feature of this interview, is her conception of gravity. It is invoked to explain the falling of objects in flight rather than any already on the ground. Discussing the landing golfball (F9) she says:

S. there's a gravity force pulling it down.... it's like the apple dropping from the tree (laughs)
I. I see. tell me about gravity
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<td>D-F</td>
<td>Energy and force separate and related.</td>
<td>Force is in the molecules in the shoulders and in the ropes.</td>
</tr>
<tr>
<td>Rocket (F2)</td>
<td>E-F; A-F</td>
<td></td>
<td>There's a lot of energy present so there must be force, where its trying to push itself off the ground. More energy means more force - force is produced by energy. Without energy we cannot force anything to do anything.</td>
</tr>
<tr>
<td>Told (F3)</td>
<td>A-F</td>
<td>Contact and noncontact forces.</td>
<td>There is force in the speech of the person - a noncontact force. Some forces - like forcing a screw into a hole are contact. Others - like the wind - are not.</td>
</tr>
<tr>
<td>Tree (F5)</td>
<td>E-F</td>
<td>Pressure</td>
<td>The wind is a force. It is forcing the tree because the wind has pressure. The tree has no force it returns to position naturally.</td>
</tr>
<tr>
<td>Diver (F4)</td>
<td>D-F</td>
<td></td>
<td>The person is the force, not the board. There is no force in water. The board returns to its usual position because like the tree, it is flexible.</td>
</tr>
<tr>
<td>Robber (Fl0)</td>
<td>A-F</td>
<td></td>
<td>Robber has force because he has a weapon.</td>
</tr>
<tr>
<td>Golfer (F8)</td>
<td>M-F</td>
<td>Gravity</td>
<td>The golfer is the force which goes into the ball. Gravity pulls it down.</td>
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<tr>
<th>IAI CARDS</th>
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<tbody>
<tr>
<td>Green (F9)</td>
<td>C-F; M-F</td>
<td>Gravity</td>
<td>Gravity forces ball down. It has something to do with air. It doesn't act if you are stuck down on the ground, only if in the air.</td>
</tr>
<tr>
<td>Sledge (F7)</td>
<td>E-F; M-F</td>
<td>movement</td>
<td>Sledge has force and speed. Force is in the slope which gives force to sledge. Force runs out on the straight and there's no movement.</td>
</tr>
<tr>
<td>Thinker (F6)</td>
<td>Noneg</td>
<td></td>
<td>You don't pull your brain.</td>
</tr>
<tr>
<td>Book (F11)</td>
<td>Noneg</td>
<td>movement</td>
<td>There's no movement - it's just sitting there. There's nothing moving it.</td>
</tr>
<tr>
<td>FORCE IS...</td>
<td>M-F; D-F</td>
<td>movement</td>
<td>The ability to move something or to do something. There must be movement for there to be a force.</td>
</tr>
<tr>
<td>Balloon (F12)</td>
<td>D-F</td>
<td></td>
<td>The gas inside the balloon has force to go up. No gravity on the balloon unless it comes down.</td>
</tr>
<tr>
<td>Astronaut (F13)</td>
<td>D-F</td>
<td></td>
<td>The astronaut has force; will float like the balloon if he's not tied to the rocket.</td>
</tr>
<tr>
<td>Moon (F14)</td>
<td>Noneg</td>
<td>Gravity; pressure</td>
<td>No gravity on moon; pressure is different too. Astronaut will float. There is no gravity he's not falling. It's hard to sit on the floor in space.</td>
</tr>
</tbody>
</table>

Figure 74
S. I think it's got something to do with air hasn't it .. I'm not sure

I. you haven't mentioned it before with these /other cards/

S. .... air. in a way they're /the earlier cards/ linked with this. the gravity's in the air but.... no they've really got nothing to do with gravity because they're stuck down..

Later, she discusses the balloon - which has no gravity unless it bursts and is then brought down. For the astronaut on the moon she also argues that there is no gravity - consequently in tripping he will not fall. She says

S. there's no gravity and the pressure there's different so everything floats.. he'll just float. he won't fall down or hurt his bottom he'll just float like that... its like this one /the astronaut in space/ ... there's no gravity because he's not falling..

It is not just that she identifies gravity as being present because of objects falling but that it is only on falling objects.

**Susie's Energy Interview**

Susie categorises over half (seven out of thirteen) of the cards as non-examples. This is generally on the basis of whether or not something is happening in the picture. She returns to the distinction began in the force interviews in the sledge (E9) and meal (E7) cards and particularly when she is asked to define energy. This then dominates the remainder of the interview so that the remaining cards are all considered in this vein (figure 75). Energy and power are synonymous throughout. She uses this more to describe forced
<table>
<thead>
<tr>
<th>IAI CARDS</th>
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<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Snow (E10)</td>
<td>Noneg</td>
<td></td>
<td>Not much energy there.</td>
</tr>
<tr>
<td>Smell (E13)</td>
<td>Noneg; D-E</td>
<td>Power</td>
<td>No energy. Maybe some in the person.</td>
</tr>
<tr>
<td>Lens (E6)</td>
<td>Noneg</td>
<td>Power</td>
<td>No energy at all. Not power but strength</td>
</tr>
<tr>
<td>Ice (E8)</td>
<td>O-E</td>
<td>Power; speed</td>
<td>There must be energy. Something is happening in the ice. The ice is producing some energy.</td>
</tr>
<tr>
<td>Sledge (E9)</td>
<td>O-E</td>
<td>Power</td>
<td>Speed is energy, it is the power of the movement. The sledge has no power in itself but in the way it comes down. There's no energy if it's standing still</td>
</tr>
<tr>
<td>Clouds (E16)</td>
<td>Noneg; O-E</td>
<td>speed</td>
<td>Even snow has more energy than clouds - at least it is doing something (i.e., falling).</td>
</tr>
<tr>
<td>Clock (E11)</td>
<td>Noneg; F-E</td>
<td>Power</td>
<td>Like the sledge it has no power itself. It works automatically. There's no thought behind it. Power is when you make things happen. Otherwise, it's nature.</td>
</tr>
<tr>
<td>Meal (E7)</td>
<td>A-E; O-E</td>
<td></td>
<td>Energy comes from the person in their movements.</td>
</tr>
<tr>
<td>Stars (E15)</td>
<td>Noneg; O-E</td>
<td></td>
<td>They're not doing anything.</td>
</tr>
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</thead>
<tbody>
<tr>
<td>ENERGY IS..</td>
<td>T-E; I-E</td>
<td>Power and energy are synonymous; A distinction is drawn between natural (force energy) and 'forced' (force; energy).</td>
<td>There are different sorts of energy - physical energy; electrical energy; movement energy; chemical energy; in the steam in power stations to turn turbines. It originates in coal or oil and when the steam is used it turns into electricity and produces power. Energy is stored and then released to the parts that need it. Must do something to it to release it.</td>
</tr>
<tr>
<td>Flower (E14)</td>
<td>P-E; D-E</td>
<td>Force</td>
<td>Makes its own energy in the leaves.</td>
</tr>
<tr>
<td>Hot Water (E4)</td>
<td>P-E; I-E; D-E; T-E</td>
<td>Force</td>
<td>If there's steam then there's energy but not much. The water won't stay hot for long. It needs energy to produce energy. Some energy is rechargeable (like in water) but others not (coal). Hot water is forced force.</td>
</tr>
<tr>
<td>Box (E1)</td>
<td>Noneg; O-E; A-E</td>
<td>Force</td>
<td>The box has no force or energy; the person has. The box can't do anything the person has 'forced' force and can walk away.</td>
</tr>
<tr>
<td>Battery (E2)</td>
<td>D-E; I-E</td>
<td>Power and energy are synonymous; force</td>
<td>There is stored energy in the battery which produces power from the chemicals. The circuit must be joined before energy is released. It's 'forced' force; the chemicals are not naturally found together.</td>
</tr>
</tbody>
</table>

Figure 75
energy situations (deliberate ones) rather than natural (automatic) energy cases. The search for things 'happening' in each instance is important and evidence for an Ostensive framework (O-E). The 'forced-natural' distinction takes place only after some occurrence has been established.

Part of the 'forced-natural' distinction is in the deliberate release of energy. That is, typical of an I-E framework, energy can be present in an instance but waiting for some agent to release it, or some action to take place for it to occur. In describing the battery for example, she says:

S. when the power /in the battery/ is allowed to be let loose it can go along to the bulb and light it. but I'd call that forced force.. because the chemicals are thrown together.. I mean they're not naturally found together so I'd call that forced force

I. I see well tell me what happens in the circuit

S. well it's /energy/power/ sort of all along the wires ... but it won't do anything unless something else comes along to push it around

I. how do you mean?

S. its a bit like the sort of energy in the food that won't do anything until we digest it or something like that

I. and in this case

S. its the switch that does it...

Susie's Light Interview

This is a comparatively short interview and many of the responses are recogniseably similar to responses in the other three light interviews in this chapter. Susie responds to mirrors projectors and lenses in a way that is typical of a Decoupled framework.
### IAI CARDS FRAMEWORKS OVERLAPS COMMENTARY

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<thead>
<tr>
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<tbody>
<tr>
<td>Mirror (L1)</td>
<td>D-L</td>
<td>Reflection</td>
<td>Light is reflected. If the room was dark, one couldn't see the reflection there must be some light in order to see it.</td>
</tr>
<tr>
<td>Projector (L2)</td>
<td>O-L; P-L; D-L</td>
<td>Reflection; image</td>
<td>The bulb in the projector is obviously light which produces the image on the screen. An image is what you see. It is projected onto the screen and does not bounce off. A reflection comes back. A projection is something going away onto a screen to be seen.</td>
</tr>
<tr>
<td>Candle (L6)</td>
<td>O-L; P-L; M-L</td>
<td>Synonymity between heat and light from the sun; otherwise separate and related.</td>
<td>Candle is an obvious source of light - it 'throws' it out. Burning produces light (as does electricity). Light is to do with heat but not heat with light - except both the same in the sun. Otherwise heat produces light.</td>
</tr>
<tr>
<td>Rainbow (L4)</td>
<td>M-L; C-L</td>
<td>Refraction; colour.</td>
<td>Refraction causes rainbow by light going through water and then being refracted into colours. Colours are different forms of light; light is a mixture of colours, rainbow is a mixture of primary colours (!). Colours from a filter are given to light.</td>
</tr>
<tr>
<td>T.V. (L3)</td>
<td>P-L; C-L</td>
<td>Distinction between pure (natural) and manmade light colour.</td>
<td>The picture is made of light (manmade) to produce three colours projected from a gun at the back of the screen - faster than the eye can see.</td>
</tr>
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<tr>
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<tbody>
<tr>
<td>Painting (L5)</td>
<td>Noneg; O-L</td>
<td></td>
<td>It is not a source of light. If it were dark, you couldn't see it.</td>
</tr>
<tr>
<td>Sunbathing (L8)</td>
<td>O-L; C-H</td>
<td>Heat and light are separate yet related</td>
<td>The sun is a source of heat and light combined. The light causes the tan (as in sunbeds).</td>
</tr>
<tr>
<td>Lens (L9)</td>
<td></td>
<td>Reflection; image</td>
<td>Light is reflected onto words and then magnified. The lens pulls and stretches the image to magnify it.</td>
</tr>
<tr>
<td>X-Ray (L7)</td>
<td>Noneg</td>
<td>Radioactivity</td>
<td>These rays are radioactive and not light. They pick out the light and dark bits of the body.</td>
</tr>
<tr>
<td>Battery (L10)</td>
<td></td>
<td>Heat and light are combined</td>
<td>The bulb is heated by electricity and gives out light. The battery is like a pumping station, so that electricity is pumped out of the battery to the bulb. It eventually runs out.</td>
</tr>
</tbody>
</table>

**Figure 76**

6.75
Initially she treats images and reflections as synonymous but later makes a distinction, so that an image is what one sees on a surface whilst a reflection bounces off it. Similar to others, she makes a separation between pure (natural) light and artificial (man-made) electric light. The interview outline is figure 76.

One point of difference is that she makes references to refraction as the 'separation' of light into colours. This is in the context of the rainbow (L4). It is an interesting discussion because it embraces the colours in a slide projector as well as those (later) on a television screen. Although she is sure that refraction is the separation of light into colours. She is unsure if it is separated into the primary colours or not. A second complication arises with a question about a colour filter (for the projector). That does not separate the light but changes it (later, the television relies on primary colours again).

The conversation is as follows:

S. we only get rainbows when its raining and the sun's out so the light goes through the water and is refracted into its colours

I. .... what are colours?

S. .... they're different forms of light.. the white light is refracted into its different colours

I. is it similar to what you were saying about the projector?

S. .... that's light being shone through something and it just sort of gives that colour which it's being shone through it's not being refracted.. it's just going through something straight.... you see when you have a slide its not just a blur of colours it has definite areas of colour... in this case /she waves her hand in front of her to indicate the light in the room/ it's white light which is a mixture of colours

6.76
I. why can't we see them?

S. because they're not refracted.. but in that / a colour slide or filter/ as the light goes through. its white and as it goes through say red so it turns to red

I. what do you mean when you say it turns red?

S. it's just sort of being given that colour which it's shone through. it /the filter/ is just giving that colour..

This conception of light filters as 'giving' colour, or dyeing the light is part of a Modal Light framework. That is, white light has things added to it in certain circumstances. Susie is clearly unsure quite how refraction works (she does not, for example, elaborate on what a 'form' of light might be).

Susie's Heat Interview

This final interview again, raises some already familiar issues. It entertains notions of temperature (as a 'measure of heat'); of particles in motion; of heat rising, of cold as the opposite of heat and other such conceptions. It is outlined in figure 77. There are two departures from the other heat interviews discussed in detail so far. Firstly it presents a slightly different conception of energy, in terms of exothermic and endothermic reactions. Secondly, it retains a remarkably consistent conception of phenomena - after natural force, natural energy and natural light an introduction is now made to natural (as opposed to 'forced') heat.

The first of these departures is of interest because, like Susie's conception of refraction, it represents an
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<tr>
<th>IAI CARD</th>
<th>FRAMEWORKS</th>
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<th>COMMENTARY</th>
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<tbody>
<tr>
<td>Ill (H1)</td>
<td>N-H; R-H</td>
<td>Temperature</td>
<td>There's some body heat and some heat in the blankets. Temperature is a measure of heat.</td>
</tr>
<tr>
<td>Reaction (H2)</td>
<td>D-E; P-E; P-H</td>
<td>Reaction; energy; exothermic; endothermic; atoms; molecules</td>
<td>Endothermic reactions take in energy so that the surrounding air temperature drops. Exothermic reactions give out energy so air temperature rises. It is how atoms combine - they either have energy to give out or require it to combine. It depends on the chemicals.</td>
</tr>
<tr>
<td>Pies (H3)</td>
<td>M-H; R-H</td>
<td>Temperature</td>
<td>Both pies have the same heat since they're in the same oven. The top of the oven is hotter since hot air rises. Both pies cool at the same rate. The small one heats up more quickly though as long as there is enough time, they both then have the same heat.</td>
</tr>
<tr>
<td>Argument (H4)</td>
<td>N-H</td>
<td></td>
<td>Maybe body temperature rises if adrenalin flows in the blood.</td>
</tr>
<tr>
<td>Iron Bar (H5)</td>
<td>R-H; M-H; A-F</td>
<td>Force</td>
<td>The hot end will be hot, the cold end cold, the middle cool. Heat might spread but coldness will move up the bar from the cold end. The bar is not forcing itself to be heated, it's just happening to it.</td>
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<tbody>
<tr>
<td>Ice (H6)</td>
<td>A-E; D-H; C-H; M-H</td>
<td>Force; temperature; particles</td>
<td>The temperature of the ice is rising; it wouldn't melt otherwise. The room must be heated by gas or electricity. Frozen particles can't move, if heated they move about. Ice does not want to change but is forced to by heat or cold. Some substances are frozen at room temperature. Heat makes mercury particles move about and up a thermometer.</td>
</tr>
<tr>
<td>Flower (H7)</td>
<td>C-H</td>
<td>Energy; light, is separate yet related to heat, photosynthesis.</td>
<td>The energy from the sun is needed for photosynthesis; is heat not light. There are different kinds of energy (for example; heat, electricity). The flower is similar to a human body; it has its own temperature.</td>
</tr>
<tr>
<td>Pepper (H8)</td>
<td>P-H</td>
<td>Exothermic reaction.</td>
<td>Pepper must be a chemical reaction - exothermic. One could do an experiment to see if one's temperature rises.</td>
</tr>
<tr>
<td>House (H9)</td>
<td>C-H; R-H</td>
<td>Light is produced by heat</td>
<td>The sun is a ball of fire. Heat produces light. The heat accumulates in the house.</td>
</tr>
<tr>
<td>Astronaut (H13) Noneg</td>
<td>Vacuum</td>
<td>There is no heat in a vacuum. Also its colder on other planets - one is just ice.</td>
<td></td>
</tr>
<tr>
<td>Mixer (H12)</td>
<td>R-H</td>
<td>Force; electricity</td>
<td>Electrical appliances get hot where the electricity comes in. They are not meant to - the electricity forces them.</td>
</tr>
<tr>
<td>HEAT IS...</td>
<td></td>
<td>Distinction between natural and unnatural heat</td>
<td>There's natural heat in bodies and unnatural heat from electricity.</td>
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</table>
attempt to explore and examine (quite consciously) and
to introduce it into her account. It is an account that
lasts for about four minutes, that may not seem long but it
represents some 12% of the whole interview (thirty three
minutes). During that period she describes reactions com-
fortably — it is a description she seems to feel is system-
atic. That is, the strong impression one has of her descrip-
tions suggests that she makes sense of the propositions
and images that she has incorporated into her conceptions
of 'reactions' and 'energy'. At one point, for example,
she says:

S. it is to do with how the molecules combine... it depends
on the electron structure of the reactants... the
electron structure is basically re-arranged and if
it's more stable... or if it's less stable heat will
be taken in... and heat. sorry. not necessarily heat
but some form of activity will be given out if the
reactant. if the products are more stable... its the
electrons in the chemical reactions which determine
whether there's any energy change

Curiously, to balance this level of argument and
explanation, she refers at another time to heat in contrast
to cold (as spreading up the iron bar, for example). It
is a juxtaposition of sophisticated A-level explanation
(almost) alongside a more unorthodox conception of hot and
cold. Of the iron bar she says:

S. is it cold or hot water?
I. well let's say it's cold
S. well in that case that end /burner/ would heat up
and that /tap/ end would.... remain... the same..
it depends how cold the cold water is
I. and what happens at the middle?

6.80
S. oh... if it's very cold water then the sort of coldness would move up the bar.

In the course of the interview this apparent dislocation of explanation (between reactant stability and spreading coldness) is not immediately discernible. Each card is taken as it comes and, in a period of just over half an hour, it is only possible to ask for inter-linking explanations once or twice without disrupting the flow of conversation. Hence the single reference to 'exothermic' in the 'pepper' card.

The second departure - the reintroduction of the natural/unnatural distinction - begins, again, with the iron bar card (H5). At the very end of this discussion - as she is about to consider another card - Susie says:

S. ....... er... the iron bar's sort of it's not forcing anything on itself it's just being heated or cooled by different means it's the same as the pies...

Within the flow of events this statement is allowed to pass. However, some minutes later (during the next card, H6), she says of the block of ice:

S. ...the water/in the ice/ is being forced... no... the water's not wanting to be heated or cooled but if it is/forced/ it will go through a change...

This element of anthropomorphism continues, particularly towards the end of the interview. She says of a cake mixer (H12):

S. I suppose most things do get hot... after a while but. they're not meant to get hot... they're meant to do something else like mixing cakes/a moment later/
the thing /mixer/ is not actually meant to get hot ... but it does of its own accord because the electricity makes it..

She then continues, following a request to define heat, to say:

S. yes. I'd say there's sort of... natural heat... body temperature... the sun... and there's ..... unnatural heat (laughs)... sort of electricity

6.5: Summary

Chapters four and five have both been entirely concerned with alternative frameworks. This chapter has been taken up with more personalised conceptions. Four young people, four separate interviews each. The intention has been both to flesh out some of the frameworks that have been discussed previously (beyond the example extracts that have been provided) and to draw specific insights from a more detailed appraisal of individual interviews.

Before embarking on a generalised summary, however, a number of caveats are in order. One thing which is clearly problematic is the status of a particular utterance in the response of an individual about a specific instance. The person may, of course, be lying, fantasising or teasing the researcher throughout the interview. Whilst any, or all, of these is possible, where it is discernible it is noted as such and due allowance is made. If it is a subtle, forty minute charade undetected by the interviewer then it is included here as a serious and respectable transcript. The researcher has no other way of knowing.

More serious is the probability that, to another
interviewer, in another context, these students would have perceived different opportunities to examine the same concepts. Perhaps the experience of having formulated a position and allowed it to mature is both context bound and yet context independent - the next time it happens it is a little different. In this sense the interviews are moments in the history of conceptions that are changing. At the same time uttering and reconstructing a view of a situation (some months later) does a considerable amount to change that view. The interviews are quite clearly potent learning events.

The first general point focuses on the uneasy alliance between their 'school science' explanations, and the students' own. This division is, of course, a contrived one and not easy to maintain. School, after all, is a major component of the students' own world and therefore their 'own' awareness cannot be independent, warring factions against those they use from science. Yet it seems unlikely that the natural/man-made division of phenomena is one that is emphasised in school science. All four of these students use it at some point and two of them (Colin and Susie) make use of it as a strong theme for many (for Susie, - all) of the concept areas. Arguably, then, it is a conceptualisation of phenomena they find useful that is independant of the statements made in school science.

It is interesting to speculate why it might be useful. Tempting as it may be to look for parallels between Aristotle's natural and 'violent' (forced) events, these are not pursued here. It would seem that for these students these two
categories allow them to organise, and reorganise, explanations. They have different expectations of each set of actions and of their own confidence in being able to invoke explanations for them. To some extent this rests on their expectations of repetition and generalisable application to new situations - part of the 'rules' of the interviews. This works both ways: if an occurrence can be designated 'natural' then it can be given a cursory explanation, safe in the expectation that one need not have explanations for nature - and can carry this expectation over into other situations. It is man-made, artefactual, actions that are to be explained - and can be explained - because they are deliberately done for reasons which are supposedly known. On the other hand, there are man-made explanations they can hint at, but not provide, because they are not privy to them ('we haven't done that yet'; 'I don't do chemistry'). In this sense they might be more willing to give 'natural' explanations in their own terms (of power, speed, strength, flexibility and so on) rather than attempt complex 'scientific' explanations which they might feel are beyond them.

One problem with that interpretation of their use of natural and man-made categories is that it suggests the students opt for safe, comfortable explanations and reasons. This, however, is certainly not always the case and Colin's transcript (appendix III) is a useful example of a student using the interview to explore tentative ideas and to voice puzzles and paradoxes. However, the two categories do appear useful as a means of organising the type of explanations one might expect of it.
A second feature of these four sets of interviews is the abundant evidence for a Decoupled framework. To recall from chapter four, this framework derives its name from a study reported by Jung (1981). In the report, Jung says of a common-sense framework of light that:

'Light is conceptualised as brightness, which is the condition for actually perceiving colours through a transparent medium such as air, water or glass /....../ In this and many similar arguments the relation between light and the eye remains implicit /.../ there is a clear indication of the decoupling between seeing the mirror and receiving light from the mirror into the eye' (emphasis added)

Much of this can be read into the responses given by all four of these students. Part of it is a distinction between (pure white) light and images. It is one thing to discuss ray optics in terms of the streaks of white light from a ray box and quite another to explain seeing an image in a mirror. Light of course, reflects off a mirror, as happens when one 'dazzles' a friend by reflecting the sun into their face. But it seems far less obvious that ones image reflects off a mirror (if so, where does it appear?). The school science answer that a visual image is formed in the eye would seem too remote a description for the 'living' image on the mirror in front of you.

Not all of the responses should be seen as an antipathy between personal models and school science. As is quite clear, many responses are reconstructions of school science and examples of this are the many discussions of energy, forms of energy, the behaviour of energy and so on. Needless to say, all of those reconstructions take place in a personalised way so that Cushla's 'happening' energy and Petina's (and Colin's) 'rechargeable energy build ups'
are individual conceptualisations.

A final point of interest to be drawn from this set of interviews concerns some of the differences discernable in the accounts. None of the responses to the same card are identical in detail which, given the theoretical persuasion of this study, is entirely to be expected. For example the four responses to the iron bar (H5) can be paraphrased as follows:

Co: The burner heats the first quarter of the bar - on the outside. The other end is simply wet from the water. Heat 'reacts' with iron in various ways.

Cu: Heat is exerted onto the bar from the burner. Hot molecules move but heat itself does not.

F: Some three quarters of the bar is hot and only the end at the tap is cold. The burner reacts with the iron to produce heat.

S: Some one third of the bar at the burner end is hot, the middle third cool and the third by the tap cold. Heat spreads in one direction and cold in the other. The bar is not forcing itself to be heated or cooled.

Given that these descriptions are significantly different across the interviews, the question is, how well do they sit with responses within the interviews? The answer is that, as can be seen from figures 64, 69, 73 and 77, that they are at once both within and 'without' of the remainder of the interview. As much, of course, can be said for any of the responses to any of the cards. However it is worth staying with iron bar card (H5) as an example. For Colin, this instance marks a departure from other explanations in that he does not use it to develop the dominant conception of heat being a sensory experience. Nor in other instances does he restrict heat to local regions as he does here. However, in terms of 'reactions' taking place,
he uses this in a number of other cases (the chemicals, the ice and the flower).

For Cushe this is the only example where she discusses heat moving (if only later to contradict herself and decide otherwise). However she discusses 'particles' in other instances. Petina incorporates it, partly, into her conception of heat as 'given off' (by the burner) but introduces, for the only time, the notion of the heat at the tap end, simply 'reducing'. Elsewhere she describes it as being transmitted to the surroundings. Finally, for Susie, the bar is another example of her forced/natural conception of phenomena and yet is the most explicit description of 'moving coldness'.

The point to be made is that there is no overall general trend towards a greater unification of ideas across all instances. In some cases, students create new conceptions quite separate from previous ones; they amend on-going ones to cater for new circumstances and, in many cases persist with initial theories for as long as they can. In some situations they effectively override complicating factors and argue a simplified case, in others they introduce seemingly unnecessary developments and argue an expansive and elaborate construction. Moreover, these different conceptions can sometimes sit side by side in an interview with apparently no anomaly being acknowledged by the student. A powerful example of this, is Susie's description of exothermic and endothermic reactions followed a few moments later by iron bars not 'wanting' to be heated.
CHAPTER 7

CONSIDERATIONS, IMPLICATIONS AND EXPECTATIONS

7.0: Introduction to the Chapter

7.1: Methodological Considerations
   i) Authenticating the outcomes with students
   ii) Communicative authentication with teachers
   iii) Communicative authentication with co-researchers
   iv) A Summary

7.2: A Consideration of the Research Outcome

7.3: Some Directions for Future Research

7.4: Some Implications for Classroom Practice

7.5: A Concluding Remark
Introduction

The preceding chapters have endeavoured to explore the central themes and pervasive concerns of this study. This final chapter is an attempt to review some of these, to raise further points, and to re-place the study in a wider educational context. In broad terms the major issues concern the particular methodology used; the research outcomes and their relation to the research questions; the implications of these outcomes for future research and pointers discernible for the principles and practice of science education in schools. These issues are discussed in this order and are accorded a section each.

7.1: Methodological Considerations

In chapter 2, part of the discussion focused on the methodological checks to be employed. It was argued there that methods of justifying research outcomes in paradigm 2 research might well differ from the traditional methods of paradigm 1. The proposal in this study is that the traditional meanings of the terms reliability and validity are inappropriate in their application to the style of work accomplished here. Terhart (1983) describes this shift in perspective from paradigm 1 to paradigm 2 as follows:

'The old empiristic idea of reaching truth by a maximum correspondence between facts and concepts has been changed to the idea of gaining 'truth' by establishing a maximum correspondence between the 'naive' folk-models and their scientific description and systemisation.'
Terhart continues by accusing more recent research of solving the problem of validity by ignoring it on the grounds that 'the quest for validity is seen as a treason leading back to the old 'positivistic' obsessions.'

In this study there is no intention of ignoring the necessity to present the outcomes of the research to critical scrutiny and re-interpretation. However the traditional meaning of the term validity encompasses something to one side of this: commonly the assessment of a measure in terms of its degree of association with dimensions whose natures are, supposedly, already understood. The options are, therefore, either to redefine the term validity to encompass a broader set of 'validating' activities, or to choose a separate term which does not address validity in its narrow sense but focuses attention on a wider range of validatory processes. The first course is one taken, for example, by Bliss, Monk and Ogborn (1983) who point out that any system of description needs to be 'in some sense' both valid and reliable. They suggest that validity can encompass the notion of being 'appropriate in kind', 'complete', 'faithful', whilst reliability might include a 'good enough degree of agreement between people as to how to use a system to describe data.'

The intention here is to choose the second course. Without wanting to lose the richness and functionality suggested by a broader meaning of validity, the term still retains its overtones of prediction and measurement rather than description and interpretation. This is not to eschew the use of the term, suitably defined, in other contexts.
However, to be compatible with a study that hopes to gain insights into the 'constructed worlds' of the participants and the researcher, the 'validity' of such constructions is not at issue. Here, the term chosen is 'communicative authentication'. The position to be adopted is that:

a) it is a necessary outcome of conducting research in a constructive alternativist mode that there can be no single set of criteria by which to judge the outcomes of an interpretative exercise;

b) it also follows that the opposite pole of the notion of authentication need not necessarily be in-authentic, or false. The process of authentication is not a validation whereby failure to concur with various criteria demarcates a particular interpretation as in-valid, but rather as an alternative (if less useful) one;

c) therefore, the methodological procedures of checking and authenticating data outcomes are party to the same arguments as shaped the generation and analysis of the data in the first place. As Bannister and Mair (1968) suggest, they are 'an intrinsic part of the same argument and not a sudden breakthrough into an independent reality';

d) that a constructive alternativist approach informs methodological pluralism (Swift, Watts and Pope, 1983). That is, not only are there many varied criteria by which to judge research outcomes, but there are many methods by which these criteria can be approached, so long as they are consistent with the metaphysical assumptions implicit and explicit in the study;

e) an important criterion for the authentication of
research must be the utility of the outcomes to both the researcher, the researched and the appropriate interested community. The outcomes must be more than just ends in themselves and some attempt must be made to assess the possible consequences of their proposed use; f) it is incumbent upon researchers in such inquiries as are encompassed by paradigm 2 to test out their hypotheses by generating and developing different ways of evaluating the significance of their research outcomes. The 'box of tools' (Swift, Watts and Pope, 1983) available in the field is still short of varied yet appropriate instruments.

Much of what has been said of validity can be applied to the term 'reliability' as well. In this study, for example, the interview is not intended as a closely replicable 'reliable' test instrument nor, given the basic assumptions of active personal construal by the students involved, would that be an obviously useful avenue of approach.

Bliss, Monk and Ogborn (1983) do offer some guidelines, which are that a system of description:
- be judged within the terms set by the mode of research within which it is embedded;
- give a description of data intended (that is, intended by the analyst) and be judged by how well it fulfills the analyst's intentions;
- should be clear and complete enough for its purposes: it ought not to leave obvious relevant holes;
- should be self-consistent, not allowing self-contradictory or absurd accounts of things;
have a level or grain of detail that matches the task, given that it is best if concise;
- be understandable and learnable;
- should avoid clumsiness of expression;
- should be fitting, give a faithful rather than a distorted picture;
- should, in some significant sense, transcend the original, to describe data as something rather than merely repeat or copy it.

Such an approach to the justification of research is sufficiently different from paradigm 1 accounts of reliability and validity as to deserve renaming. Here, the term 'communicative authentication' is chosen in the sense of a process of establishing and attributing credence for a piece of work and as a process of facilitating the generation of alternative interpretations. Thus it is not justification in a passive sense but a dialogical engagement with the participants to explore the interpretations of the data.

There is no suggestion that the activities to be described are comprehensive, complete or in any sense a finished and polished 'product'. They do, however, represent an exploration of the views of three groups of people on how far, and within what limits, the research outcomes are seen to be feasible. At a personal level, this means checking that the interviewer has managed to avoid misinterpreting or misrepresenting the responses of an interviewee. At a more public level, it means generating debate as to whether the reported research outcomes (in terms of frameworks)
are credible, coherent, functional and, in some cases, utilitarian.

Terhart (1982) gives three general criteria for considering the success of such a dialogical authenticating exercise, that:

- the production of the data and the research process itself be lucid and understood by all its members, including its subjects. This 'communicativity' is similar to some of the criteria used by Bliss, Monk and Ogborn (1983) above;
- the results gained should enhance the consciousness of all those involved in the research process, and make visible its implicit rules of action and routines. That is, interpretative research aims at the lucidity of the implicit grammar of educational processes, a notion Terhart calls 'transparency';
- the transparency of structures must be displayed in such a way that it is possible to draw out consequences. This suggests that above being a subtle description of the processes in question the results have to be action-able. Terhart calls this 'intervention.'

One potential line of approach to authentication, then, might be one that observed some of the check list guidelines of Bliss, Monk and Ogborn (1983) and might be evaluated as to their appropriateness by Terhart's (1982) criteria. As suggested earlier, the three audiences adjudged to be relevant are the researched (the students involved), the possible users of the outcomes (science teachers) and interested members of the research community. In the

7.6
discussion of the processes of communicative authentication used here, these three groups are discussed in this order. It needs to be said that the chronology of events differed from this, a point to be taken up in the summary.

i) Authenticating the Outcomes with Students

There are two levels at which authentication can take place with the students - at the level of their own conceptions and at a level of constructed frameworks. Both levels present their own advantages and difficulties.

The first involves an attempt by the interviewer to re-present the conceptions argued for by an interviewee, during a particular part of the session. The intention is both to summarise some specific set of pronouncements and to gain comment from the student on the interviewer's interpretations of their arguments. This strategy is described at the beginning of the interview when outlining the task and commonly follows the pattern established in the following (interviewer's) extract:

I and then one of the questions I'll ask you is if I've got it or not ... I'll be trying to work out if I can see what you mean and some times I'll try and sum it up . what I think you've said . and if sometimes you don't agree that that's what you've said you'll have to tell me . say 'I never said that' you know . because sometimes I don't quite get what people mean and might go away without properly understanding what you meant to say...

During the conversation the interviewer signals this process by (typically) saying 'hang on a moment . let me see if I understand what you're saying'. In the following extract J (J,3H) is conceptualising heat as being either 'artificial' (as in chemical reactions or
chili powder) or 'natural' (as in body-heat or a burner flame).

**Extract 130**

I. aha. okay. can I see if I've got you right! you've got some /cards/ as natural heat and this one /pepper H8/ you call this one artificial do you?

J. because that one is like an artificial heat and so is this one /chemical reaction H2/

I. I see and have I got you right about the natural ones?

J. yes... I'd call that one /ill, H1/ natural. ill in bed. and these are natural. they're kind of. they come from us so they're natural but these are made up. and so's that one /Ice, H6/ so I think them three should go together. /in one pile/ (J,3H)

On some occasions, students take the opportunity to deny or amend the interviewer's summary, however, the majority of such summations (on average four or five in a forty minute session) are similar to that above. An ammendment, for example, might take the form:

**Extract 131**

I. ... have I got it?

C. well it sounds different when you say it like that. I mean its almost like that but there are other things as well and you have to mention those

I. oh what sort of things? (C,4H)

In both of these extracts, whilst there is (almost) agreement on the interviewer's interpretation of meanings, it is rather more the case that the summary serves as a point for elaboration or further description. Whereas the
interviewer is searching for some check on similarities between constructions, the interviewee makes use of the opportunity to secure the argument and 'drive it home'.

The advantages of such an authentication process are that it allows some clarification of conceptions at the actual time of their presentation - an attempt to test out constructions at the point of issue. That the student uses this as a platform for consolidating the conception is not a disadvantage unless there is no disagreement at all. That is, if the roles of the two participants are perceived as such that the student will not contradict or dispute the interviewer's representations. Whereas there are examples of this, more so with students in the youngest age groups, there is ample evidence of 'differences of opinion' in the majority of interviews to allow some modicum of confidence in the interviewer's eventual interpretations.

The second level of approach concerns some authentication of the constructed frameworks from a number of transcripts. In practice this has taken on a more elaborate procedure than that described above. It has revolved around a questionnaire concerning the frameworks from each of the concept areas. An example of one such questionnaire (on the energy frameworks) is shown in appendix II. The questions for each set of frameworks follow a similar pattern. As can be seen from the energy example, the first page is a set of instructions. These are presented as follows:

'On the following pages you will find some of the sorts of things that young people in school might say about the word energy. Their discussions of
of energy have been summarised by seven different statements, one on each page. I would like to know how you react to each statement. Under each one, are some extracts from their talk that could be examples of the statements. There are also some pictures of what is being talked about.'

The statements are non-technical summaries of the frameworks, the extracts are 'tidied' by the inclusion of punctuation and capital letters and the pictures are reduced versions of the relevant IAI cards. The instructions continue by requesting:

'Please read each statement and write a brief note of your reactions in response to the following three questions:

- Do you find it believable? That is, do you think these are the sorts of things that young people would say?
- Is it sensible? Does it make sense for someone to talk about energy this way?
- Is it a useful way to talk about energy?'

The three questions stem from an attempt to tackle Terhart's 'transparency' in the particular context of this research. That is, it is a process of going beyond some interpretation of students' 'inner worlds' to generating a dialogue (between the interpreter and the interpreted) concerning the plausibility of the interpretations. The purpose is threefold:

- to assess the credibility, sensibility and utility of interpreting concepts (and students' responses to them) in this way:
- to sharpen the presentation of the research outcomes;
to develop further insights into other interpretations of the same phenomena.

Whereas in some cases (discussed later) the frameworks have been presented in full along with sample transcript material, here it was thought necessary to 'decode' the frameworks into the framework-statements on the questionnaire.

These have been used in three distinctive ways. Firstly, students have been asked to complete the task as a written questionnaire to gather individual assessments of the frameworks portrayed. Secondly, and most commonly, they have been used as a basis for interviewing individual students. Thirdly, and in one case only (for energy), they have been used as a focus for a group discussion without an adult present but whilst being videotaped. In the first two cases, the students who responded to the questionnaire have been students previously interviewed about the concepts.

These procedures and the responses gained are discussed in this order below.

a) The students' written responses

It needs to be said that this was the least successful approach to gathering responses to the frameworks. In all, nine energy and three each of force, heat and light questionnaires were used in this way. They were all used with year 4 students, bar two energy questionnaires, which were used with year 6 students. The responses received in this way were cursory, often in the extreme. Few gave any other response other than a 'yes' to each of the questions (some simply ticked each one). The energy
questionnaire was prepared and used first, and from that point it became quickly apparent that its use as a simple written exercise was flawed.

One notable exception to this low level of response is on one of the energy questionnaires where a year 6 student made an attempt to provide fairly detailed responses. She answered for all of the framework statements that they are believable - that they are the sort of statements one might overhear someone else saying. She made one exception, to statement 6, where energy is said to be associated with machines. She noted that this might well be what 'young boys' might say, but that it was neither a sensible nor useful way of talking about energy. Of the others, she suggested that they are all in part both sensible and useful but are rather 'limited' ways of talking about energy.

b) The questionnaires as a basis for interviews

Given the shortcomings of the first approach it was decided to continue to explore this process of authentic- ation by adapting the questionnaire for use as a basis for interviews. The interview's were conducted in a manner similar to the concept interviews themselves, that is, in an anteroom to the classroom, one-to-one and audio-recorded. In total, four energy and three each on force, heat and light frameworks were conducted. The interviews on the whole are of much shorter duration than the concepts ones - being about 15 to 20 minutes long.

There are two main categories of response detectable in all thirteen of the interviews. The first concerns comments about the interviewee's own conception of energy,
force, heat and light. The second concerns their comments around the framework - statements as attributed to other students. For the first of these, it is quite clear that students find great difficulty in commenting upon other people's statements without raising, structuring and developing their own conceptions. Their own conceptions are then used as a backdrop against which to judge the framework-statements. That is, they are often unwilling to attempt a disinterested scrutiny of the credibility, coherence or utility of someone else's argument. The evidence of these interviews is that they prefer to make such judgements as and when other students' arguments interact with their own. This aspect is more pronounced when disparities occur, rather than in agreement with the statements. In the latter case it is more difficult to decide whether the students see the framework-statements as credible, sensible and useful because they themselves would use it, or because they see it as useful for someone else to argue in that fashion. In disagreeing with the statements, however, they are more inclined to point out its shortcomings by reference to their own conceptions. For example, B is a year 4 student discussing framework-statements about force. In this example B is discussing a short statement of the Operative Force framework (O-F):

\[ '\text{Force is an action: the amount of force is related to the amount of activity taking place.' }\]

In response to this B says:

Excerpt 132

B .... yes I .. I understand what they're getting at. you know they sort of think of it as things happening and the more force there is the more things are
happening. I mean I can believe someone would be actually talking about it like that ..

I. you see what they're getting at

B. I think I do . I mean I wouldn't say it like that but you can see why someone else might ...

I. does it make sense to talk about force that way?

B. in a way it does you know where there are lots of things going on there must be some forces there but I think there's some force there too ./a person holding a balloon; card F12/. I mean he's holding the balloon but he's not doing much .. I think there's force in him

I. so is it a useful way to talk about force?

B. well it is in a way but it doesn't cover everything I mean its useful because it can be understood and people know what you're talking about ...

In this example B has reservations about the sensibility of the statement only in that it is a partial description of force and fails to encompass his own view that force would be designated to the person (evidence for a Designated Force (D-F) framework).

A second example is taken from an interview about the energy frameworks. E is a sixth year student who is discussing the last statement on the energy questionnaire - about the 'flow' of energy. In the questionnaire the statement reads:

'Energy is something that can flow from place to place. It can also move from one object to another'.

Extract 133

E responds as follows:

E. ... I think it's quite a useful way of describing it I suppose . I mean it doesn't actually flow (laughs) in the literal sense but ... umh .. electrical energy .. that would be a good way of describing it . the
battery and the bulb and all that and the energy goes through him to the box (laughs) it does in a sense I mean I suppose youngsters talk about energy like that. that'd be the way they'd describe it

I. do you find it believable?

E. yea I can believe somebody would say you know ... a child would say that. yea..

I. do you think it is a useful way of talking about energy?

E. ... yes I think .. well .. in the case of electrical energy it is because I mean it's sort of flow of electric and electrons ... I'm not sure about things like light and heat .. that's a bit more difficult

I. and does it make sense to talk about it in terms like that. in the case of the box for instance?

E. no (laughs) not really ... no it's because ... you've pushed and got energy into the box and sort of give ... you transfer some of your energy .. to make the box move .. I mean you don't actually .. oh I don't know ... maybe a child or a youngster might see it that way I mean they might understand it like that I mean pushing the energy through them into the box .. it could be I suppose ... ..

Here E is unsure as to whether or not her own notion of energy transfer is the same as a flow of energy. Although she says that it is not a 'literal' flow and that it is not 'actually' the case, she is not at all sure how her own notion of 'transfer' differs from that of the statement.

These two extracts are also useful in pointing up the second category of the interview responses - comments directed at the statements themselves. These can be seen to fall into three groups - full agreement with the statements, partial agreement and no agreement at all. Of the thirteen interviews, seven responded positively to all of the frameworks. This is taken as evidence that these students could identify with the researcher's analysis and re-presentation of typical statements about the four
concepts. They could accept, too, how those statements might have been made in a serious attempt by other students to use the concepts during explanations of the situations depicted. In the remaining six interviews (2 energy, 2 force, 1 heat, 1 light) some of the statements met with only partial agreement and some were disputed. Examples of partial agreement are illustrated in the two extracts above. In all cases, the point was made that various statements were inadequate as a full description of the concept in question although it served to describe some aspect of it. This is a pertinent comment. Given the description in previous chapters of how the frameworks have been constructed, and how they can be seen to be weighted towards different question types, it is likely that they might be seen as only partial in their description of a concept. As has been pointed out at several points, because the frameworks are not intended as all encompassing descriptions, they are likely (quite rightly) to be seen as descriptors of one line of argument. These comments then, are not taken as evidence of the unrepresentative nature of the frameworks (or the statements) but of the recognition by students of the limited range of convenience and applicability of the frameworks.

The frameworks most discussed in these terms are as follows:

Energy: I-E; O-E; P-E; F-E; T-E
Force: C-F; O-F; S-F
Heat: N-H; P-H; R-H
Light: A-L; C-L; I-L

7.16
The third level of comments concern student disagreement with some of the framework statements. An example of this is given below, where M, a year 4 student is discussing one of the energy statements. It says:

'Energy is to do with machines where there are no machines switched on there is no energy.'
(Statement 6)

M responds to this by saying:

Extract 134

M. ....... no I don't agree with it (laughs) no .. no I think that's a bit of rubbish really (laughs)
I. I see (both laugh) .. in what way?
M. well it's sort of silly
I. do you believe that someone would say that sort of thing?
M. they might. but then I'd say no they're wrong
I. do you think it would be a sensible thing to say?
M. .... well it all depends on what you're talking about . what kind of energy . energy as a whole . no not really because I mean light sound heat that isn't really anything to do with machines
I. is it a useful thing to say?
M. no . I'm not happy with that one it doesn't help you to think of energy just with machines

A year 6 student, L gives a similar response, as follows:

Extract 135

L. ... energy isn't to do with machines necessarily . it has something to do with them ... and the second statement doesn't sound right as well
I. not the second statement
L. no . a machine can have energy even if it's off . it's difficult to think that someone would say it's /energy/ just about machines when you've got fires and the sun and that
I. I see .. do you think it makes sense at all?

7.17
L. well in a way .. I'd understand how they thought of energy but I wouldn't agree with it .. it isn't very useful. I suppose either. I'd want to correct them and say what about other things' all the time...

These extracts highlight the fact that it is possible and worthwhile representing outcomes to students, that they are able and willing to comment upon them, and that they can make their opinions clear to the researcher—particularly in an interview situation.

c) **Video-taped peer discussions**

This aspect of the process is noted here for completeness rather than for comparison. As an adjunct to their main study on children's perceptions of energy, Gilbert and Pope (1982) used the energy questionnaire as a basis for group discussions of the framework-statements. After an introduction to the task the students were left to discuss the questions without an interviewer. At this point of writing the resulting videotape data awaits a detailed analysis by the original researchers and so specific comments are not possible.

From a number of brief viewings of the tapes, however, it is possible to say that in general, the data is consistent with Gilbert and Pope's (1982) analysis of peer group discussion about energy itself and with comments made above about the use of the framework questionnaire. That is, youngsters are able to empathise, if not sympathise, with the framework-statements (and the included extracts) often on the basis that they represent credible—if partial—descriptions of energy.
Before moving on to the next phase a general comment is worthwhile. Magoon (1977), in reviewing constructivist approaches in educational research, argues that researchers need to take the constructions of participants seriously if the discipline of educational research is to be 'reasonably comprehensive and self critical as a scientific endeavour'. Communicative authentication with these student participants has shown that the critical process is both possible and worthwhile.

ii) **Communicative Authentication with Teachers**

Authentication with teachers has taken a different approach to that described above: based on group discussion rather than individual interviews. A small group of four science teachers were asked to consider the frameworks in each of the concept areas in turn. These were discussed within the group so that the teachers made themselves familiar with the frameworks, the research technique and the purpose of the exercise. They were then provided with a short (3 page) extract from four separate interviews, one each on energy, force, heat and light. They were asked to discuss each of the transcript extracts in terms of the relevant frameworks. The teachers are all experienced (London) teachers (more than three years of physics teaching), the session lasted some 2½ hours; and notes were taken on the discussion (it was not audio-recorded).

Once described, the process of generating the original transcript data seemed to be taken on trust (without query) and all four teachers took the remarks made by students as
credible. In this sense the authenticity of the database was not questioned - in some cases it was supported by anecdotal evidence provided by the teachers themselves. The majority of all the frameworks in each of the concept areas were accepted as being cogent summaries of the responses made by students, particularly in relation to those frameworks which could be evidenced from the sample transcript material. Five frameworks (one in each of the concept areas, two in light) did generate debate: Produced -Energy; Configurative-Force; Normal-Heat; Composite-Light and Modal-Light. It is important to note that none of these frameworks were evidenced from the sample transcripts. In most cases the debate was concerned not so much with the frameworks as a pithy articulation of a common viewpoint, but rather with the style and reasons for students' responses that gave rise to the framework. Typically the questions asked of the researcher were 'what sort of things were said in the interview?' and 'what would prompt the student to answer in that way'. Rather than challenging the framework as an interpretation of the data it was more an act of trying to see how such responses might have come about.

In three cases the frameworks were challenged. The configurative force framework was felt to be too broad; it attempted to summarise too wide a range of responses. In part this criticism stems from the discussion above and the researcher's reporting of typical responses as evidence of the frameworks. Composite-Light and Modal-Light were also debated at length. Much of the discussion centred on whether or not the division between the two

7.20
frameworks was 'forced' or not. In contrast to the Configurative-Force discussion, it was felt here that perhaps the two frameworks were overly constrictive. A good deal of the latter part of the discussion on all of the frameworks was taken up with debating common curriculum approaches and teaching points - whether or not they 'compounded' students' conceptions or not. In this context the frameworks were felt to be an invaluable source of information on likely individual conceptions in a class.

The debate as a whole has resulted in two outcomes. The first is a degree of confidence concerning the clarity and communicability of the frameworks to classroom practitioners. The frameworks, the data, the purposes of the methodology and the intentions of the analyst can all be communicated - and handled - by others so that constructive criticism can emerge as a consequence of discussion. The second outcome is that the researcher undertook a considerable re-examination of data and frameworks, resulting in a tighter, clearer, more economically worded description of frameworks in relation to the transcripts.

The advantages of such a process of authentication are much in that vein; it allows for some credibility of the frameworks to be established or contested, it allows the researcher to portray the mode of research within which the frameworks are embedded, it focuses debate on the 'fit' of frameworks to data in terms of commission or omission, it highlights the comprehensibility of the frameworks by others, and gives some indication of the utility of the research outcomes to the possible users. The disadvantages are the
it is difficult for people other than the analyst to make
judgements of categories on the basis of a small amount
of data, and yet a substantial amount of data is both
unwieldy and time consuming. Certainly by bringing a
particular audience together to consider research outcomes
as a group, rather than approach them singly, means that
the session is richer in the cross hatching of ideas and
can therefore cover only a small amount of data and inter­
pretation of frameworks in any depth and detail.

iii) Authentication with Co-Researchers

This has taken two main forms using frameworks from
only two of the concept areas. Both forms of the approach
have been with members of the Personal Construction of
Knowledge Group at the University of Surrey, both working
sessions of some 1½ hours duration. The first, on force,
followed a similar design to that discussed earlier for
teachers. The force frameworks were provided and discussed
although in this case, the people present (11 members of
the group) were already fairly familiar with the methodology
and purpose of the research. Each person was then provided
with sample transcript material from three separate inter­
views and asked to code the responses towards the provided
frameworks. The process was audio taped by permission of
the group. The latter part of the discussion was taken
up by focusing on one or two issues in the procedure.
The data was left with the group members until a short while
after the session to be completed and returned to the
researcher. All were returned within two days.

The outcomes of this process can be described as
follows. Specific comments concerned with attributing responses to certain frameworks met with a high degree of agreement. Most of the differences of opinion lay more with attributing certain responses than with the formulation of the frameworks themselves. That is, they were disagreements about interpretations of the intentions of the speakers and not so much with the wording of the frameworks. The overriding comment was how similar responses were in the three transcripts therefore how the task of attributing the responses grew easier with each one. The three were not originally chosen on that basis but were part of a batch of transcripts which had only recently been analysed and were, so to speak, on the top of the pile and so easily available. They were all from year 4 age group interviews, two female, one male.

Some general comments concerned the transcripts and the responses of the students in the wider context of science education. It was noted, for example, how unwilling (or unable) students are to differentiate between force, pressure and gravity, gravity and weight, force and energy etcetera. It was also noted that students seem quite willing to use 'thought experiments' to clarify their own thinking. A further point focused upon the consistent and widespread anthropomorphism in the responses. A final point concerned the interview itself being a 'learning event' and therefore not open in a straightforward way to traditional approaches of replicability.

The second approach to authentication with co-researchers used a similar working session, of similar duration, but this time with the energy framework questionnaire discussed
earlier and shown in appendix V. Again, the exercise was introduced by a short discussion of the task and its context, and the session was then spent by the group responding in writing to the questions. Nine questionnaires were returned at the end of this session before a general discussion on the activity itself. As before, the framework statement most singled out for comment was number six concerning energy related to machines. In contrast to the other statements this was seen to be the most unbelievable, unlikely and limited framework. Only one of the nine returns suggested that they might 'see how children could think this way from experience.' The other eight very much thought it was a 'rogue' statement and some hinted that it was a deliberate strategy by the researcher to insert into the questionnaire a clear 'non-example' of students' frameworks. All of the other framework-statements met with both agreement and approval in the sense that they were taken to be authentic re-presentations of students' frameworks.

General comments within the group about the authentication procedure were mixed. It was seen to be a viable means of gaining perceptions on the outcomes from interested people only where they are prepared to make extended written responses. Otherwise it seems much more appropriate as a focus for individual or group interviews.

iv) A Summary

The methods used in this study for authenticating interpretations of the data bear little resemblance to the
traditional methodologies of educational research. A plurality of methods have been used to generate dialogues with relevant audiences concerning the interpretative outcomes, and the process of 'communicative authentication' has been explored in action. The order of presentation has not been the order of events and this is an important point. The discussion of the force frameworks with the research group preceded all of the other work with the exception of the summarising and representation of argument during the course of the student concept interviews.

Much of the discussion and comments which resulted from the discussion session with co-researchers has helped to shape the generation and development of the four framework-statement questionnaires. These in turn have been adapted for use as interview schedules after their initial use with students as written questionnaires. That is, the methods have evolved over time in response to critical scrutiny and dialogical argument.

The fruits of the exercise can be seen in the light of Terhart's (1982) criteria discussed earlier. The communicativity of the process of data production and analysis has met with very few obstacles. In some senses this has been eased by taking the research outcomes back to students who have been through the data gathering stage - even if they have been asked subsequently to comment about outcomes in concept areas different from their own interviews. In this context the co-researchers, too, have been familiar with the style and operation of the research. It is important, then, that the teachers (as the audience most removed from the research context) quickly
accepted the basis and conduct of the research without debate and instead focussed comment on the outcomes and the authentication process.

Two main comments about the process of authentication can be noted. The first concerns a strong statement by both teachers and co-researchers that the enactment of a similar process with students, whilst desirable in principle is doubtful in practice. The reason given is that one could never be sure that agreement reached between student and researcher is trustworthy. It was argued that because the relationship between researcher and researched is not equivalent when this is between student and adult, then social roles play a part in distorting perceptions. That is, students will agree, or fail to disagree, simply because of their perceived subordinate position.

This argument, coming as it did before the use of the questionnaires with students, did not concur with the broad basis to be employed in this study. Some evidence to counter the argument - to indicate that students (particularly older ones) are both able and willing to debate interpretations of the interview data - has been given.

The second comment concerns the frameworks and the framework-statements used in the questionnaire. The frameworks themselves have generally been quite straightforward in terms of their communicativity with notable exceptions (already mentioned) where some minor re-phrasing and re-shaping has taken place as a result of dialogues with teachers and researchers. The concept-statements, however, have been subjected to greater debate.
The process of de-coding the frameworks into pithy summary statements has in some cases resulted in too great a dislocation from both the frameworks themselves and the originating responses. The decoding itself has been criticised as disembodying the frameworks to such an extent that it invites confusion as to the purpose of the task - is it to judge the students who might have said such things, the framework - statements or the frameworks themselves? Moreover, pithy framework-statements open the possibility to missing the essence of the framework and therefore of either being summarily dismissed or not allowing critical appraisal of the framework itself. This is taken to be the case in the discussion of statement 6 of the energy questionnaire. Whereas the Functional Energy (F-E) framework is readily summarised and evidenced from a range of transcript responses, the framework-statement used may have had the effect of rendering the framework unrecognisable.

This is a dilemma for this style of validatory activity that remains unresolved. The mechanisms of decoding from constructed research outcomes to more available representations are essentially explicative. Within this explication, as the complexity of the outcomes is reduced so the risk of minimalising their import increases. To interpret data in a way that resulting descriptions transcend the original might often require some re-description to make them available to differing audiences - with the attendant risk and vulnerability to dismissal.

However, the enterprise is not geared to consensus but to debate, and the approach adopted here is taken as
a qualified success. The quality of comment generated from all three audiences - as evidenced by the example extracts - has allowed shaping to take place on the emphasis, wording and presentation of the frameworks in chapter 4. Clearly, it is important that such an authentication process take place alongside the analysis of data (formatively) rather than at the very end as a one-off summation.

Terhart's (1982) notion of 'transparency' is less easy to evidence as a criterion of success. There is a very strong suggestion from each of the audiences (and most particularly from the students) that the procedure did raise awareness of their own conceptions of each concept area. In this sense it can be said to have enhanced the consciousness of the participants not least when making such remarks as

'I hadn't thought of heat that way before' (student, year 4)

'I don't think of it /force/ like that but I can see how some of them would think that sort of thing' (teacher, about student frameworks).

In this sense transparency can be seen as a growing appreciation of other viewpoints (as represented by the stylised frameworks), an appreciation of the very essence of constructive alternativism.

The application of the frameworks to school science - their facility for intervention - is as yet untested. This is a point to be taken up later. In this case the most appropriate audience to judge (the teachers) were unanimous about the potential of the frameworks, even if they were less than clear as to how best operationalise
that potential.

7.2: A Consideration of the Research Outcomes

Much of the early work of this study within the first few chapters has been to establish the field of enquiry and the terms in which the discussions have taken place. Much of school science is broached in terms of concepts and it has been necessary to make a distinction between the concepts in the public-collective domain and the personal conceptions of individuals. The latter have been portrayed as actionable processes in the intentional internal organising of experience that are endemic to human affairs. They very much resemble Vygotsky's (1962) sense when he says:

'A concept is not an isolated, ossified, changeless formation but an active part of the intellectual process, constantly engaged in serving communication, understanding and problem-solving .... concept formation is a creative, not a mechanical passive process; a concept emerges and takes its place in the course of a complex operation aimed at the solution of some problem, and the mere presence of external conditions favouring a mechanical linking of word and object does not suffice to produce a concept.'

This approach to concepts has engendered a number of pervasive streams of emphasis in the work, which are as follows. Firstly, there is a strong leaning to a relativistic view of knowledge. The 'changing format' of knowledge is not something that takes place simply through the gradual veering of time but is alternatively constructed by people in a manner that is dependant upon their vantage point as theory builders.

This aspect of the approach is illustrated from the individual conceptions which are detailed in chapter 6.
Intuitive and implicit ideas on the nature (for example) of light are articulated to solve the problem as posed by the students' own perceptions of the instance cards. Selected snippets of previous experience; fragments of public knowledge from lessons, text books, television, hearsay; all combined with attitudes and interests, are synthesised to find a solution to the task that confronts the student. For Colin, for example, the need to account for images on screens (projector and television), the notion that these involve light, which in turn travels at a colossal speed, the vague workings of television transmitters and receiver circuitry, are coalesced to form a conception of light that can be projected and yet slowed (to 'normal' speed in the television) and stopped (on the projector screen). Other such conceptions about energy, force, heat, molecules, gravity, pressure and so on illustrate this active creative process admirably.

The abundant diversity of responses to each instance card has made the most obvious strategy, of simply categorising responses, inoperable. In Kelly's (1970) words, the 'wit and imagination' of the students' alternative constructions is such as to preclude a direct collation of accounts. The frameworks are at a separate level of interpretation of the data, based on the cyclic process of analysis described in chapter 2, and are in terms of 'modes' of light, 'regionalisation' of heat, 'affective' force, 'depository' energy and so on. They are an interpretative device that has been a means of coping with the notion central to Kelly's theory: that people construe situations in a wide variety of different ways depending on
their needs, imagination and the courage of their (in this case, linguistic) experimentation. The emphasis has been upon the very breadth of contextual variation of meaning employed by these youngsters.

Secondly, this approach (and the emphasis of the study) leaves open the question of the durability of either conceptions or frameworks. How long lasting, for example, is Colin’s conception of light, is difficult to say. The design of the study has not allowed for re-interviewing on the same concept area (with the same, or equivalent, cards) and so the issue cannot be approached directly. However, some points can be made. For instance, Susie’s conceptions of ‘natural’ and ‘unnatural’ (or ‘forced’) entities are ones she retains for some two years and over four concept areas. They serve her throughout her O-level physics work and into her A level studies. In contrast, some of her other conceptions do not re-emerge even within the duration of a single interview. Clearly, some conceptions are much more relevant and/or useful than others. As with Colin’s conception of pressure (which increases with height) conceptions are put forward at a particular moment in an interview so that they offer a good chance of both accounting for the phenomena and of potentially coping with others yet unseen.

One point to be taken from this is that conceptions will last for as long as they are found to be useful. And utility may well be more a function of the purposes to which the conceptions are put (communication, understanding, problem-solving) than simply of time. It emphasises
Kelly's (1969) notion of the 'tentative utility of /.../ constructions' which he suggests are tested against 'such ad interim criteria as the successful prediction and control of events.' Petina's main conception of energy in chapter 6 can be seen much in this vein. It is useful because it allows her to cope with a wide range of the instance cards (batteries, ghosts, food, sledges, etcetera) successfully and yet it is tentative in that she shapes it during the progress of the interview and does not rely on it for all of the instances. In this case, Petina's main conception lasts throughout the interview and it remains an open question as to how long afterwards she will find it useful.

A further point to be made about Petina's 'energy', Colin's 'light' or Susie's 'force' is that these are strong and pertinent conceptions as they are being used. They are not seen as a lapse, or as a retreat into a more primitive form of account in comparison with school science. It is their way of making sense of what they know and what they have been taught and it runs parallel and in some cases, complementary, to their other more scientifically orthodox conceptions. As Zylbersztajn (1983) so aptly points out:

'The fact that some pupils fail to align their views with those of 'curricular science' does not mean that they are less intelligent than the ones that do. It could be that they do not have compelling reasons for changing their current views if these, from a personal perspective, enable them to cope with everyday life situations.'

A similar point can be made about frameworks. In that a framework is a constructed type and belongs to no one individual then the durability or stability of frameworks cannot be discussed in the same terms as conceptions.
However, the tables in chapter 5 provide some suggestion that certain frameworks (particularly anthropomorphistic and anthropocentric ones) are not so in evidence in the year 6 group. An interpretation consistent with what is said above would be that this group of students see this as a less useful way of accounting for situations than others and so the responses that evidence the frameworks are less frequent. It is clear, however, that some year 6 students still do find this a useful way of discussing, say, the force on a golfball.

A third and major part of the study is about the interlacing of the relationships between conceptions. The complex multi-level overlaps in meanings emphasise the notion that personal conceptions are not solitary isolated entities, but, though bounded, are fluid and protean. The meanings held for each of the concept-labels are sustained, shaped and balanced by a web of interrelated conceptions. It is not that students fail to differentiate terms, or to integrate previously diverse notions under one label. Their differentiation is made on a different basis (things have force if they are alive, large, or moving, etcetera); or across different lines ('natural' energy, 'forced' energy for example). Similarly, the integration of various elements does take place but based upon a wide variety of contingencies.

This strongly militates against an all-or-nothing view of conceptual development. As conceptions are being forged around one particular term, so other words are used to store up its meaning, words which are left suitably
vague at the time of use. Force is 'a bit like pressure'; 'is a kind of energy'; 'has power'; 'is the strength something has' are typical statements. On balance the tables in chapter 5 show a growing differentiation of terms so that, for example, light and energy are more often seen to be separate and yet related with increasing age group, particularly so between years 3 and 4. This indicates a growing awareness to both place semantic constraints on a particular word (to sharpen the focus of convenience) and to organise the relationship between them (mark the ranges of convenience). There are several possibilities as to why this might be the case. Part of the semantic constraints might be to realise, for example, that the verb form (to force, to light) differs in substance within science to the noun (a force, light) and that this difference is significant. Part of the greater organisation of relationships might arise because of the growing appreciation of a larger number of discriminations (net force, centripetal force, police force; red-light, neon light and so on).

Two points can be drawn from this. The conceptions that students use in responding during the interviews both shape, and are shaped by, the words that are used. In the former case, the exercise of advancing an hypothesis concerning the nature of, say, heat in relation to the IAI cards may be a new experience for the student. In this case their meaning for the word is shaped, differentiated, and integrated in his/her system of conceptions in a way that might not have occurred explicitly before. In the latter case, their previous meanings for the word (and experiences of it) quite clearly shape the way in which it is used


during the interview. This process of semantic development applies not only to the target word, but to all the supporting terms as well. Whilst heat may be the word under discussion, other words (temperature, radiation, conductors etc) are used functionally to generate a 'total' meaning to be expressed: a process that might be called 'constructive formulation'.

An analogy for this exercise might be an attempt to cross a river with insufficient materials to build a bridge that would reach from one bank to the other. At each stage a small island is constructed by disassembling the structure previously assembled to reach that point, and re-constructing it to advance the journey a further stage. The elements from which the fabricated island is made remain much the same in each case yet lessons are learnt from each previous assembly and new ideas are tested in each move forward. In terms of the responses students develop during the interviews, it is not always clear where, or how far, the other bank is. Therefore, some of the resting places need to be fairly durable in order to form a substantial platform before continuing - allowing some retreat to a safe base.

Some of the safest and most durable bases are tried and tested constructions which, in the course of the interview, are being subjected to both internal and external examination. To be consistent (to have continuing utility in the face of new situations) a conception must also be related to other conceptions so that it makes sense within a larger whole. This is not to say that, as has been shown in chapter 6, a student might not use a number of apparently incompatible conceptions to structure similar sets of situations. As was mentioned earlier, it is this individual
diversity that supports both Kelly's (1955) notion of constructive alternativism and his fragmentation corollary.

An example element from the supporting structures used in a large number of interviews is the term 'power'. It is a word that is used functionally as part of the account for numerous instances. In only one or two interviews (at year 6) was it given its orthodox school science definition. Even in these cases this was not strictly adhered to, rather it was used in a general sense to support descriptions of the cards and of the target concept. Throughout the interviews all of energy, force, heat and light are seen to 'be a form of power', to 'need power', 'use power' or 'have power' and so on.

This very much impinges upon the fourth major emphasis of the study which is the use of the interview as a data gathering instrument. Part of what has been said can be seen as a consequence of the tasks inherent in the interview, which is not only for students to describe and account for situations, to articulate their own conceptions both in terms of the instance cards and (implicitly) those to follow, to draw out expectations in terms of a particular concept-label, but also to justify and elaborate on their answers. This is Harré's (1982) appropriation and catachresis in the context of these interviews. Put this way, it seems a daunting set of requirements which, on the whole, students undertook without overt reluctance or mistrust but with diligence, flair and assurance.

One aspect of this style of interview is that it is linear. That is, in most cases, the IAI cards have been discussed one at a time and then grouped together in some
appropriate way. An alternative approach might have been to ask for the pictures to be sorted first and then discussed in terms of individual cards and the piles they are in. Such an approach might allow students to anchor their conceptions and to defend them by such a compositional strategy. The linear model that has been used contrasts with this by asking students to begin to shape explicitly their conceptions from the very first card, to initiate their preferred web of meaning from the outset. The question at the heart of this is, of course, which method (if either) is the best to draw the students into making explicit the understanding they have? They are not under any requirement to reveal their personal theories (in this light it is of immense credit to them - and relief for the interviewer - that they do so, so freely) and it may mean that differing approaches might suit different students. As an hypothesis (because there has been no attempt to find out) Cushla may well have benefited from a different approach whereas Colin (witness the transcript in appendix III) seems to have managed extremely well on the format used.

7.3 Some Directions for Future Research

Seven distinctive directions for further work are indicated here as developments of this study. The first revolves around the general stance adopted - of a second order enquiry within a paradigm 2 tradition. The balance between first and second orders, and between paradigms 1 and 2, is far from equitable and much more work is required in order to gain some understandings of personal meanings.
in many spheres. Systematically following learners' activities, and inviting them to discuss their actions and their impressions at the time of acting, will bring a closer understanding of the learning process. Important though this is for science education it is important too, for many other aspects of learning. However, within science alone much needs to be explored in terms of the learning that takes place in relation to the reading of science texts, to the writing of science (and of learning experiences within science), to practical work and laboratory experimentation, to problem solving, to computer simulations and assisted-learning software, to individualised-learning materials, to peer-group interaction and so on. Each one of these aspects of science education implies that students' own conceptions of both the task itself and the substance of the task are important elements in the learning process. As Cicourel et al (1974) suggest, the treating of students' own understandings:

'as natural aspects of educational encounters would enable the participants to have access to them and become less preoccupied with a rigid notion of what is right and what is wrong.'

The direction to be suggested, then, is that an exploration of students' conceptions, of the personal theories of what (and how) they learn deserves considerable study.

Secondly, there is a clear indication that much work needs to be done in terms of semantic development in adolescence and later. Much of the research into language development, and semantic development particularly, seems not to extend very far beyond 8 or 9 year olds. This leaves the mistaken impression
that language development ceases somewhere near this point. Given the fruits of this study, that the paths of development are varied - differing for individual words and individual students - then a progression towards semantic competence must (in a large sense) continue throughout life. There is much to be learnt about the way in which (older) students come to terms with a new and unfamiliar lexicon be it in science, social science, the philosophy of science or whatever.

A third avenue of research to be indicated concerns a specific part of Kelly's theory. Whilst many aspects of the theory have been explored and developed the Fragmentation corollary seems to have suffered some neglect. Beyond the work described in chapter 3 there is considerable scope for activity. The notion of conceptual 'subsystems' - so important to this study - is still in need of further elaboration. In terms of science (and students' conceptions of science) the consistency, coherence, compatibility or contradiction of the subsystems are all aspects that require drawing out in greater detail. The local domains of understanding themselves, their dimensions and attributes are clearly important to both the learning process and the teaching of science.

In the most obvious sense, too, such conceptions as have been discussed here for the four target concepts can be explored for many more. The candidate most urgently in need of examination is power. Discussions earlier have earmarked power as being a fairly deep seated notion within the fabric of everyday meanings. In many senses its role in physics is a peripheral one (the 'rate of transformation
of energy') that is, it is not a 'basic' or 'fundamental' concept. This would point to an interesting juxtaposition if (as seems possible) it is an important unifying (superordinate) conception in many students' accounts whilst being relegated to a more marginal one in physics. 'Reflection' in light is perhaps a similar example. At first glance this term seems less complex than 'power' because many of the uses of the term reflection are as a noun rather than a verb. In this sense a 'reflection' and an 'image' are interchangeable - and differ from the orthodox process of rebounding light at an optical boundary.

Other terms, like 'form' and 'system' also feature in different roles - both within and without of science. Do, for example, the statements 'heat is a form of energy' and 'diamond is a form of carbon' have the same meaning for the word form? Quite what students make of such terms is much in need of clarification.

A fifth avenue of inquiry concerns some of the origins of individuals' conceptions and the role played by informal sources of science education (as suggested, for example, by Ryder, 1982; and Lucas, 1983). What roles do sight, touch, hearing and smell play in forming conceptions of phenomena? How do experiences in science museums, exhibitions, fairs and so on, influence conceptions already held? Can individual students trace back through various strands of experience in order to catalogue some of the influences that have been brought to bear in its formation? Such questions seem to be of direct relevance to shaping both the formal (and, as far as possible, the informal) science education that is currently made available.
A sixth and important research direction to add to this list is in terms of the methodologies that have been used. The interview method itself is open to diverse variations both in terms of the IAI approach and in its other forms. Many of the lines suggested above are suitable for exploration using the IAI method - other concepts, notions of touch or hearing, what it means to learn, where ideas are derived from, could all be tackled by a sensitive use of the IAI format. A particular approach might be an increased use of students' own drawings (as indicated in Swift, Watts and Pope (1983) under the label Responding-Within-Pictures (RWP)). It is a procedure that has, so far, raised more questions than it has answered. There is a point at which such a task is both very familiar (making their own drawings) and yet quite foreign to students (sketching their own examples of science concepts). In this sense 'exploratory drawings' (to use Ryder's (1982) term) are not common features of science lessons - any more than exploratory talk is. Exploratory drawings, as the basis for interviews, seem to be another way forward. Other arrangements of the interview need further study too. For example, group discussions and interviewer-less interviews around the IAI cards (as initiated by Gilbert and Pope, 1982) need more development.

Beyond the interview lies the important process of authentication. The activities explored in this study have been just some in a number of possibilities. Given that the active engagement of the researched in the process of research is important, then there are many more 'tools'
to be added to the box. One example might be to take back the analysis of a single interview to the student a short while after the session. There might not have been, by then, the possibility of analysing a wide range of interviews, however the student's perceptions of the outcomes might be productive whilst the data is still 'fresh'. Authenticating frameworks is more difficult because they are deliberately more de-personalised. One approach might be to ask students to role-play a particular framework in order to explore how plausible and credible it might seem - an exercise perhaps more suited to older, more articulate students.

The seventh direction of research lies in the application of the research to classroom practice. The problem here lies in examining the many ways in which students' conceptions and illustrative frameworks can be both explicated and used in a classroom setting. These are, in essence, two separate problems. Explication not only implies the articulation of individuals' conceptions (or small group frameworks) but the generation of a working atmosphere that will allow these to stand and be elucidated without the threat of ridicule. Using the frameworks is then another problem. Little has been uncovered so far as to an optimum set of working procedures for safe-guarding exploratory ideas whilst at the same time detailing their relationship with an orthodox set, less still about engendering meaningful conceptual change along these lines. The gulf between what has been said and what has been achieved is still very wide.
Some Implications for Classroom Practice

Some pointers to be taken from what has been said can be summarised as follows. Firstly, the very nature of knowledge and of learning itself are matters for some deep consideration by both teachers and students. So often learning is seen as an 'increase' in knowledge that comes about by memorising or acquiring facts, procedures, or rules etcetera. Seldom is it seen as a person's imposition of meaning, as an interpretative process aimed at some understanding of reality. If this epistemological orientation has some basis then it suggests a widely different role for teachers and students. In the normal context of school science the teacher might cease to be solely a conveyor of information but become a facilitator of learning. It has been a basic assumption all along that students' personal conceptions are of importance, a cry that is being taken up in a number of quarters. The Association for Science Education (1981), for example, say:

'The key role for the teacher of science is that of enabling each pupil to relate to his or her own perception of scientific understanding to the wider community of scientific ideas. Whilst such a process involves moving the pupil closer to the 'accepted truth', all concerned should accept the absolute legitimacy of the 'perceived truth' - the right of the individual to interpret his or her experience in his or her own words.'

Pursuing this vein, one of the aims of the Secondary Science Curriculum Review (1983) is that: at appropriate stages in their science education (in this case between the years of 11-16) all students should have adequate opportunity to

'discuss, reflect on and evaluate their personal understanding of the key concepts, principles and generalisations of science.'
This approach is taken as heralding a clear movement towards an appreciation of students' conceptions within science classes. It indicates the beginning of a shift away from memorising long tracts of written science towards a genuine reconstruction of science to meet the students' own needs. The important aspect of this is that such a shift is a necessary prerequisite for any implementation of what is said here.

Following from this, a second implication for classroom practice concerns the processes by which the relationship between the students' personal conceptions and the orthodoxy of science become realised. It seems entirely reasonable from what has been said (in chapters 5 and 6 particularly) to see shifts by an individual student towards orthodox concepts in science as piecemeal and of varying strength and duration. Much will depend on the shape and utility of his or her conception for a particular phenomenon. One possible outcome is that as the phenomenon is approached by a student in terms of a specific conception then the conception (and the phenomenon) might both be changed and incorporated. A second possibility is that the phenomenon is rejected from one conception to be incorporated within some other (less useful) one. Thirdly, it might remain as an isolated unintelligible entity without much meaning at all.

For the teacher, the important facets are an understanding of an individual's conceptions before, during and after some exercise in school science.

This is simply to recapitulate on the general emphasis
of much that has gone by in earlier chapters. What is picked up from what a person says (writes, or does) is a small snapshot in the development of a conception that will change. To influence the change is to know about it as and when it is happening. Arguably it is easier to influence the development of conceptions in their early stage of an exploratory, little-formed, rejectable state. However, as Driver (1983) suggests, science teachers are often in the position of wanting to discard various models in preference for progressively more sophisticated ones. This argues for an understanding by the teacher of the conceptions held by the students of the old model before a new one can be introduced.

The process of 'realising' student conceptions might fall into two categories:

a) student initiated
b) stage-managed

The first concerns the many instances when a student begins to articulate his or her own conceptions either as a question, in response to a question, in the course of requesting information or clarification, or as a source of doubt or puzzlement. This point is arguably a most important time since, given favourable circumstances, it has been shown here that students are both willing and able to volunteer their own conceptions, analogies, metaphors, paradoxes and generalisations. In situations where circumstances are not favourable, where students' views are not seen as valuable, where teaching is directed towards memorising to the exclusion of understanding, where the approach
is directed exclusively towards the 'transmission' of knowledge, then such a fruitful exchange of ideas is unlikely to take place.

The second concerns the variety of teaching strategies and methods that allow adequate opportunity for students to articulate their own ideas. Some of these have been explored at different levels - in principle (for example, Watts and Pope, 1982; Watts and Gilbert, 1983) and in exploratory practice (Gilbert and Watts, 1982). These might include small group discussion techniques, or the whole class tactics as used by Nussbaum and Novick (1981) and Minstrell (1982). The teacher audience of the authentication process made much of the potential use of the frameworks as indicators of possible student conceptions. Herein lies their utility, though yet untested. The potential is that early diagnosis and preparation for a particular part of science education can be made on the basis of identified frameworks. A group about to tackle force in year 4, for example, might be asked to consider the IAI cards in small groups or as a whole class. Early indications (a straw pole, for instance) might establish the prevalence of some or all (or other) of the frameworks so that preparation can be made to explore further, or to challenge various aspects.

It is arguable that in some parts of science (force, the particulate nature of matter, for example) sufficient work has now been achieved to allow some early design of classroom programmes that overtly take into account student conceptions and frameworks, along with the very process of
active conceptualisation. Ogborn (1983), for example, has suggested that the laws of 'naive' dynamics are now sufficiently familiar for instructional programmes to exploit them purposefully.

One aim of science education must surely be to tap the creative resources of students like the ones here, as they struggle with the task of imposing meaning on a somewhat mysterious and enigmatic set of theories and principles called science. For the teacher this poses the very real problem of how to approach a person who may be immersed in one particular set of personal conceptions (or personal paradigms, to coin a term from Driver and Easley, 1978) and to inveigle them towards another (hopefully, more powerful and functional) set. Clearly they need to know much more about the systems - and subsystems - of the other person. One way must be to stay with youngsters' language in an exploratory mode until they are prepared to make the move to another mode. The burden of the teacher becomes clear. If he or she wishes to guide the student, the guidance has to be given in a language, and directed at systems, that the student can understand. The role is that of teacher/translator. The translator has to understand the usage of terms in other people's languages and also large parts of their network of beliefs and expectations. He or she has to find some way of discussing scientific ideas that preserve the meanings of words used by students and be able to express new intentions in such a way that new meanings are possible and that a new understanding emerges from an initial engagement of old terms. For the teacher to become translator means they have to take seriously
the views of those they would hope to guide.

7.5: A Concluding Remark

There has been no attempt to disguise the ways in which this work is reflexive - how it is itself an example of what it tries to explore. In discussing the exploratory ways in which young people draw together elements of ideas, propositions, theories and personal experience this study has (necessarily and unavoidably) followed a parallel route. Suitable judgement of the result, of course, lies elsewhere except to note that, as many students have noted in the aftermath of the interviews, how the exercise has been both salutory and exhilarating, and how, in their words, 'it's funny how you understand things differently now.'


HARRISON, R.D. (1968) Forces. Longmans; London


MAYER, R.E. (1979) Twenty Years of Research on Advance Organisers: Assimilation Theory is still the best Predictor of Results. Instructional Science, 8 pp 133-167.


NUFFIELD FOUNDATION (1977) Nuffield Physics Pupils' Text Year 3
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Appendix I: The IAI Cards for Energy, Force, Heat and Light
E1
Pushing a heavy box up a hill. Is there any energy here?

E3
A ghost. Is there any energy here?

E2
A battery, bulb and switch. Is there any energy here?

E4
Some hot water in a beaker. Is there any energy here?
A chemical reaction. Is there any energy here?

Eating a meal. Is there any energy here?

A hand lens. Is there any energy here?

Melting ice. Is there any energy here?
An alarm-clock with a luminous dial. Is there any energy here?

Sledging down hill in the snow. Is there any energy here?

Two people colliding as they run. Is there any energy here?

A person in the snow. Is there any energy here?
A bad smell. Is there any energy here?

The stars at night. Is there any energy here?

A flower in a pot. Is there any energy here?

Clouds. Is there any energy here?
A person listening to a radio, blown over a cliff.
Is there any energy here?
F1

Dragging a huge stone. Are there any forces here?

F2

A spacecraft taking off.

F3

Being told what to do. Is force being used here?

F4

Diving into a pool.
A tree blown in the wind. Are there any forces here?

Sledding down a hill in the snow.

A thinker. Are there any forces here?

A golfer hitting a golf ball.
The golf ball about to land in the hole.

A book lying on a table.

Are there any forces here?

A bank robbery. Is force being used here?

Walking along with a balloon.
The astronaut has tripped over a crater on the moon.

Are there any forces here?

In an astronaut floating in space.

Two similar torches. Has one more force acting on it than the other?

Drops of water on a shiny surface.
AN IRON BAR IN A BURNER FLAME AND IN TAP WATER

A FLOWER IN A POT

ICE MELTING

CHILLI PEPPER POWDER
A House in Sunshine

A Stone Being Thrown Over a Cliff

A Fun Coat and a Metal Dustbin Left Out in the Snow All Night

An Electric Mixer Turning Some Thick Cake Mix
AN ASTRONAUT IN SPACE

THE FRIDGE HAS BEEN LEFT OPEN TO COOL THE ROOM

THE FRIDGE HAS BEEN LEFT OPEN TO COOL THE ROOM

A TIRED RUNNER

PUTTING SUGAR INTO A CUP OF HOT TEA
Looking into a mirror.

Watching television

A film projector and screen

A rainbow
L7

A person sunbathing

L8

An X-ray machine

L5

A bright red painting

L6

A burning candle
PHYSICS IS WONDERFUL

A hand lens.

A flower in a pot.

A battery, bulb and switch.

A shirt that has been washed and is now 'whiter-than-white'.
The stars at night.
Appendix II: The Interviewees and the Extracts Used
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</tbody>
</table>
## THE LIGHT INTERVIEWEES

<table>
<thead>
<tr>
<th>GROUP</th>
<th>INITIAL</th>
<th>SEX</th>
<th>SCIENCE/PHYSICS GROUP</th>
<th>EXTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3L</td>
<td>G1</td>
<td>M</td>
<td>3yr physics</td>
<td>1, 71</td>
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<tr>
<td>(9)</td>
<td>A</td>
<td>M</td>
<td>3yr physics</td>
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<td>L</td>
<td>F</td>
<td>3yr science</td>
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<td>3yr science</td>
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<tr>
<td>4L</td>
<td>C1(Colin)</td>
<td>M</td>
<td>4yr physics O level</td>
<td>75, 81, 87, 120</td>
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<td>F</td>
<td>5yr physics O level</td>
<td>72, 73, 103</td>
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<td>F</td>
<td>4yr physics O/CSE</td>
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<td>79</td>
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<td>F</td>
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<td>100</td>
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<td>M</td>
<td>A level physics</td>
<td>101, 129</td>
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Appendix III: A Sample Transcript (C1,4L)
I don't believe it is going to be like that all the time do you reckon.

C I don't know

I or is it

C when they get a teacher it'll probably be better... it doesn't sound as if they've got one

I no it doesn't it. it's alright... today.. the same sort of routine. as before /in the other interviews/

C ... hum.....

I got a teacher...

C . obviously (laughs)

I um. and... some of them you'll recognise cos some of them are going to be the same... some of them are different..

C ...... so er... you want me to say about it

I um... well as before it's it's do you think there's any light there?. and then eventually I'll ask you what you think light is... and you have to sort of say what you think and then.. I ask you uou know whether you think it's an example or not of your idea of light whether you if what you think light is can be described using the pictures and I try to sum up your ideas to see if I've understood them or not.. okay?

C yea I see yea okay

I . okay what about that one? /projector L2/

C well there's obviously light there

I okay

C coming from the projector.... from the bulb.... and it's being projected. on to the screen. its travelling..

I okay um... and then I . as usual I sort of ask you what questions come to me as as as you're talking. is there any where abouts would you say the light is?

C . well the light. there is . the light is obviously originated from the projector but it's being...
... thrown on to the screen... well it's travelling to the screen. there is no light on the screen itself.

19 I so so light travels

20 C yea... yea

21 I yea okay and you say it's going from there /projector/ and on to the screen what happens to it after it's got to the screen?

22 C .. well it depends. it depends what. what sort of screen it is I mean if it's a mirror it'll reflect if it's .. if it's a black screen .... it'll absorb it. if it's a white screen it'll reflect it and . show it up . and you'll see the light .

23 I say it's a slide projector or film projector?

24 C well then if if there's a slide in there

25 I yea

26 C then you'll see the image ... because the light'll be darker . or lighter or a different colours in different places .

27 I . okay and what's an image?

28 C ............. uh (both laugh) an image

29 I yea

30 C um .... is something . that's been ............ projected ... it's something that somewhere .... that's been thrown somewhere else. it's the same thing but in a different place and . maybe bigger as well or the same size

31 I I see the same thing somewhere else I mean I was thinking if sometimes you . um can look in a mirror and see an image

32 C yea

33 I is that the same thing?

34 C ............. more or less it's it's not quite the same as you know . an image from a projector .. because that's being thrown that's ... that is. an exact image I mean a mirror's a . opposite image
Tape 175

Colin

35 I okay. and in this case it's a sort of thrown image?

036

36 C yea it's thrown on to the screen

37 I okay lets leave that one for a minute .

38 C alright

39 I and have a look at some of the others

40 C right . /television set L3/

41 I again is it an example of what you would call light? do you think it's got anything to do with light?

42 C well I I don't really know much about the . insides of television sets I should imagine there are ... bulbs and things somewhere in there . but obviously .......... the light comes from a television screen . I mean if you turn all the lights off . it will . you will see light . coming from it ... in different forms

43 I and what happens to that light?

44 C .... well . um ... its picture . its waves . coming through are being caught on the aerial and being transferred to the from the tele into a picture . and it's obviously bright I mean . oh I don't know (laughs) I don't quite know why it's bright ... um ... I suppose ............ I don't know I don't .. I suppose electric . electricity . really ... is light I don't know .. I suppose

45 I you've got a feeling it's got something to do with electricity?

46 C yea

47 I and the pictures are caught on

48 C that's definitely

49 I the aerial?

051

50 C yea

51 I and and then?

52 C comes down the aerial the waves .. and there /in the television set/ . it's transferred into a picture ..

53 I is that an image?
Tape 175

54 C yea. it's an image rather than just light or a picture it's an image ... a thrown image same as the projector really. that it's it's just that it's on a bigger scale I mean the television company are throwing out... more waves. than a projector would.

056

55 I I see so in this case it would be similar to the um.

56 C like the

57 I the projector

58 C projector

59 I would it?

60 C yea the projector would be the sort of transmitter or something yea and the um. screen. more or less the aerial picking it up

61 I I see and then what does a T.V. do then in that sense?

059

62 C .... um... it's more or less the same. the er ... the projector should be sort of like the antennae the aerial at the T.V. station and it's being caught on here. and er... see what I think what they do is um... jumble up the picture into .. light waves or sound waves and the the circuitry of the television set. unjumbles it and puts it back in its original place

63 I okay and then then then that how does it get from the circuitry on to the screen?

064

64 C on well I I mean ... sort of . there there's a picture valve I mean I don't know what it does

65 I no okay (laughs)

66 C I mean there's loads of transistors and things in there that's somehow that that gets it onto the screen

67 I and then what happens to the light at the screen?

68 C I don't know I think I think there's um something in there that lights it up like I mean there's all . if you look closely at a television set there's um . a little sort of . dots of different colours .... and they they light up or they darken or they change colour things like that so you know to
.. adapt to the picture.

69 I  . okay . and and then what happens to the light after it hits the screen?

073 70 C well it .... well he's /the person viewing/ I mean it's the same as this I mean if you're sitting there . and you're looking at that screen and the projector one you'll see . you'll see the picture there /at the screen/ it's the same .. but ... that screen /the T.V. set/ the li you can actually see the light I mean in a dark room you'll be able to see the light waves coming through before they hit the screen but here . there'll be light projected from the screen ..... in a way it's also like the projector I suppose throwing the picture as well as ... having a picture

71 I when you were first talking you were saying that the sort of transmitter was a bit like the projector throwing the

080 72 C but then again

73 I waves

74 C but this itself could also be a bit like it

75 I yea ....... yea okay we'll leave that one .

76 C right I'll put that one with that one /puts L3 and L2 together/

77 I you would

082 78 C yea

79 I what about something like that then. /flower L11/

80 C .... a flower in a pot er.

81 I anything to do with light?

82 C well . flowers I mean obviously everything needs light to live ... is um ............ flowers open in light and close in dark well most of them do ............ and depending on what flower it is I mean if it's a sunflower it'll always sort of aim to face the sun

83 I do they?

84 C . yea .... it's the like heads they sort of turn round to face the sun ... and um.
85 I well why do they do that then
86 C . I don't know (laughs) obviously they can...
090 obviously they they pick up .. the heat .. coming from a certain direction I mean it's not visible but . if one if . if the sun's um is changing direction you'll notice the flower changes with it .. you can't well you could if you had a slow motion . a camera and then showed it back in .
095 screen it up you'd see it moving
87 I .. oh I didn't know that before
88 C yea
89 I so . you said then it was it it might have been the heat from the sun
90 C yea the heat from it
91 I do you mean the heat or the light?
097 92 C the heat .. yea I don't think it's the light . that makes a flower .. open or anything it's the heat ... I mean it I mean (laughs) in this sort of a day there's not much sun about and there's . not much heat well I mean obviously it's still light because the sun's still up there behind the clouds
93 I right so it it . as an example then if if you you actually stuck one of these things out . in the weather like today would it still operate?
101 94 C it's oh yea that's a point I should imagine it's no . I suppose it'd die . so I suppose it needs heat more than light
95 I so you've got a feeling it needs light
96 C yea because in in the tropics and things the plants are open almost all the time because it's hot all at night as well
97 I would you say this one was more heat or more light?
106 98 C yea I I'd say this is more heat and not light
99 I okay are you going to put it with those ones or
100 C well sometimes flowers react with light . anyway I mean they change colour depending on ........ the waves I suppose . of the light
101 I . that's the second time you've said waves I mean what have waves got to do with light?

102 C . well light's more more or less the same as sound I should imagine with waves I mean I suppose it's still ..... I mean talking I'm transmitting light waves and this . this light bulb's transmitting light waves as well ... I'm just I'm giving out sound waves while I'm speaking and that's giving out light waves as it and it's ...... I don't know I suppose it goes on longer than the sound wave I mean . as soon as I stop talking . you you don't heat my voice but the light is sort of bouncing around all the time .. lighting the whole world

111

103 I that's what you think of it as sort of . being like a a wave that's coming out of there /the light bulb/ and then bouncing around

104 C coming in different directions yea

105 I have I got you right it's different to sound is it because

106 C yea

107 I eventually it sort of

108 C fades away with time yea

109 I ... okay . lets go on a little bit further has that /rainbow L4/ got to do with light?

110 C well ... it's a rainbow it obviously . the sunlight has got a lot to do with rainbows cos it's um .. you know like prisms .. the rain it's raindrops and the sun . they the shape they form ... acts as a prism ..... and er .... as the sun hits it it gives the colours of a spectrum and er

111 I I mean how does it do that .. or why does it do it . do you know?

112 C well ... it's the angles . the angles it hits the er I mean if you had a prism just say raindrops were the exact shapes of ... a prism as it hits one side . the angles are at such an angle that it'll bounce up .. and I don't know why it . splits the I the um . cos pure light is made up of all the colours ...... or all the colours is pure light you could say

113 I and so what's the prism doing?
114 C  a prism is splitting light yea ... into the true
colours /C puts L4 with the television card L3/

115 I  does a colour tele work then I mean does that do
something similar?

133 116 C  .. um ..... I suppose .... I'm I don't really know
much about the waves that they send out . for tele
I mean I ... obviously radio it's electrical waves
obviously . I mean cos it's got to be sent through
elec electricity and all this .. but I mean it's
not sort of like sound waves is it I mean ... if
I shout out nobody's going to pick it up on their
radio ..... and er . I don't know .. I suppose
they sort of .. split it up .......... which which is
the same as the um .. rainbow is it's the (*) the
prisms are splitting the light up and I suppose
they split the er picture up . and throw it ......
which is what this does it forms a semicircle

144 117 I  uhum . uhum so you can see some sort of similarity?

118 C  yea though not quite but there's . they are
similar yea in the way it sort of breaks light up

119 I  aha . aha okay right let let's let's do you see
that as being similar to the others or is it
different?

147 120 C  I'll put it . near the television and the .
projector but it's not . sort of . on the same
basis

121 I  okay

122 C  although I don't know .. I mean you could say the
sun is the projector .. and it's going through a
prism as the lens and . just the air is the screen..

123 I  .. lets see if I get you because in this case
something like I mean ...

124 C  yea

125 I  in this case you've got the sort of

151 126 C  you've got the projector your lens . which is um
... focusing it and then the screen which you could
say about the rainbow as well

127 I  okay well leave it up there what about something
like this is just a .... somebody looking at a a .
bright red painting or something like that /L5/
(sighs) well obviously there's electric light on or he wouldn't be able to see it.

why do you say that.

... well he just wouldn't see it your our eyes aren't well . he if he stood there for hours .. he probably eventually would get to see it ... but not the colour I shouldn't think he'd just be able to see the . outline of the painting ... so I suppose if he had the light off .... it'd still the red painting uhm I don't see that the red painting unless it's luminous is giving off any light.

.. okay well wh what's special about luminous then?

... well you can get all sor I mean something like ... I mean this is kind of obviously we don't they don't make pants sort of out of radium any more that are radio active ... but for instance radium glows in the dark I mean I don't know why ... I don't know the physics of it yet (laughs)

yea . it's got something to do with physics?

yea

then has it ...

.. and um ........... I don't know luminous ... I suppose certain colours ... are just ... glow in the dark I don't know why

uhum but that's not what you'd . I mean

I.. if it's just a bright red .. painting I shouldn't see ... that that's got anything to do with light at all

I see.

.. oh it . oh I suppose it's the only reason it's bright (*) red is because there are is actually light shining on it I mean if the lights were off you wouldn't probably notice that it's . exactly bright red he . might be able to work out it's red but not bright red..

okay but are there

cos it's reflecting light isn't it and . showing you what colour it is.
I and and is the fact that it's coloured anything, like what you were talking about with the projector and about the sort of rainbow. Has it got anything to do with that or is it different?

C ......... no I don't think cos this is um more like the flower really. I mean if the flower if all the light was turned off. and that for the flower it'd probably you wouldn't really notice it. I mean flowers. it's oh it's more or less the same it's colour basis the um the only reason you notice a bright red flower is because its light out. if it was dark it'd just be a flower in your eyes and I suppose it's the same with the painting you wouldn't notice if it was dark.

I hum. okay so you you see a sort of similarity between?

C I'll put I'll put that. by the flower.

I okay what. this one /shirts L12/ is supposed to be you know like the T.V. advert where one shirt's supposed to be white and the other one's whiter than white or something.. I mean has that got to do with light.

C er obviously if it was dark you wouldn't notice if the shirt's dirty or clean but um. .......... I suppose the only reason you can work out that that shirt is clean is because of the light I mean if you hold it up you can see through and you know notice all the particles have gone I suppose. if supposing this is natural sunlight this is in then um the light is obviously giving off heat as well and I suppose heat helps dry it out and then most of the dirt would fall off I mean heat's. I suppose heat and light are very very tightly connected.

I yes that's a question I mean .. can you can you get heat without light or can you get light without heat?

C well I. all fires give off light more or less. and all light bulbs give off heat so I don't know. and the sun gives off heat and light yet yet the moon gives off. no the only reason the moon gives off light is through the light of the sun anyway I mean ....

I ... how do you mean?
Tape 175  Colin

151 C well I don't know the li the moon isn't bright is it it's not like the sun giving off continuous light. the only reason we can see the moon is because it's being lit up by the sun wherever the s I mean obviously we can't see the sun because it's round the other side we've gone round it but the moon's still in view of it and you know can.. depending where you are it might be a full moon cos you it's all lit up well half of it's lit up one side and only a part of it's lit up

206

152 I right I think I get it. okay so is what you're saying in this case though it's in natural sunlight it

153 C it yea is it's in natural um.. sunlight ....... then um ....... I don't know I mean it wouldn't I'm not saying it'd make it cleaner or anything but in natural sunlight you'd definitely be able to tell which one was best.

211

154 I okay I've got a I suppose I was thinking of something like um. people sometimes say. they don't want to look at the colour of something in a shop un un under the sort of shop light

216 155 C under the shop light

156 I they take it out and have a look at it in sunlight or something like that

157 C yea because they want to check and see what the colour of the material is or something whatever it is a shirt or trousers or something.. natural light obviously isn't the same as sunlight I mean ... when you look at the sun .. I mean depending on how how cloudy the day sometimes it'll look yellow which most people paint it as yellow but if on a really clear day if you look straight at it which you're not meant to do anyway but if you do anyway it's just pure white I mean I don't I don't think it's yellow I mean it might be but I don't know.

220

158 I okay but you're not quite sure that that's going

159 C no (shouting) (both laugh) um..

229 160 I okay lets leave that one for a minute

161 C yea I'll leave it on the side

162 I if you get any further ideas about that one
163 C yea
164 I you know just shout about it .. (both laugh)
  - that was a mirror one /L1/
165 C ... well ... obviously ... if it was pitch black
in there he wouldn't be able to see himself
233 166 I so what's happening there?
167 C ... well the mirror because it's .. transparent .
you know on one side ... and you get a reflection
off it in light but in dark you don't .. see what
it is is um . I suppose .. I suppose it's like the
projector the sun's behind you .. or in front of
you or wherever it may be .... and it's um project-
ing you on to it .... the the light waves waves
are hitting you .. and they're also hitting the
mirror .. and rebounding off the mirror and . hit-
ting you and ....... forming a reflection I suppose
........ er .. I don't know mirrors are strange
things ... they're difficult to explain because
........ I mean you don't know what really makes
them work I mean obviously you know .. in principle
but you you don't really know the physics of
it all you know .. anything like that .. fully
... why it .. you know light reacts with it
245
168 I uhum but you've got a feeling it I mean it is ..
what you were saying that they have something to
do with light?
169 C I think like the light's sort of projecting you
on to it .. yes I'm I've got a feeling it's some-
thing like that ..
170 I hum .. hum .. good okay .. and is it similar to
any of the others?
171 C .. I'll put it ... sort of near the rainbow and
projector and .. stuff like that becuse I thi
. I don't know I've got a feeling it's you know
sort of ... on the same basis .. but in a diff
using a different method
254 172 I okay okay good what about something like that
then this /lens L9/ . do you remember that one?
/from previous interviews/
173. C ... yea I do . er ... a hand lens ....... well
it's obvi I mean the only reason it makes it bigger
is obviously the shape of the lens .... um .......
174 I do you know what happens?
oh well you need it's I suppose it's like the
mirror I mean .. you need .... you see if with
a hand lens you can burn paper and things can't
you with pure sunlight you can't do it with
electric lights on a hot day you can .. I don't
know whether you're catching rays or whatever but
you can .. sort of . fiddle about with the lens
higher and lower ... and you can get ... pure light
almost . and it gets so hot that it just burns
straight through the paper and it can go through
sort of . burn varnish off desks and things as well

get away really

yea /both laugh/ I .. I've seen it at home once
/both laugh/ burning a bit of paper and I burnt
the varnish on my desk as well

I mean is that the light that's doing that or is
that is that the heat?

270 C well it's ... again that's that's the difficult
part about the difference between light and heat
... I mean I've .. I've never s . although ...
you ..... no I was just thinking those things I
mean you can buy these things now that are . hand
held . heaters they're meant to be I was just saying
they I was thinking to myself they don't give off
light but I suppose if you take them ... apart
there's got to be a ... piece of wire that's heating
up inside maybe it's not .. hot enough to see
that it's light but I suppose under a really really
dark ... situation you would be able to tell ....
or if you just charged the electricity up a bit
more . then it would go . you know and light up
sort of like electric fire or something

it would be glowing?

yea or pieces of it would be anyway

how do they work have they got a battery in
them have they? .... and then a little sort of

no I think it's a dynamo .. it's more or less the
same and you've got to hold it like this . rub
it up /C demonstrates with an imaginary one/ and
then it gives off the electricity and it warms up,
the .. filament

and then it just keeps you hands warm

yea .. it's not very good but .... I suppose if
you you know really went mad with the dynamo you could get it. to light up but I mean that's not likely but then that's

186 I to put it in your

187 C electricity

188 I pocket or something is it and then

189 C no you hold it in your hands it's meant to keep your hands warm

190 I oh oh I see is it worry go on

191 C but this is a ......... I mean that's elec that's electric again that's sort of artificial light .. pure sunlight. I've never s I mean .... all light is artificial apart from the sun I should imagine oh I don't know if you can call you can't really call fire artificial it gives off light and heat I mean then but then again .. we suppose ... that the sun is just burning off hydrogen all the time which is then fire which then you could call it natural light

192 I what are you thinking of when you say natural light if it's not the sun and it's not um?

193 C I don't know I think I suppose .

194. I what's the natural sort?

195 C I mean all light all the lights really we're used to are electric .. and you can't call it's man-made isn't it it's not natural it's not .. I mean if .. if we didn't have the technology to make electric light bulbs ... I mean it'd be dark in the dark in night apart from certain things then again you've got fires and candles and things which is .... you know very closely related to the sun

196. I hum ... so which one would be the natural one and which one would . would?

197. C well I'd I'd call I wouldn't call anything you know . charged with electricity natural it's just heating up a filament . and getting the gas . around the filament . to brighten up .... um ...... so I but I mean obviously I don't know may be you could I've I've never seen anybody . sort of set a piece of paper alight of a hand lens from a ... fire .. a coal fire or anything .. but then again it's not you know it's not as intense as the heat from the sun
so it's I don't know I suppose light and heat are very very closely related then .. if you're talk-
ing you know in sort of natural form ... hum ..
it's difficult to think of something like snow having to do with you know I'm and sort of walking out there as having anything to do with light . you know you there you're

what are you thinking about sort of .?

but then again I mean .. or or this thing here the radiator for instance yea ....... you see this radiator is warm is because somewhere . in this school I don't know whether it's .. an oil burner I I doubt if it's coal it's probably oil ..... heating the water and it's the only reason they're warm

and wherever that is . there's going to be some light?

yea because um something's obviously burning ... and it will produce light

I see I see

um ... I mean snow .. snow's obviously .... very .... cold to be in but it's also very bright .. but that's only because it's pure white and it's giving off reflections from the sun

I see uhum uhum ..

but a hand lens I don't I don't

yea it's a hard one isn't it?

yea it's a difficult one I mean it's not ... I doubt you can't use it without light ... and you can also produce heat with it . well it's not producing heat it's sort of . enlarding or intensifying the heat from the sun .

........... good yea I mean again

I wouldn't . I don't know it's .. it's difficult it's like the mirror I mean . without light it's obviously totally useless ... yet with it it's difficult to explain so I'll put it with the mirror

okay good ... maybe now's the time to ask you . you know what you think light is I mean you you said something before that you think it's it's got
waves or something. how would you how would you describe it to somebody I mean?

211 C I don't well. if I was describing it to somebody I don't know. i'd say er... obviously you wouldn't be able to see without light... so there's obviously some...... nerves or you know... something in your head... in your brain nerves that um react to light very strongly. and colour... um.... then you. wh when you're say when you're talking about waves you get you know to the sort of contro... controversy of the speed of light. and when somebody says the speed of light I mean obviously we don't know wh what it'd be like to travel at the speed of light but people have got different theories. I mean I think... if you ever got to the speed of light you'd end up like a light wave it'd break you up and then as you slowed down and slowly... I suppose I don't... I mean the television this television set. one I mean obviously it's... the waves are travelling at the speed of light... as far I mean. I don't know I suppose they're travelling at the speed of light... because I mean... it is light you you could say and it's got to be travelling at the speed of light and as it slows it I mean as it hits the um aerial. and gets into the circuitry it slows it down and puts it back onto its original form.. I don't know I've never really sort of thought for a long time about that... light... and the... speed of light.

212 I ... well why do you think the speed is important I mean?

353 213 C well I don't know it's going so fast that it's breaking.... I don't know well they s I mean... there's all this about splitting the atom maybe... maybe it's the atoms that are... splitting... but you know they're not...... not reacting... as we found with nuclear bombs splitting the atom... I suppose it's splitting up... and then reforming not actually... breaking... just splitting into bits... so that it's tran... well it's I don't light light is transparent... you can see through it..... um...... yea I mean obviously no nobody really...... and truly knows.

364 214. I hum..... which makes it a bit of an unfair question

215. C yea /laughs/

216. I for you /laughs/ I mean. but I mean you've got this feeling that it it that it's it's travelling very fast.
Tape 175

217 C . yea .

218 I and that the

219 C definitely

220 I speed of the speed of light is important and that the sort of pictures we were talking about (*) for instance on the television before

221 C yea

222 I are going at the speed of light?

223 I well they are before they actually I suppose

224 I until they get to the television

225 C yea and then it's like the screen I mean .. the projector's throwing it out at the speed of light because obviously light will move at the speed of light and then ..... just sort of abruptly hitting this screen and stopping .... throwing the image keep and then going back to its original image it's like a barrier I suppose . whereas the television just slows it down

226 I aha so something like the screen'll actually . sort of . is a barrier

227 C yea

228 I and stops it and then .

229 C but then again if if you was projecting that into a mirror it wouldn't would it . it'd reflect off depending on your angle I mean if you were straight on it it'd reflect .. but if you were slightly at an angle it'd reflect off somewhwere else

230 I hum .. and what about the lens?

231 C ..... well that that this this has come back to the hand lens this is bringing it into focus I mean it's you've got your picture there and you're . you've got a light bulb .. behind the picture . and if you just let it go you'd have to you know be sort of standing nearer and further . you're / straining trying to get it .. in focus and .. it'd end up probably being very very small....... um and a lens . depending whether it's convex or concave .. um ........ makes it bigger or smaller and you know nearer or further . depending what you want
that's interesting actually I mean well as you 
think about it I mean how can it make it bigger 
I mean does that mean there's sort of more or it? 
it's not... you're .. well it's is sort of more 
of it isn't it but obviously the further ... I mean 
.. for instance that coat there . I can see it 
quite big now but if I was um ....... five hundred 
yards away .. it'd look small 
yea ........ but if you put a lens in front of it? 
yea but then again it depends what lens it is 
doesn't it I mean if it was a hand lens if if you 
didn't have a lens in your projector you just had 
your . light here .. and um and your slide or 
whatever you're film or whatever then you could 
fiddle about going backwards and forwards with 
your hand lens .. lens and eventually get it into 
focus and because of the shape of the um hand 
lenses ... it'd it breaks it sort of pushes it 
outwards .. and makes it bigger . well enlarges 
it I wouldn't say makes it bigger cos it's . 
the same picture . and then obviously if you go 
too far back .. it's going to you're not going 
to get a clear picture anyway no matter what you 
do . it's going to be faded 

doesn't that mean that when it's gone through the 

lens you've got more than there was beforehand? 
no it's not more it's just . spreading it out 
stretching it ... it's not more it's the same 
picture I mean .. I suppose ... I don't know ... 
....... um .. 

yes I see you are getting at I mean it looks as 
if you're sort of getting more when it's 

but .. but you're not no 
I'm I'm going to I'm going to ... quickly ask ask 
you about another one what about something like 
that this is to . you know /X-rays L7/ 

oh .. may be totally different or maybe not I don't 
know it depends . something ... an x-ray 

yes an x-ray machine 

alright . well this is obviously to do with um 
....... light . and radio-active light .... I mean 
I I don't really know much about . you know um .. 
radiation .. I mean I've I've had x-rays when I've
broken bones or anything

244 I have you ever seen them afterwards?

245 C yea

246 I hum and you can actually sort of see like a white shape where your elbow

247 C yea

248 I where your where your bones were or whatever it is that

249 C yea

250 I you you've broken yea

251 C .. um ....... but I've I've never actually seen one like this where you stand behind it and . ah yea the only ones I've ever seen like that are sort of chest x-ray ones where you actually have to . um there's a there's a sort of er a end of the box like that and you have to stand with your chest against it . all it does and but you never see it doesn't look like that you don't you don't actually you don't see it through the other side

252 I no no

253 C no

254 I you don't no you don't . cos they they they take one of those

255 C its just

256 I sort of you know square plastic sheets

257 C yea

258 I things and do it that way . no no here I was just

259 C well

260 I trying to sort of . as a picture

261 C um ....... obviously . what they it's like it's like (*) sort of a camera . I mean a camera's obviously got a lot to do with light .. um .. and this is like ...... a very strong camera ...... I mean I I the ... most of the x-rays that I've actually seen of myself have been of my arm .... and my hand .. and um .. you know you just sort of
you've got to put your hand down and keep it very very still ... and ... well no. when I've had them done of my teeth .. at the orthodontist they put your the plate in your mouth . and then they bring this thing up to you it's like . I don't know it's black sort of plastic thing you know

oh it comes to a point

a bit like a cone

like a cone yea and they touch it against you and you know they stand back cos obviously they can't be . in contact with the radiation too often . and they press it and . I don't know I suppose it gives off a very limited amount of the radiation ....... and whatever's in front .. oh I don't know .. Is . yea . you see they're always when I've had them done the um plate's always been it's never actually been behind me ... behind the set of my teeth it's always been in front ....... I don't know why

yes I know what you mean because .

because I

they put it in

I think

between they put

they have to

it inside your gum don't they

yea ... by your gum and I I think they'd have to . really thinking about it. put it behind to get the picture of the tooth ... underneath the gum but then I'm not sure . oh see that's that's a very difficult matter.

it is isn't it

I've never really thought of that before

well has that got umh just to just bring you back a bit has that got anything to do with light at all I mean that sort of camera?
Tape 175  Colin

277 C  yea I'd say it has yea because the um ....... radio active particles .... are um assumably giving off light .... and um ..... hitting this um .. paper or whatever that's very sensitive to the light .... and ..... giving you an image which you've then got to develop and you can see it

278 I  I suppose what made me think was what you said before that that that light was translucent that you can see through it . and and I was thinking of seeing through things that's why I thought of that ..

279 C  .. yea um ........... yea. that's that's a good point actually if you I mean you can see through .... and that is helping you see through .. yea but that I mean . that's again I mean we if we hadn't . you know ... discovered anything .. about radiation well you know or radio activity .. we'd never know about x-rays . then again I suppose sort of . x-rays . once people have discovered about . radium and radio activity I suppose that's just sort of . an enlargement of a camera you know on a sort of diff............. 3-D scale you could say

280 I  when you were talking about the the hand lens you were talking about collecting rays of light .. you weren't sure but you thought it could be some­thing like rays of light I mean does that is x-ray anything to do with rays of light .. I mean is the ray the sort of same thing in that?

486 281 C  well I

282 I  well what would you say a ray was put it that way.

283 C  ............... well if you've got a torch it gives off a beam . and I suppose . a beam is made up of . millions and millions of . rays .. like waves .. single lengths ... like a piece of rope I mean .. a piece of rope . is quite thick usually I mean even the thin pieces but they're made up of very you know loads and loads of very very thin strands and I suppose it's like that you know you get very thin strands .. and you've just got to build them up and make ........ yea .. and make um beams . get single rays . but I don't know x-ray ... I mean that's . I don't .. I don't think that's a very apt name for the thing . because I . I mean ...... obviously you know .... there are rays ... of radio activity or . radio active light . passing through your body hitting this .......... see wh . I mean .... oh see this is . this is confusing me now cos when you stand up against these chest ones
and you know they they click the thing thinking about it now I think to myself why aren't you in front of it ... to get one of your chest why are you in front of the um thing standing back to it . then the radio activity is passing through your bones and then hitting the film giving an image but this isn't if you sort of ...

264 I is it a bit like back to the tooth one again?

285 C yea

517 286 I where the where it seems to be in the wrong place?

287 C yea that's right it seems it seems all to be in the wrong ................ although ...... I can't really remember I sup . if if I suppose .. wh I've sometimes I've when I go to an orthodontist . you know to find out about my teeth you lay you you have to sit on a chair and keep your head laid down on a plate to get you know the sort of whole jaw effect . and they put this plastic thing here . so the radiation's passing through you and then going on to the plate . so I suppose on this they probably put the ... thing .. oh of course it is you've got the plate underneath you for instance on my arm . and then the radiation goes through it's still the same . so I suppose on this one they'd put the um . thing that gives off the radiation on your back and it's sort of giving off a light a very sensitive light that the plate can pick up .. and producing an image on the other side.

288 I . hum . so you've got a feeling then it it

289' C then it is light

290 I it could be?

536 291 C yea I suppose it is light ........ um . yea

292 I okay then let's stick that one somewhere and let's look at another one are there . are these more difficult or easier than some of the others I mean /from other interviews/ ........ are are you finding

293 C . it's I don't I find it difficult I mean . just sort of sitting here thinking about it's quite good because . you know sometimes you think of things .. that you haven't thought of before er . I'll put this .. I don't know . I'll just . put it . on its own /not with the other cards/
Tape 175

294 I ........ let's jump those for a minute and how about how about something like that that.

295 C .............. sun-bathing /L8/

296 I attractive picture though isn't it?

297 C yea (both laugh) great I can't also can't work out how a stick man's got bones like that.

551 298 I (laughs) I mean that one's (both laugh) that one's actually sort of like a bit of a cartoon isn't it?

299 C yea

300 I you know where you've got the sort of the (laughs) I didn't know how else to draw it I mean (laughs).

301 C .... er someone sun-bathing ........ that's obviously a lot to do with light and heat together ....

302 I hum ........ I mean how does it do that I mean what were you thinking of?

562 ... is virtually pure ... but light from the sun is mixed with all sorts of other lights you know.

303 C ........ well this is again heat

304 I does it do it normally on your hand when you're out sort of walking around every day?

305 C .. I don't know your hands are sort of ... obviously um .... because it's not hot enough like it's got to be hot enough and bright enough although I don't know you I mean .. I've been to Switzerland ski-ing and it's very cold. and yet you come back with a sun-tan....

306 I .. you've been to Switzerland ski-ing

307 C yea and you come back with a sun-tan I mean . only on your face and the back of your hands and your arms if I I sometimes I used to walk around in the hotel or whatever in a T-shirt .. and then you I know I came back with a sun-tan but obviously that's . the sun is . there's har . there's when I was there there wasn't a cloud in the sky .... and the sun was very very strong but it wasn't hot.
it was still very cold ... and um .................. 
.. and . the um light reflecting . off the sun 
. oh um off the snow .. because the snow's you 
know . virtually like a mirror.......... was giving 
um .. giving me the burn

308 I do you actually get an image in snow?

309 C no

310 I I mean you said it's like a mirror

311 C I mean .. if you polish it down to ice then you 
can but then again snow and ice is different I 
mean then it's not really the same you don't get 
an image it's not ... it's you're not it's not 
like an im a mirror because you know . it's like a 
mirror because it's reflecting something not just 
because you can see your face in it and it's refl-
ecting something .. and I don't know I .. this is 
.. what . as I said (*) you know I think .. light 
and heat are very very ...... closely .. together

312 I yea .. but which one is actually doing the sun 
tanning you're not sure?

313 C well I don't it's I'm not sure

314 I when you say burn do you mean sun burn

315 C well you don't always get burnt I mean you usually 
go brown ... some people do burn and go red but 
it's not really a burn it's a tan .. I mean it's 
just ...... well I don't know I mean ............
I suppose hitting a white person it's reflecting 
...... yet hitting a black person it's absorbing well 

316 I hum ... well can a can a black person get a suntan?

317 C .... no that's oh that's a difficult question I 
suppose . they can .. I don't know you always feel 
better somehow . you know if you're sun tanned 
you always feel well usually it feels better I 
mean obviously .. it relaxes you and . I don't 
know (*) I suppose if it's ultra violet rays. it 
could be sort of re-charging your body ...... and 
doing something to your body cells I mean I don't 
know if a black person get a can get as I suppose 
they can yea um ..... but then again it obviously 
depends what part of the world they originated from 
I mean my theory is . I mean it may sound a bit 
silly but a black people that are living in this
country now as the generations are going on I mean you can notice it visually they're slowly getting lighter and lighter whether they've had you know .. a white person in their family at any time they.. whether they have or haven't they're slowly getting lighter and lighter because of our climate ... and they're saying at the moment .. that we're going to have snow like this for the next ten years anyway .. in the winter

I and you imagine people get paler and paler?

yea and er .. I mean unless you know .. you go to Jamaica or .. somewhere really hot for a month . month every year then it'd keep you sort of .. in trim I mean .. I don't know .. some .. it's different it's a difficult thing thinking of a sun tan (you know I mean?) you can't tell whether it's the .. I mean you can't get a tan from an electric light .. but . you can now you buy . sun ray lamps . they're giving off ultra violet light and that does brown you ..... so it's definitely something to do with ultra violet rays

okay wh what about something like that one . /candle L6/

I don't know this is the thing it's a candle .. you can obviously get ... it's giving off light because it's .. a flame ... and it's . I mean it gives off heat as well well a candle will only give off a bit of heat ...

.... oh yea you can actually burn yourself when you stick your hand on top of it

yea . but I mean it's not enough to sort of if you're freezing cold to huddle round the candle but you can obviously burn yourself yea ....... um .. but it

can I ask you another question ... does it make a difference to the candle whether it's whether it's day or night?.... if you stand away from it?

yea ..... I see what you mean no it doesn't does it . it doesn't make a . blind bit of difference . to a candle whether it's day or night ....... I mean at it at night obviously it will shine out brighter . because there's no other light . around .. but it during the day (end of tape)
Appendix IV

LIST OF SCHOOLS INVOLVED IN THIS PROJECT

Carnforth High School, Lancashire.
Cranford Community School, Hounslow West, London.
Featherstone Comprehensive, Southall, London.
La Sainte Union Convent School, London, N.W.5.
St. Joan of Arc, Rickmansworth, Hertfordshire.
Stantonbury Campus, Milton Keynes, Buckinghamshire.
Thurston Upper School, Bury St. Edmunds, Suffolk.
Warigel Copse School, Reading, Berkshire.
Appendix V: The 'Energy' Authentication Questionnaire
On the following pages you will find some of the sorts of things that young people in school might say about the word energy. Their discussions of energy have been summarised by seven different statements, one on each page. I would like to know how you react to each statement. Under each one, are some extracts from their talk that could be examples of the statements. There are also some pictures of what is being talked about.

Please read each statement and write a brief note of your reactions in response to the following three questions:

- Do you find it believable? That is, do you think these are the sorts of things that young people would say?

- Is it sensible? Does it make sense for someone to talk about energy this way?

- Is it a useful way to talk about energy?
'The person has got a lot of energy in that one. I mean, he can push it the whole way up to the top of the hill. But once the box is there it can't do anything, so the box definitely hasn't got any energy, whereas the person can walk back down.'

Pushing a heavy box up a hill

'They (the two reacting chemicals) have energy in them. I mean they don't go around talking to things, but I mean they've got energy in them. So I suppose in their own sort of way they are living.'

A chemical reaction

Is the statement believable?

Does it make sense?

Is it useful?
Some things are a source of energy. Other things need energy, which they can get from a source. Some things don't need energy at all.

'Well, the battery has got energy, the bulb needs it. The wires ... well they're just ordinary wires, aren't they?'

The energy is in the person, he's using up energy, in his arms, legs, and muscles. The sledge doesn't have any energy. No, it's all in the person.'

Is the statement believable?

Does it make sense?

Is it useful?
Statement 3

Energy is an ingredient in things. It will only take effect when something else happens to it.

'Well there's energy in things, but it needs another form of energy to make it come out. It's like a seed, it's got energy inside it to grow but it needs the sun to make it happen.'

A flower in a pot

'One chemical needs another chemical to make it react and for it to have energy.'

A chemical reaction

Is the statement believable?

Does it make sense?

Is it useful?
Statement 4

Energy is things happening

'I think energy is a fire burning, a telephone ringing, chemicals frothing, people running, that sort of thing.'

Two people colliding as they run

'The bell would be doing energy as well, and the ticking of the clock, that would be energy.'

An alarm clock

Is the statement believable?

Does it make sense?

Is it useful?
Statement 5

Energy is being made all the time. The energy that is made is then either used or given off.

'Sugar and glucose produce energy in the body. It's the body that makes the energy, it is things in the body that make it from the food. And then you use it up.'

Eating a meal

'Chemical reactions, they produce a lot of energy. If they are violent ones they give off a lot of energy too. Chemical energy is energy produced by chemicals.'

A chemical reaction

Is the statement believable?

Does it make sense?

Is it useful?
Statement 6

Energy is to do with machines. Where there are no machines turned on there is no energy.

'Energy has got to make something else work. If it was electrical energy then it would make something like a tape recorder work.'

A power station

'Oh no, the sledge has no energy. I mean, it hasn't got a motor or an engine or anything so it hasn't got any energy.'

Sledging in the snow

Is the statement believable?

Does it make sense?

Is it useful?
Statement 7

Energy is something that can flow from place to place. It can also move from one object to another.

'Energy comes out from both leads. It comes out of the negative end, flows round the circuit, encountering the light bulb on the way. There it can transfer some of the energy, and then goes back to the battery.'

A battery, bulb and switch

'Well, the energy goes through him into the box. As you push, you push the energy into the box to make it move.'

Pushing a heavy box up a hill

Is the statement believable?

Does it make sense?

Is it useful?