A CONCEPTUAL FRAMEWORK FOR SCIENCE EDUCATION:
INVESTIGATING CURRICULAR MATERIALS AND CLASSROOM
INTERACTIONS IN SECONDARY SCHOOL PHYSICS.

by
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TO CECÍLIA

(she knows why)
In this study a framework considering the transformations and interactions of different forms of knowledge is proposed as a way of conceptualizing cognitive aspects of science education at secondary school level. It is argued that the framework is compatible with a recent constructivist trend in research which stresses the role played by children's existing conceptions in the construction of their knowledge.

In the first part of the thesis the components of the framework (scientists', curricular, children's, teachers' and students' science) are described. The second part consists of the presentation of four case studies in which textbooks and instances of classroom interaction in secondary school physics are explored.

In the first two case studies the framework is applied in the exploration of two topics of secondary school physics: "Light and Colour" and "Force and Movement". Aspects of the curricular presentation of the topics and of the instances of classroom interaction observed are analysed. In the remaining case studies, two instances of classroom interaction involving laboratory practice are also analysed. The case studies present a critical review of the aspects observed in the light of a constructivist view of knowledge.

In the concluding chapter of the thesis some implications for practice and research in science education are considered.
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CHAPTER ONE

INTRODUCTION
1. INTRODUCTION

1.1 Alternative Conceptions and Construction of Knowledge

The fact that children tend to develop their own conceptions about certain aspects related to the nature of the physical world has been known for a long time. Formal research on this topic can be traced back to the earlier work of Piaget (1929; 1930) in which the clinical interview technique was employed for the investigation of children's interpretation of natural phenomena.

Only in recent years, however, research workers in the field of science education appear to be realizing the full educational implications of this form of knowledge. Gilbert (1980), reporting on the "Cognitive Development Research Seminar - Science and Mathematics Education", held at the University of Leeds in September 1979, observed that:

"The area that attracted the greatest interest, as manifest by the number of papers, liveliness of discussion and number of informal group meetings, was that of 'alternative frameworks', i.e., student conceptions that differ from scientific norms, and their implications for teaching."

(Gilbert, 1980)

Steadily increasing research evidence, accumulated from different sources, indicates that these conceptions, in the form of expectations, beliefs and meanings for words, cover a large range of science concepts. They can be seen as providing an understanding of the world from the person's point of view. There are also indications that, for most of the pupils, some of these alternative conceptions are strongly held and resistant to traditional formal teaching.
Rather than the discovery of a new phenomenon, what seems to be emerging from this new research wave is a new interpretation. Instead of being regarded simply as primitive forms of understanding, that can be easily disposed of in the process of formal schooling, these alternative views of the world are now starting to be seen as personal explanations, which make sense from an individual's point of view. Therefore, their integrity should be granted and respected in the educational process. The corollary is not that alternative conceptions should remain unchallenged, but that the challenging processes must be reviewed.

This change of perspective is clearly reflected at the semantic level. References implying a negative connotation, such as "misconceptions" are being replaced. Driver and Easley (1978), for instance, prefer to talk about "alternative frameworks"; Osborne (1980) suggested the expression "children's science" to signify pupils' world views which do not conform with the accepted scientific ones; Claxton (1982) suggests that children develop "mini-theories", and uses terms like "gut science" and "lay science" in order to contrast them with "school science".

The new terminology can be interpreted as signalling a movement towards a constructivist perspective in science education. According to this perspective science education should acknowledge the role of individuals in the construction of their personal knowledge. This implies the acceptance of the fact that pupils do approach teaching-learning situations not as impotent reactors, or as a "tabula rasa", but with already existing conceptions which play a role in the way they
make meaning of what they are expected to learn.

Apart from being influenced by the research in the field of alternative frameworks, the shift towards a constructivist position was also influenced by a growing awareness by research workers in science education of the changing perspectives experienced by philosophy of science in the last 20 years. Naïve realism—postulating a one-to-one relationship between theory and reality—and empiricism—assuming scientific knowledge to be directly derived from sensorial experiences—were discarded as accounts of the nature of scientific knowledge. The work of Hanson (1958), Toulmin (1961, 1972), Kuhn (1970) and Feyerabend (1975) among others, stressed the role played by worldviews or "Weltanschauungen" in the generation of scientific knowledge.

The connections between a constructivist perspective, the modern views in philosophy of science, and recent developments in science education research were indicated by Driver (1979):

"... pupils, like scientists, come to science lessons with some ideas or beliefs already formulated. These beliefs affect the observations they make and the inferences they draw from them. Pupils, like scientists, have construed a view of the world to enable them to cope with situations. Changing this view is not as simple as giving pupils additional experiences on sense data. It also involves helping them to reconstruct their theories or beliefs, to undergo, if you like, the paradigm shifts which have occurred in the history of science."

(Driver, 1979)

In the passage, quoted above, Driver was making use of a metaphor, "man-the-scientist", created by George A. Kelly to symbolize his view of human behaviour, expressed in his
Personal Construct Psychology (Kelly, 1955). Although not the only theorist whose views could be accommodated in a constructivist framework, Kelly deserves special mention, since, more than any other, his name has been associated with a constructivist posture. The view that Kelly's Personal Construct psychology, and its associated epistemology, Constructive Alternativism, can provide a new and relevant approach for education in general and science education in particular, has been voiced recently (ASE, 1979; Pope and Keen, 1981; Gilbert, 1982).

Personal Construct Psychology is a growing field of research, but since it was initially developed for clinical purposes it is not surprising that its applications to the educational field, although promising, are in an embryonic stage. The full implications, arising from the adoption of Kelly's framework as a basis for science education have yet to be developed, and it is outside the scope of this study to do a profound analysis of Personal Construct Psychology and its possibilities for science education. Nevertheless, since some of Kelly's ideas can illuminate aspects of the constructivist perspective followed in this thesis, the presentation of some of its basic assumptions is worthwhile.

Kelly's approach to human behaviour is based on a metaphor, "man-the-scientist", which is justified on the grounds that:

"To a large degree - though not entirely - the blueprint of human progress has been given the label of 'science'. Let us then, instead of occupying ourselves with man-the-biological organism or man-the-lucky-guy, have a look at man the scientist."

(Kelly, 1963, p. 4)
When speaking of "man-the-scientist", Kelly makes it clear that he was not referring to those who made science their main activity or profession but that he was speaking:

"... of all mankind in its scientist-like aspects, rather than all mankind in its biological aspects or all mankind in its appetitive aspects. However, we are speaking of aspects of mankind rather than collections of men. Thus the notion of man-the-scientist is a particular abstraction of all mankind and not a concrete classification of particular men."

(Kelly, 1963, p. 4)

Kelly's insights in exploring the scientist-like aspects of human behaviour led him to reject the model of man assumed by behaviourism, the dominant current in psychology in the 50's. Instead of picturing people as "impotent reactors" Kelly stressed the idea that people understand themselves and their surroundings, by anticipating future events through the construction of tentative models. These models are evaluated against personal criteria, such as prediction and control of events based in the model.

Although admitting the existence of an external and independent reality, Kelly claimed it to be presumptuous to assume that a person's constructions of reality are convergent with it. He suggested that events are subject to as great a variety of constructions as our wits would enable us to contrive and rejected an absolutist view of truth. In this sense even the most highly developed scientific theories are to be considered as provisional in nature and open to reconstruction. However, taking into account that an independent reality does exist, some constructions are better than others in coping with it.
The acceptance of a constructivist perspective would certainly imply a revision of approaches to science education. Addressing this issue Pope (1982) points out that:

"For Kelly, successful communication between people depended not so much on commonality of construct systems but upon the extent to which people could 'construe the construct system of the other' - i.e., have some empathy and understanding of someone else's constructs whilst not necessarily holding the same constructs oneself. There is now a growing group of educators who argue that, for the teaching learning dialogue to be effective, it is important for the teacher to come to an understanding of the students' frameworks."

She also stresses the pedagogical importance for the pupils to be exposed to a range of conceptions held by the teacher and their peers. This interchange of ideas can facilitate communication and "offer a further range of experience within which pupils may reconstruct their models" (Pope, 1981).

The Personal Construction of Knowledge Group (PCKG) at the Institute of Educational Development - University of Surrey, has been particularly concerned in working out some of the implications that a constructivist view can have for science education. The study forming the thesis is intended to be a contribution in that direction. It is one of its aims to explore some possibilities by adopting a critical analysis of some current practices as a starting point.

1.2 A Conceptual Framework

From the constructivist perspective assumed in this study, alternative conceptions held by school pupils (and older students) are to be regarded and respected - and by this I do not mean remain unchallenged - as part of an in-
individual person's view of the world. Osborne (1980) suggested the expression "children's science" to describe those views of the world (composed by beliefs, expectations and meanings for words) which do not usually match with their scientific counterparts, "scientists' science".

In a paper written in 1980, Gilbert, Osborne and Fensham (1982) introduced the expression "teacher's science" to represent the teacher's viewpoint or ideas, as presented to a group of pupils. Teachers, however, usually prepare their lessons by using curricular materials, and since a specific curriculum can be viewed, in itself, as a particular version of scientific knowledge, the expression "curricular science" can be suggested to mean this version. With this fourth element included a more complete picture of the transformations and interactions between different forms of knowledge, in the context of secondary school science education, can be articulated (Zylbersztajn, 1980) as depicted in Figure 1.1.

Fig. 1.1 The Conceptual Framework
In a first stage, "scientists' science" (Sₜ) is transformed into "curricular science" (SCR), in a process mediated by the action of curriculum planners (e.g. textbook writers; members of curricula development projects). Science curricula, either in their simplest forms (e.g. a textbook) or in their more refined versions (e.g. as an integration of printed, AV, and laboratory materials, plus teacher's guides) are here conceived of as structures representing versions of scientific knowledge.

The second stage of transformation occurs when a curriculum is implemented by a particular teacher, concerned with a particular group of pupils, in a particular school. One of the assumptions of this study is that teachers interpret the structure of a curriculum in the light of their own conceptual structures and their perception of the situations they are involved in. Therefore, what is conveyed by them to their pupils - "teacher's science" (Sₜ) - can be seen as a result of the interaction between teachers and "curricular science", in a specific context.

The third stage of transformation takes place in science courses, when pupils perceive, interpret and process what is presented to them, constructing their own personal meanings from the activities they are asked to perform. It is in that process that their previous knowledge - "children's science" (Sch) - seems to play an important role. Those activities are conceptualized in the framework as the interaction between "children's science" and "teacher's science", the result of which is named "students' science" (SST).
The conceptual framework presented above offers a simplified picture of the complex reality it is intended to represent. Teachers, for instance, may complement their lessons with information extracted from sources other than curricular materials; pupils in their turn may interact directly with textbooks and other sources of information, particularly in the case of individualized learning schemes.

Nevertheless, even considering these possibilities, it can still be argued that the framework described, represents major transformations of knowledge occurring in the context of secondary school science education. As such, it provides a distinct way by means of which science education at that level can be, on first approximation, conceptualized. A way that stresses the important role played by the pupils' alternative conceptions, and therefore is compatible with the recent trend taken by research in science education.

1.3 Statement of the Study and Outline of the Thesis

The rest of this thesis is divided into two parts. In Part A (Describing the Framework) my main concern is to characterize the components of the conceptual framework introduced in the previous section. Therefore, in Chapters 2 to 6 I describe in detail each of the forms of knowledge composing the framework and present results of research related to them. This part of the thesis is mostly based on a review of the literature. Of particular importance in Part A is Chapter 2. Scientists' Science. In it I state the view of the nature of scientific knowledge which, together with the constructivist view of human knowledge in this chapter, constitute the main assumptions of this study.
In Part B (Applying the Framework), four case studies are presented. This presentation was designed to serve two purposes. Firstly, it is intended to illustrate, with concrete instances, the forms of knowledge described in Part A, and in this sense, it has a clarificational purpose. Secondly, the case studies offer me the opportunity of exploring some situations in secondary school science education from the point of view provided by the conceptual framework introduced in this chapter. The methodology of case studies was selected because it allows the exploration of the situations investigated with a depth and level of detail that cannot be achieved in more quantitative studies.

This exploration consists basically of a critical analysis of some selected curricular materials and some instances of classroom interaction. In the former case my main aim is to show how the analysis of "curricular science" can be informed by a study of "scientists' science" and "children's science". In the latter, the focus of attention is on the interaction between "teacher's science" and "children's science". A detailed description of the case studies is presented in Chapter 7.

In the first two case studies the conceptual framework is applied comprehensively. Practical limitations inherent to the production of a PhD thesis, however, restricted the scope of the other two. In them the investigation is concerned primarily with the classroom interaction component of the framework. Even so, their inclusion can be justified on the grounds that they involve instances of classroom interaction which are qualitatively different from the ones considered in the first two case studies.
In the presentation of the case studies (Chapters 8 to 13) I follow a critical approach which allows me to highlight and stress the contrasting points between the practices observed and the assumptions underlying this thesis with regard to the nature of knowledge in general (a constructivist view) and scientific knowledge in particular (a view based on the work of T.S. Kuhn). Although acknowledging the fact that case studies do not provide scope for straightforward generalizations, I believe that the situations selected for exploration are representative, and the critique, therefore, relevant in relation to current practices.

The critical approach followed in the presentation of the case studies has a value of its own, since any change of a given situation presupposes a critique of it. On the other hand, a sense of incompleteness remains if a critique is not complemented by a consideration of its implications. This aspect is, therefore, considered in the final chapter of this thesis.

The situations considered in this study are particularized to the subject of physics at secondary school level. The decision to limit the investigation to this subject was based on the assumption that my acquaintance with it, derived from my previous experience as a physics teacher, and as a lecturer in the practice of physics teaching would enable me to have a deeper understanding of the situations studied. Therefore, this choice reflects a personal limitation, rather than a limitation of the conceptual framework proposed.
CHAPTER TWO

SCIENTISTS' SCIENCE
2. SCIENTISTS' SCIENCE

2.1 Introduction

My aim in this chapter is to approach the topic of "scientists' science" by considering contrasting views related to the nature of scientific knowledge. The major concern here will be located on a general philosophical level and no attempts will be made to analyse the nature and evolution of particular scientific conceptions (e.g. the concept of force; theories about the colours of light). This sort of more detailed analysis of particular instances will be undertaken in later chapters of the thesis.

The reason for starting with a presentation drawing heavily on the philosophy of science is that it will allow me to state from the very beginning the view of the nature of scientific knowledge which will function as a background for the rest of the thesis.

It is generally admitted that one of the aims of science education should be the acquisition by the students of an appreciation of the nature of the scientific enterprise, and even some traditional textbooks do pay homage to this ideal:

"The whole text has been planned and revised, not only as a firm basis for the studies of future physicists and engineers but also present physics as a human intellectual discipline with deep roots in the past and largely responsible for the development of our technological culture."

(Abbot, 1978, Preface)

Sometimes this preoccupation generates pedagogical advice:
"The schoolboy learning physics is a physicist and it is easier for him to learn physics behaving like a physicist than doing something else."

(Bruner, 1960, p. 14)

A view that was also to be incorporated in the so-called "Nuffield spirit":

"The pupils can acquire the feeling of doing science, of being a scientist. Some teachers even like to set the tone of work in the lab by saying: 'Be a scientist for the day'."

(Rogers and Wenham, 1977a, p. 5)

However, as it will be shown in Chapter 4, most physics curricula do convey a view of the nature of scientific knowledge that has been superseded by modern philosophy of science. In order to set the background for the illustration of this fact, and to suggest an alternative, the present chapter will consist basically of the presentation of two contrasting views on the issue.

The empiricist view of scientific knowledge, that dominated philosophy of science during nearly three centuries, is initially discussed with special emphasis being placed on the classical empirical-inductivist account (which will be shown to be still influential in school science nowadays) and on its sophisticated offspring, logical-positivism.

The section on empiricism is followed by the presentation of T.S. Kuhn's views about the nature of scientific knowledge. Kuhn was not the only one to present alternatives to the empiricist tradition and can be seen as one representative among others in the reaction against logical-positivism which took place during the last 25 years. There can be no doubt,
however, that his views have been highly influential, and the importance of exploring his views in the context of science education have already been hinted at by several authors (Cawthron and Rowell, 1978; Donelly, 1979; Richardson and Boyle, 1979).

Since this is not a thesis on philosophy of science I do not feel obliged to argue extensively for adopting a Kuhnian perspective method instead of the ones of other critics of logical-positivism such as Toulmin, Popper, Feyerabend and Lakatos for instance. The state of disagreement in modern philosophy of science, apart from its abhorrence of logical-positivism, does justify a science educator to, pragmatically, choose one particular view. From a personal perspective, however, I could explain my inclination for Kuhn by saying that it is related to the match between his views, particularly those concerning normal science, and my experience as a student in a physics department. Nevertheless, in presenting Kuhn's views I will draw attention to some of the criticisms that have been levelled against them, together with the attempts to answer those criticisms.

2.2 Empiricism

2.2.1 Classical Empiricism. The origins of a systematic empiricist philosophy of science can be traced back to the attack launched by Francis Bacon in the early seventeenth century, against medieval scholastism. By pleading that natural philosophers should accurately observe nature rather than involve themselves in sterile arguments about the Aristotelian doctrine, he established the basis of what was
to become known as the empirical-inductivist view of science (sometimes also called Baconian inductivism).

Bacon was very much a Renaissance man, and one reason for the impact of his ideas was that they captured the intellectual climate of his time, during which different aspects - logic, theology, physics and ethics - of Aristotelian scholasticism were under pressure (Quinton, 1980).

The acceptance of Bacon's approach can also be seen as a reaction against Cartesian rationalism. In opposition to Descartes, who envisaged an explanation of the universe by means of a comprehensive deductive mathematical theory based on his rules of method, Bacon proposed an inductive treatment of systematic experimentation. Universal knowledge was to be achieved through large schemes of research, which would produce massive amounts of data from which scientific knowledge could be extracted.

The cornerstone of Baconian inductivism is the principle of induction which asserts that "universal statements", which constitute the essence of scientific laws and theories, can be generalized from a finite number of "singular statements" based on observations. Inductivist generalisations are considered to be valid provided that the number of observations is large, that they can be replicated, and that they do not conflict with some of the singular statements. Once such a body of scientific knowledge is inductively built up from an observational empirical basis, predictions and explanations can be generated through a deductive procedure.
In his "Novum Organum" Bacon formulated an algorithmical approach for discovery according to which "all" observed instances of a given phenomenon were to be recorded systematically. In a second stage the compiled tables of observation were to be analysed and relations sought for. It was Bacon's belief that even people of modest intelligence could be trained to do scientific research by following his methodological rules and that, therefore, scientific progress would not be dependent on the rare emergence of scientific geniuses (Brush, 1974a).

In spite of this optimistic claim, Bacon's own contribution as a natural scientist was almost nil, and his brilliant insight in the nature of heat, as resulting from the motion of small particles of matter, was based on hypothetical-deductive arguments rather than on inductive reasoning (Jevons, 1969). On the other hand, his contempt for speculation led him to reject as non-scientific theories like Gilbert's magnetism and Copernicus' astronomy. It must be acknowledged, however, that his writings helped to establish science as a modern social institution, and that early members of the Royal Society were strongly influenced by his empirical and utilitarian view of science (Brush, 1974a).

If Bacon formulated the methodological basis of classical empiricism, its epistemological justification was first articulated by Hume in the mid-eighteenth century. Although he did not accept induction from a logical point of view, he justified it by means of a psychological account on how we form the habit of expecting the future to be similar to the
past, and how we act in accordance to this habit. Furthermore, he argued that sensory impressions are the ultimate existents and the fundamental building blocks of reality. In this way statements of matter of fact are referred to the experienced world and the truth value of such statements is determined by reference to experience (Brown, 1977).

Baconian inductivism and Humean epistemology were blended with the materialistic and mechanistic view of the world that followed the success of Newtonian mechanics, generating a view of scientific knowledge which became widely held both by philosophers and scientists during the nineteenth century. This view is summarized by Suppe (1977):

"Thus, according to mechanistic materialism science can present a picture of the world firmly based on empirical inquiry, rather than upon philosophical speculation. In this picture matter is primary, and there is no doubt that a real, objective world exists independent of individual perceivers; science is the discovery of the mechanisms in this objective world whereby animate and inanimate matter behaves and realizes itself. The product of science will be mechanistic laws governing life and the world - that is, mechanistic laws governing matter in motion. The scientific method yields immediate and objective knowledge of these laws, and is capable of doing so by empirical investigation without any resource to philosophical speculation. Thus there is no place for a priori elements in natural science or in empirical knowledge. Observation of the world is immediate in the sense that no a priori or conceptual mediation is involved in obtaining observational knowledge; observation in accordance with the procedures of natural science is sufficient to yield knowledge of the world's mechanistic nature."

(Suppe, 1977, p. 8)

The empirical-inductivist view of scientific knowledge, systematized by J.S. Mill in his "A System of Logic", published in 1868, became a common popular account of the nature of science. Chalmers (1978) observes that the appeal of this view seems to lie in the fact that it gives a formalized
account of popular impressions regarding the nature of science, such as its explanatory and predictive power and its objectivity and reliability when compared to other forms of knowledge.

2.2.2 Logical-Positivism. The empirical-inductivist account of science described above is still today a commonly held view and certainly a strong component of the school science ideology (Cawthron and Rowell, 1978). However, as far as philosophy of science is considered, it evolved towards a far more sophisticated articulation - logical positivism - which dominated the field from the 1920's to the late 50's.

Logical-positivism can be regarded as an extreme form of empiricism in which the thesis, that scientific knowledge was to be restricted to claims founded directly on empirical experience and metaphysical speculations were to be uprooted from human enquiry, was pushed to an extreme. According to it assertions about the world were regarded as meaningful only if their truthness could be empirically checked. This view generated a "verification theory of meaning" which assumed that the meaning of a term is its method of empirical verification and therefore meaningful discourse was to be made (or at least rephrased) in a phenomenal language (Suppe, 1977).

The central task envisaged by logical-positivists was the development of a precise and consistent language in order to overcome the pitfalls of ordinary language. The problems faced by logical-positivism were primarily logical problems such as the logical structure of theories and the logical relations between observation and theory. Although it is out of the
scope of the thesis to give a detailed account of the problems faced by logical positivism (see Brown, 1977 and Suppe, 1977 for this), in the next section I will consider two of them which are most relevant for this study.

2.2.3 The Problem of Induction. The principle of induction has been under attack since the mid-eighteenth century, when it was challenged by Hume, on the grounds that it cannot be justified from a logical point of view. The argument makes the point, that no matter how large the number of singular observations is, the generalizability of the universal statement is always jeopardized by the logical possibility of a counterexample to be observed. A similar critique can also be applied to the idea held by some empiricist that the principle can be justified on the basis of experience. The empiricist argument is that, since universal statements based on induction appear to be obeyed in several occasions, the principle is correct. This argument, although psychologically appealing, is nevertheless logically faulty: the fact that the principle of induction worked in several occasions, does not justify the conclusion that it will always be successful.

Attempts to solve this problem led to a retreat to a weaker position based on probabilistic inferences, and to the development of forms of inductive probabilistic logic. Chalmers (1978) observes that this line of research contributed more to the discipline of probability than to an understanding of the scientific enterprise.

Apart from the logical problems related to the justification of inductive confirmation, the Baconian view, held by
classical empiricists, that scientific discoveries that were based on inductive reasoning had also been severely criticized. Even Galileo, who was traditionally presented as the archetypical empirical-inductivist scientist has been shown in a different perspective (e.g. Koyré, 1978; Feyerabend, 1975; Wallace, 1981). The image of Galileo derived from these sort of studies is that he arrived at his theories, not through an inductive analysis of his data, but rather in spite of his data.

The difficulties facing an inductivist logic of discovery is illustrated by a comment of the Nobel prize physicist Steven Weinberg, concerning Hubble's conclusion, in 1929, that a linear relationship exists between the velocities and distances of galaxies:

"Actually, a look at Hubble's data leave me perplexed how he could reach such a conclusion - galactic velocities seem almost uncorrelated with their distance, with only a mild tendency for velocity to increase with distance. In fact, we would not expect any neat relation of proportionality between velocity and distance for these 18 galaxies - they are all too much close, none being further than the virgo cluster. It is difficult to avoid the conclusion that, relying either on the simple arguments sketched above or the related theoretical developments to be discussed below, Hubble knew the answer he wanted to get."

(Weinberg, 1978, p. 35)
(Emphasis added)

The problems concerning an inductive logic of discovery led logical-positivists to assume a distinction, introduced by Reichenbach (1938), between the "context of discovery" and the "context of justification". According to this view problems concerning the context of discovery belong to the field of psychology, and only problems concerning the justification of scientific theories are to be considered inside
the scope of philosophy of science. However, even in that restricted context, logical-positivism failed in its attempt to develop a theory of confirmation based on inductive logic (Brown, 1977; Chalmers, 1978).

2.2.4 The Theory-Ladeness of Observation. The most basic assumption of empiricism is that scientific knowledge should always be referred to on an observational basis. Enshrined in that assumption is the belief that observations performed by unbiased scientists give direct and objective access to the real world and reveal it as it is. The privileged status of the observational basis, which characterized classical empiricism and logical-positivism is a product of that belief.

One of the better known challenges to this assumption was presented by Hanson (1958). He argued that the act of perception in itself, and not only the interpretation of perception, is influenced by the observer's past experiences and worldviews. A nuclear physicist, for instance, will perceive, in a cloud chamber, tracks of atomic particles, while an untrained person would just note a succession of dots.

In the same line, a damaging challenge was directed towards the neutrality of singular observational statements, which according to the logical-positivists should constitute the public language of science. Critics of logical-positivism, such as Hanson (1958), Kuhn (1970a) and Feyerabend (1975) argue that observational statements always presuppose, at least implicitly, a theoretical background. They observe that even simple observational statements such as "the electric current is X amperes involve theoretical presuppositions about
the meaning of electric current and about the functioning of the apparatus and used to perform the measurement. In this sense, observation is theory-laden.

Popper (1968), Kuhn (1970), Lakatos (1970) and Feyerabend (1975) presented historical and philosophical evidence stressing the role played by theory in the development of science. According to their view scientists approach the observed phenomena guided by theories, which by acting as selective spectacles, dictate what is to be observed, how the observations are to be conducted, and influence the conclusions to be drawn from the data. The quote from Weinberg presented in Section 2.2.3 serves to illustrate the point.

2.2.5 Alternatives to Logical-Positivism. The difficulties faced by the logical-positivist philosophy of science in dealing with the problems above, and others such as the problem of reduction of theoretical terms to observational language and the problem of explanation in science, led to two sorts of development. On the one hand, some of its original assumptions were weakened leading to probabilistic forms of induction and to the partial abandonment of the verification theory of meaning. This moderate version of logical-positivism is sometimes referred to as logical-empiricism (e.g. Brown, 1977).

On the other hand, more radical departures from the logical-positivist programme were articulated. In the 30's Popper published his "Logik der Forschung" (Popper, 1968), in which he attempts to substitute the problematic inductive logic of confirmation by a logic of falsification. Popperian
falsificationism is based on the notion that although a theory can never be proved to be true, it can be proved to be false by observations that are in disagreement with predictive statements logically deduced from the theory in question. In order to gain the scientific status, argues Popper, a theory must be potentially open to falsification. Scientific theories are regarded as conjectures which at the same time are corroborated by successful predictions and are also open to experimental reputation. Once falsified, a theory should be abandoned and new conjectures proposed.

The Popperian proposal has been attacked on historical grounds (Chalmers, 1978). Newton's gravitational theory, Bohr's theory of the atom, the kinetic theory and Copernicus' theory are cases in which a new theory was not abandoned in its early stages, in spite of falsified predictions. In those instances, the credit given to the theory proved to be beneficial for further development in the field.

A more radical departure from logical-positivism is found in the work of Hanson (1958), Toulmin (1961), Kuhn (1970a), Lakatos (1970) and Feyerabend (1975). Contrasting with logical-positivism, this new approach to philosophy of science rejected formal logic as the primary tool for the analysis of science, replacing it by historical, sociological and psychological analysis. Suppe (1977) refers to this approach as "Weltanschauungen Analyses", because it assumes that science is done from within a "Weltanschauung" (view of the world; conceptual perspective); scientific research is then assumed to be an attempt to interpret nature in terms of theoretical presuppositions.
Brown (1977) talks about a "new image of science" being created from the new concerns, problems and methods of philosophy of science. In the next section I will present some aspects of the views of T.S. Kuhn, who is probably the most influential representative of the "Weltanschauung" approach. The presentation does not aim to provide a comprehensive overview of Kuhn's ideas, but will rather concentrate on those aspects which are more distinctive in his views, namely the notions of paradigms, normal science and revolutions.

2.3 Kuhn's Views on the Nature of Scientific Knowledge

2.3.1 The Kuhnian Approach. "The Structure of Scientific Revolutions" (Kuhn, 1970a) can be seen as an attempt to delineate a new image of science, in opposition to the one disseminated by the dominant logical-positivist movement and traditional scientific historiography. The first edition of the book dates back to 1962, a time at which authors like Lakatos and Feyerabend had not yet published their major works and Popper was almost completely ignored by philosophy of science. Although at that time Toulmin and Hanson had already questioned the prevailing tradition, the impact of "The Structure" was far greater.

Kuhn's approach departed sharply from logical-positivism. The latter was mostly concerned with the application of the "rules of truth", developed by formal logic, to the analysis of the relationship between theory and observation in science and with the development of a neutral observation language, in terms of which debates involving theories evaluation and choice could be conducted in an objective manner. Kuhn
adopted historical analysis as a major research tool and advanced arguments pointing towards an inseparable entanglement between observation and theoretical presuppositions.

Any presentation of Kuhn's views is faced with the problem that, although his basic framework remained unchanged, some of his central ideas were reformulated and clarified in the process of answering criticisms. In presenting Kuhn's views on the nature of science I will draw attention to major criticisms and modifications of Kuhn's ideas.

2.3.2 Paradigms, Disciplinary Matrix and Exemplars.
Departing from the historiographic tradition which presented a "development-by-accumulation" view of scientific progress, the model proposed by Kuhn depicts the evolving history of a mature science as a sequence of periods of "normal science" - periods of continuity to which the cumulative development view can be applied - interrupted by "scientific revolutions" - extraordinary episodes in which a change of professional commitments takes place.

Besides periods of normal science and revolutions, Kuhn also considers a pre-paradigm period which precedes the first period of normal science research in a field. This period is characterised by a proliferation of paradigms rather than the absence. As Kuhn puts it:

"During what is called, in Structure of Scientific Revolutions, the 'preparadigm period', the practitioners of a science are split into a number of competing schools, each claiming competence for the same subject matter but approaching it in quite different ways."

(Kuhn, 1977a, p. 235)
In spite of being its single most important concept, the word paradigm was employed ambiguously in the "Structure of Scientific Revolutions" (Masterman, 1970). In later essays, Kuhn attempted to clarify some misunderstandings that, as he himself acknowledged, were induced by the original presentation (Postscript - 1969 added to Kuhn, 1970a; Kuhn, 1970b; Kuhn, 1977a).

According to these more explicit explanations the term paradigm was used both in a general and in a restricted sense. In the general sense - Kuhn would prefer now to call it "disciplinary matrix" - the word paradigm was employed to denote the entire constellation of group commitments of a scientific community. When using the term paradigm in this thesis, I will be having in mind this general sense.

The main components of a disciplinary matrix are identified by Kuhn as being: "symbolic generalizations" which cover theoretical laws shared by the community and usually deployed in the form of mathematical equations (e.g. $F = \frac{dp}{dt}$; $V = IR$); "beliefs in particular models", which supply the community with the accepted analogies and metaphors and which can be either of heuristic (e.g. electric circuit as a hydrodynamic system) or ontological (e.g. corpuscular or wave model of light) character; "shared values" (e.g. theories should be accurate in their predictions, should be simple, should be fruitful, should be consistent); "metaphysical principles" (e.g. the preference for field theories over particle theories); and exemplars.

This last element represents the restricted sense in which
the word paradigm was originally used by Kuhn, and to which he attributes the greatest importance. By "exemplars" he means:

"... initially the concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, in examinations or at the ends of chapters in science texts. To these shared examples should, however, be added at least some of the technical problem-solutions found in the periodical literature that scientists encounter during their post-educational research careers and that also show them by example how their job is to be done."

(Kuhn, 1970a, p. 187)

Problems encountered by students in laboratories and textbooks are usually regarded as ways of providing practice in the application of what the student already knows - the scientific knowledge embodied in the theories and rules. Kuhn argues, however, that the cognitive content of science is centrally placed not directly in the theories and rules but rather in the shared examples provided by the problems. By doing exemplary problems, the student's perception is moulded to a common way of seeing which is specific for a particular community:

"After he (student) has completed a certain number (of exemplary problems), which may vary widely from one individual to the next, he views the situations that confront him as a scientist in the same gestalt as other members of his specialists' group. For him they are no longer the same situations he had encountered when his training began. He has meanwhile assimilated a time-tested and group-licensed way of seeing."

(Kuhn, 1970a, p. 189)
2.3.3 Normal Science. This process of modelling the solution of new problems on previous ones is one important feature of normal science research. It is by learning (tacitly rather than through explicit rules) the knowledge embodied in the shared examples which are part of the prevalent disciplinary matrix that an individual scientist develops a way of seeing a group of phenomena which is a communal property of the community to which she/he belongs.

The sharing of a paradigm by members of a community is seen by Kuhn as a sign of scientific maturity of the field to which that community is attached to. Periods of normal science are characterised by a strict adherence to a paradigm. A sense of confidence in the powers of existing knowledge to solve problems with which it is confronted pervades the community; research problems are faced as "puzzles to be solved" inside the framework provided by the existing paradigm. Eventual failures in accomplishing the "puzzle-solving" activities are regarded as a lack of scientific ingenuity rather than theoretical and/or methodological weakness. Classical examples of periods of normal science are: astronomy during the Middle Ages (Ptolemaic paradigm); mechanics during the eighteenth and nineteenth centuries (Newtonian paradigm); and quantum mechanics after the 30's (Copenhagen interpretation paradigm). It must be noted that the analogy "puzzle-solving" is employed by Kuhn to indicate the closed character of normal science problems. A puzzle is a problem which has a solution that can be found as far as a set of rules is followed.

The strict and a-critical adherence to a paradigm is
regarded by Kuhn as a necessary condition for a field to progress, since it is only by freeing themselves from the task of critically analysing the foundations of the theories and methods they utilise, that the members of a scientific community can concentrate their efforts on the more esoteric research problems faced by the field. Kuhn identifies three classes of problems which are typical of normal science research.

(1) "Determination of significant facts": Design, construction and deployment of apparatus which would increase the accuracy and scope of facts that the paradigm has shown to be particularly revealing of the nature of things. (e.g. stellar position and planetary orbits; wavelengths; electrical conductivities; composition of chemical substances).

(2) "Matching of facts with theory": The manipulation of theories leading to predictions which can be directly confronted with experiments and the development of apparatus for the verification of theoretical predictions in an attempt to bring nature and theory in closer and closer agreement. (e.g. special telescopes to demonstrate Copernicus' prediction of annual parallax; Atwood's machine to demonstrate Newton's second law; the development of theoretical techniques for the treatment of mutually interacting bodies during the eighteenth and nineteenth centuries.).

(3) "Articulation of theories": Experiments directed to the determination of physical constants (e.g. Cavendish's determination of the gravitational constant; Avogadro's number; electronic charge). Experiments aiming at the formulation
of quantitative laws (e.g. Boyle's law; Coulomb's law).
Reformulation of theories leading to a physically equivalent
but logically more coherent and/or aesthetically more satis-
fying version (e.g. the development of the analytical formu-
ation of classical mechanics).

When describing these three classes of normal science
problems Kuhn particularly stresses the role played by the
theoretical context of paradigms in the direction assumed by
empirical research. Commenting on the matching of facts
with theory he observes that:

"The existence of the paradigm sets the problem to be solved;
often the paradigm theory is implicated directly in the
design of apparatus able to solve the problem. Without the
Principia for example, measurements made with the Atwood
machine would mean nothing at all."

(Kuhn, 1970a, p. 27)

And, when discussing the formulation of quantitative laws:

"Perhaps it is not apparent that a paradigm is prerequisite
to the discovery of laws like these. We often hear that
they are found by examining measurements undertaken for
their own sake and without theoretical commitment. But
history offers no support for so excessively Baconian a
method. Boyle's experiments were not conceivable (and
if conceived would have received another interpretation
or none at all) until air was recognised as an elastic
fluid to which all concepts of hydrostatics could be
applied ... In fact, so general and close is the relation
between qualitative paradigm and quantitative law, that,
since Galileo, such laws have often been correctly guessed
with the aid of a paradigm years before apparatus could be
designed for their experimental determination."

(Kuhn, 1970a, pp 28-29)

The image of normal science depicted by Kuhn is of an
extremely conservative activity: research is conducted
according to a shared disciplinary matrix; students are
educated towards the acquisition of the views shared by the community.

This conception of normal science generated different reactions among scholars. Popper (1970), although accepting the existence of activities which fit in Kuhn's description of normal science, regards it as bad science and dangerous; Lakatos (1970) points out that "theoretical pluralism is better than theoretical monism" and that "the sooner competition starts, the better for progress". On the other hand, Masterman (1970) argues that it is "crashing obvious" that science is as Kuhn says; Brown (1977) accepts the concept without problems, based on historical evidence; Barnes (1982) regards the characterization of normal science as one of the more important contributions of Kuhn's work and regards Popper's and Lakatos' critiques as moralist and normative attempts of picturing an image of science according to their own philosophical views, rather than on historical evidence.

Kuhn himself regards periods of normal science as an essential component of the scientific enterprise. He argues that during periods of normal science, an essential tension between tradition and novelty is developed, and the adherence to a paradigm allows a scientific community to concentrate its attention to esoteric problems and matters of detail, leading to the articulation of the paradigm. As a result the accepted theories are probed to a deeper extent and new and more sophisticated problems do emerge, constituting the "puzzles" to be solved by the community.
2.3.4 **Revolutions.** Eventually, however, some of these problems will appear as extremely resistant to prolonged attack by even the ablest members of the community. On those occasions (e.g., pre-Copernican astronomy) instead of being regarded as puzzles the problems start to be considered as anomalies, generating a state of crisis in the field. Scientists, in general, young ones or newcomers to the field, begin to question the validity of the theories and methods enshrined in the paradigm. The state of crisis will be solved by the emergence of a new paradigm (e.g., Copernicus' theory) which, although unable to solve all the problems faced by the old paradigm would offer, at least to the eyes of some practitioners, a promise of solution for the most relevant of these.

A new paradigm is usually resisted by part of the influential members of the community, but if successful in solving a few initial problems, it will attract more and more adherents, becoming eventually the dominant one. When this movement is accomplished, a new period of normal science starts and it is this process of paradigm change that is known in Kuhn's theory as a "scientific revolution". The term "scientific revolution" is usually associated to those events in which major changes in a world view occurred, such as the Copernican, the Einsteinian and the Darwinian revolutions. Kuhn, however, sees as legitimate to employ the term in connection to minor changes which need not be seen as revolutionary outside a single community, provided they result in some reconstruction of group commitments. In this case Kuhn considers conceptual changes induced by "factual" discoveries, which after being noticed as anomalies
against the background provided by the dominant paradigm, are followed by some reconstruction of this same paradigm (e.g. the discovery of X-rays).

One of Kuhn's main theses is that the discontinuities which characterize scientific revolutions are smoothened in the textbooks and traditional historical accounts of scientific developments. If in war, history is written from the point of view of the winning party, in science it is written from the perspective of the dominant paradigm. The consequence is that past knowledge is either regarded as efforts towards the present paradigm and subsumed by it, or as non-scientific, leading to a linear and continuous image of scientific progress.

2.3.5 Science and Rationality. During the transitional period the old and new paradigms compete for the preference of the members of the scientific community, and rival paradigms, although overlapping in some respects, will offer distinct views of nature and pose different questions as legitimate, fundamental and meaningful. Some concepts will eventually become unimportant as objects for scientific research (e.g. the "ether" after relativity) or acquire a different meaning (e.g. the concept of mass in classical and relativistic mechanics) and some of the similarity relations which characterized a period of normal science will change (e.g. the sun and the moon were placed in the same category of planets before, but not after, Copernicus).

Furthermore, rival paradigms provide different conceptual spectacles through which the world is seen and it is to
represent this idea that Kuhn uses the expression "incommensurability of paradigms". Defenders of rival paradigms will, to some extent, be talking at cross-purposes, allowing for only partial communication between them, and therefore one paradigm cannot be logically (in the sense that a neutral algorithm can be applied) proved to be superior to another, at least during the transitional period. Rather than based on logical proof, decisions involving theory choice will depend on persuasive discussions among members of the community.

The way in which Kuhn described the emergence of new paradigmatic theories in "The Structure" led some critics like Scheffler (1967), Popper (1970) and Lakatos (1970) to attack Kuhn on the grounds that he pictured scientific change as an irrational process. In answering to these criticisms (Kuhn, 1970a; Kuhn, 1970b; Kuhn, 1977a), he apparently moved towards a less controversial position (Suppe, 1977; Newton-Smith, 1981).

It is Kuhn's point of view that members of a scientific community share a set of values which are applied in scientific arguments. Some of those values refer to qualities of a good theory such as experimental accuracy, consistency, broadness of scope, simplicity and fruitfulness, and they play a major part in the comparison of rival theories. Nevertheless, by their own nature, these values allow for variations in the way that individual scientists would apply them to specific situations and a degree of value judgement is always present in the process of scientific change, a point that even some of Kuhn's critics agree with (Newton-Smith, 1981).
Commenting on Kuhn's critics on the issue of rationality, Brown (1977) remarks that they seem to equate rationality with algorithm application, which is just the situation in which human reasoning powers are less needed; it is mainly when decisions involving value judgements in situations in which an algorithm cannot be applied, continues Brown, that human reasoning has a part to play.

This sort of argument justifies Kuhn's point of view that scientific debates can be carried on rational grounds. In his later work Kuhn seems to regard the incommensurability of paradigms as less problematic than he initially stated. To start with:

"The stimuli that impinge upon them are the same. So is their general neural apparatus, however differently programmed. Furthermore, except in a small, if all-important, area of experience even their neural programming must be very nearly the same, for they share a history, except the immediate past. As a result, both their everyday and most of their scientific world and language are shared. Given that much in common, they should be able to find out a great deal about how they differ."

(Kuhn, 1970a, p. 201)

What is suggested then, is that scientists participating in a communication breakdown which characterizes inter-paradigmatic debates should treat each other as members of different language groups and act as translators. In this way, after an analysis of each group's discourse, they can resort to their shared vocabularies in order to elucidate the terms and locutions that are responsible for the inter-paradigmatic divide, and this translation process is somehow equivalent to "wearing the other one's shoes", or as Kuhn describes it, trying:
"...to discover what the other would see when presented with a stimulus to which his own verbal response will be different. If they can sufficiently refrain from explaining anomalous behaviour as a consequence of mere error or madness they may in time become very good predictors of each other's behaviour. Each will have learned to translate the other's theory and its consequences into his own language and simultaneously to describe in his language the world to which that theory applies."

(Kuhn, 1970a, p. 202)

The translation process proposed by Kuhn can certainly help to rationalize inter-paradigmatic argumentation and is almost essential when the conversion of research workers strongly attached to a research paradigm is at stake. But it also certainly does not assure conversion. Scientists can agree on the sources of their disagreements and still stick to their theories, since the values they share can be applied differently. For instance, accuracy can have different relative weights, when compared to scope or simplicity, for different scientists. The classical example of scientific revolutions in which that sort of values played an overimportant role is the so-called Copernican Revolution (Kuhn, 1977b).

The degree of arbitrariness that is intrinsic to debates involving value judgements, even when conducted according to high standards of rational argumentation, is regarded by Kuhn as an important element of scientific practice. It makes sure that, at least for a while, the community will be divided, with the result that the old paradigm which can, maybe suffer further articulations, will not be immediately replaced by an emergent one; but at the same time it also guarantees that the new paradigm will have a chance of proving itself more successful.
2.4 Summary

In this chapter I presented two contrasting views on the nature of scientific knowledge. Initially, I introduced the empiricist tradition which has its origins in Baconian inductivism and Humean epistemology. Although versions of classical empiricism are still today prevalent among educated laymen and in school science, this tradition generated in the twentieth century a sophisticated philosophy of science: logical-positivism.

I pointed out that the logical-positivist analysis of science concentrated on logical problems regarding the structure of scientific theories and the relation between theory and observation. I also pointed out that logical-positivism failed to give satisfactory answers to its problems, and discussed two critical issues in particular: the problem of induction, and the theory-ladeness of observations. This generated an alternative approach to philosophy of science, based on the historical analysis of the scientific enterprise, rather than on the logical analysis of scientific theories.

Of the representatives of the new approach ('Weltanschauungen' analyses), I singled out the work of Kuhn for more detailed consideration, particularly his notions of paradigms, normal science and revolutions.
CHAPTER THREE

CHILDREN'S SCIENCE
3. CHILDREN'S SCIENCE

3.1 Introduction

In this chapter I intend to clarify and characterize the notion of "children's science" that was introduced in Chapter 1, as part of the conceptual framework suggested in order to represent the transformations of knowledge in science education. On that occasion "children's science" was used to express the views of the world - in the form of beliefs, expectations and meanings for words - held by pupils entering an instructional situation, and that differ from the accepted (scientific or curricular) explanation.

In the presentation I will concentrate on some general features of "children's science" rather than on matters of detail, as for example, what particular beliefs children have in relation to a specific physical concept. Later in the thesis I will have the chance to focus on some particular conceptions. I will not, at this stage, refer to problems related to the issue of changing these conceptions in an instructional context, postponing the discussion for the final part of the thesis.

The presentation of general features of "children's science" is preceded by a brief discussion in which the meaning of the expression in relation to two aspects is considered. Initially I situate "children's science" in relation to the "physical knowledge" -"logical mathematical knowledge" dicotomy, which underlies research developed according to a Piagetian framework. In the second place I attempt to justify the use of the expression "children's
science", in spite of the existence of a more established one in the literature.

3.2 Physical Knowledge and Logical Mathematical Knowledge

As I pointed out in Chapter 1, the fact that pupils bring to science lessons some already developed conceptions about the nature of the physical world has been, only in recent years, acknowledged as a relevant issue by research workers in science education. Reviews of studies about concept learning in science, published before the early 70's, reflect the dominance of normative approaches, in which the assessment of the student's knowledge was based on criteria stating the accepted correct conceptions (Driver and Easley, 1978). In such studies little, if any, attention was paid to the pupils own understanding, that is, "children's science".

With the recognition that the narrow behaviourist input-output approach was insufficient to disclose the subtleties of the learning process, a revival of studies concerned with human thinking took place, and the most influential line of inquiry in that direction was based on the work of J. Piaget. Studies carried out in the early and mid-seventies, and which were concerned with pupils' thinking, used, with few exceptions, Piaget's perspective on intellectual development (Erickson, 1979); Driver (1981) points out that the Piagetian perspective was used as a basis and rationale for the development of several science programmes throughout the world; Gilbert and Swift (1981) suggest that a review of literature on science education is likely to lead the reader
to conclude that the ideas of J. Piaget dominate the field, constituting a received view for most teacher educators and their students. The influence of Piagetian based stages is also mentioned in ASE (1979).

Although the investigations conducted by Piaget and collaborators provide rich and useful insights into children's intuitive ideas about the physical world, in the course of his career his interests shifted more and more towards the assumed logical mathematical structures of knowledge and to the age related stages of intellectual development based on the acquisition of these structures. In general Piagetian based research and development in science education tended to be concerned more with this latter aspect of Piaget's work.

The distinction between the two aspects of knowledge mentioned above can be illustrated by Piaget's example of a child playing with a number of pebbles (Piaget, 1970). The experience allows the child to discover more about the properties of the pebbles as physical objects, such as their weight and texture ("physical knowledge") and at the same time the child may also discover that, when the pebbles are laid in a row the same total is arrived at when they are counted from left to right or from right to left ("logical-mathematical knowledge"). According to Piaget, logical-mathematical operations are internalized systems of actions, and although this kind of knowledge can be distinguished from "physical knowledge", these are interdependent developments. The advance in understanding reality presupposes a system of inter-coordinated actions, and conversely, in
order for these operational systems to develop, the child must have experience of physical reality.

In recent years criticisms have been presented against the emphasis placed by the Piagetians on the context-free logical mathematical aspects of knowledge and stages (Novak, 1978; Brown and Desforges, 1979). But, even accepting the view that the absence of certain logical mathematical structures may place constraints upon the ability of children to develop more sophisticated arguments or to understand more abstract and formalized concepts, it can still be argued that physical conceptual knowledge is basic to our intellectual repertoire used in communication, being the principal subject of both classroom and scientific discourse (Erickson, 1979). Accepting this last point implies accepting that this form of knowledge deserves its own place as a topic in science education research, and the recent wave of research concerned with alternative frameworks can be seen as an attempt to redress the balance.

In this thesis, wherever using the expression "children's science", I will be meaning the notion of "physical knowledge" rather than "logical-mathematical knowledge".

3.3 Misconceptions, Alternative Frameworks, Children's Science

I have already referred in Chapter 1 to the tendency of attaching a positive value to the alternative conceptions held by pupils, which characterizes a large part of research work in science education nowadays. This tendency can be linked both to the acceptance of a more constructivist view
of the nature of human knowledge, and to the change of perspective in the philosophy of science from an empiricist view to a Weltanschauung one: children, as scientists, are supposed to interact with reality through the mediation and guidance of conceptual frameworks (paradigms in the case of scientists).

The tendency mentioned above is symbolized, at a semantic level, by the steady replacement of words commonly used in science education such as "misconception" (e.g. Doran, 1972, Za'rour, 1975; Linke and Venz, 1979; Helm, 1980) for others with less low-graded implicit value. The implicit low graded value, that was attached to the word misconception, can be exemplified by a quote from Za'rour, 1975:

"It requires very good teaching to make students detach themselves completely from erroneous beliefs that appear to be backed by common sense such as 'The sun revolves around the earth' or 'Heavy bodies fall faster than light ones'. If misconceptions are related to irrational thinking or to a misinterpretation of the cause effect relationship as explained by Hancoek (1940), then proper teaching learning situations aimed at the development of rational thinking and at fighting these shortcomings should help in reducing misconceptions."

In quoting the above passage I would not like to imply that everybody who employed expressions such as misconception or misunderstanding, went so far as Za'rour in associating conceptions which do not match the accepted scientific or curricular explanations with irrational thinking. In quoting the passage I wanted to illustrate the extreme negative sense that the notion of misconception could acquire. By suggesting the expression "alternative frameworks", Driver and Easley (1978) had in mind to encourage the opposite alternative
view which considers pupils' conceptions as being their interpretations of the world, and therefore valuable as far as the individual is considered. Although the expression is becoming widespread, its use has been criticized for conveying a sense of conceptual rigidity (Sutton, 1982b).

The introduction of the expression "children's science" (Osborne, 1980) can be regarded as a step further in the direction of enhancing the status of pupils' ideas. It is to be regarded as a metaphor, which reflects the basic assumption that children attempt to make sense of the world through their current knowledge and experiences. To that extent the Kellyan metaphor, "man-the-scientist", can be properly applied to them, and in this thesis I will use the expression "children's science" to encompass the more established expression "alternative framework" in the context of school science education. In brief, the adoption of the expression symbolizes a commitment towards a constructivist view of human knowledge.

3.4 Features of Children's Science

Most of the work in the field of students' alternative conceptions have been directed towards the identification of forms of prior knowledge with reference to particular science concepts. Different investigation methods have been used, as for instance clinical interviews (Erickson, 1979), interview-about-instances (Osborne and Gilbert, 1980) and paper-and-pencil tests (Watts and Zylbersztajn, 1981). Although none of them are free of problems as research tools (Sutton, 1981a), they are certainly increasing our
inventory of children's ideas. On the other hand very few attempts have been made towards the systematization of general features of "children's science". The rest of this chapter is devoted to the presentation of some of the general features which were identified in a review of literature.

3.4.1 Spread Over a Large Number of Phenomena. Instances of "children's science" have been identified in the major scientific disciplines, but certainly the most investigated one has been physics. In physics the most explored area has been mechanics, whose attractiveness is probably due to the fact that besides being a central topic in school science, children are confronted very early with mechanical phenomena, and therefore tend to develop very defined sets of beliefs and expectations concerning these phenomena. But, apart from the predominance of studies related to this area, the investigations in physics cover the majority of central topics in the subject, as the following selection indicates:


b) Heat: Albert, 1978; Tiberghien and Delacote, 1978; Andersson, 1979; Erickson, 1979; Tiberghien, 1979; Erickson, 1980.

c) Electricity: Osborne and Gilbert, 1979; Rhöneck, 1981


Apart from the investigation of children's ideas about specific science concepts there has been research, on a very much reduced scale though, concerned with children's ideas about more general issues such as the notion of physical laws and conceptions of science and scientific method. Rodrigues (1980) concluded that the quality of the explanations given by her subjects to the questions designed to investigate their awareness of regularities in physical phenomena, approaches the adult-level explanations at around 12-years-old, and that even children at a lower level of explanation can use some statements consistently as a law. Swift (1981) interviewed a sample of primary school children to post-graduate students about their views on science and scientific method. He reports that the interviewees (particularly those under the age of 16) were not always able to provide a description of scientific method. Those who were able to, most usually gave an essentially Baconian account.

3.4.2 Patterns of Children Understanding. One of the unique attempts of identifying some general patterns of understanding is presented by Gilbert, Watts and Osborne, 1982. Being very cautious about the comprehensiveness of these patterns, their distribution among a population or the commitment of any student to only one pattern, the authors suggest the possibility of five patterns of understanding in "children's science":

a) The use of everyday language: A word is made sense by placing an everyday interpretation on it.

b) A self-centred and human centred viewpoint: Words and situations are considered in terms of human experience and values.
c) A belief that non-observables do not exist: A physical quantity is not believed to be present in a given situation unless the quantity itself or its effects can be observed.

d) The endowment of objects with the characteristics of humans or animals: Objects are endowed with feeling, will or purpose.

e) The endowment of an object with an amount of a physical quantity: An object is endowed with a physical quantity which is given an unwarranted physical reality.

Although these patterns were identified in a study concerned with the concept of force, the possibility exists that they are more general features, a point that should deserve further investigation by research workers in the field.

In a different paper Osborne, Bell and Gilbert (1983) discuss general characteristics of "children's science" in the process of articulating similarities and differences between "children's science" and "scientists' science". In the positive side of the analogy they agree that children, like scientists, use similarities and differences to organise facts and phenomena, search for elements, and relationships among elements, to build structures of relationships. In addition, they continue, children, like scientists, gather facts and build models to explain known facts and make predictions.

On the negative side of the analogy they state three ways in which "children's science" differs from "scientists' science":

1) Young children seem to have difficulty with the kinds of abstract reasoning that scientists are capable of. They tend to view things from a self-centred or human-centred point of view, and they consider only those entities and constructs that follow directly from everyday experience.
2) Children are interested in particular explanations for specific events. Unlike scientists they are not concerned with the need to have coherent and non-contradictory explanations for a variety of phenomena. With their limited experience and concern for a specific explanation only, children can latch to any one of a number of possible explanations which are reasonable from their more restricted outlook.

3) The everyday language of our society often leads children to have a view different to the scientists' view. Such views may not change as the child grows older, or they may even become with time, increasingly different from "scientists' science".

One has of course to be cautious about these generalizations. Some of them are also referred to by other authors. Hewson (1980) stresses the scientist-like characteristics of students, pupils and even younger children when referring to their search for structure and order in the world. Donaldson (1978) points out that even young children strive to make "human sense" of situations in which they are placed.

3.4.3 The Persistence of Children's Science. A feature of "children's science" noted by several authors is the fact that these alternative conceptual systems are remarkably resistant to change by exposure to traditional instructional methods (Driver and Easley, 1978). This feature has been specially noticed in mechanics, where pre-Galilean conceptions about force and movement seem to be present even in science and engineering university students (see Chapter 10 for a more extended discussion).

Although more evident in mechanics, the persistence of "children's science", in spite of formal instruction, has been observed in other areas. Stead and Osborne (1979) state that Australian Form 3 students who had received
formal teaching on light presented concepts of light transmission similar to Form 2 ones, who had not been taught in the topic. Osborne and Gilbert (1979) noticed that, although some 17 and 18 year-old physics students demonstrated an understanding of the concept of electric current similar to that of the trained physicist in terms of the discussed instances, others showed an understanding of the concept very similar to those displayed by 7 to 13 year-old children who had received no formal teaching about the subject. It seems, for example, that intuitive ideas about what happens when electric current goes into a lamp (it simply disappears according to many interviewees) have not changed since childhood for a number of sixth-form students, including some Upper Sixth. On the other hand it was observed that often, more formal statements, indicating, at a superficial glance, an explanation close to the Physics type, covered misconceptions like, "the voltage is the sort of speed of the electrons"; "there is an equation ... the voltage ... the speed it moves along the wires V = IR"; "light is electromagnetic waves and electric current is a flow of electrons, therefore light must be a flow of electrons".

Closely associated with the persistence of "children's science" is the view that the alternative conceptual systems are not facilitative to the learning process. In different science areas students interpret instructional events in the context of the conceptual scheme they hold, and not the one that the events are designed to convey. Again an analogy can be traced between "scientists' science" and "children's science": both in the former and the latter observations and interpretations are theory-laden. These theories are
part of paradigms in one case, and part of alternative conceptions in the other. In every case the meaning which is given to a situation is influenced by the conceptions held either by scientists or pupils.

3.4.4 Children's Science and Past Ideas. One of the central theses of Piaget's genetic epistemology is of a parallelism between the progress made in the logical and rational organization of knowledge and the corresponding formative psychological processes (Piaget, 1970). He claims that there is a weak resonance between children's ideas and ideas from the history of science, in the sense that the former recapitulates the latter (Ginsburg and Opper, 1969; Driver and Easley, 1978).

Although research workers in the identification of alternative frameworks will tend, in general, to be cautious about strong generalizations of that view, there have been instances in which the parallelism has been noticeable. One area in which this is clear is dynamics, where alternative frameworks displayed by children and adults are very close to Aristotelian or medieval (impetus theory) conceptions of the relation between force and movement (Driver, 1973; Viennot, 1979; Watts and Zylbersztajn, 1981; Clement, 1982).

Investigating children's conceptions about heat and temperature, Erickson (1979) points out that some of children's interpretations on experiments involving heat conduction were virtually identical to the caloric theory of heat prevalent in the late 18th and early 19th centuries. He remarks, however, that many other ideas advanced by children could not be accommodated by a caloric theory.
Piaget (1929) mentions that for most children vision is conceived as passing from the eye to the object; a similar conception, which resembles ancient Greek theories of vision, is also reported by Guesne (1978) who interviewed a sample of 20 French school children (age 13-14 years).

3.5 Summary

In this chapter I have attempted to clarify the meaning I am giving to the expression "children's science" in this thesis. Although, in principle, the expression could be used to encompass both physical knowledge and logical mathematical knowledge (in a Piagetian sense), I will be concerned mainly with physical knowledge, or to use a more established term, children's alternative frameworks. The expression "children's science", I would argue, has some advantages over alternative frameworks.

First of all its meaning can be extended to encompass more than children's views about specific physical phenomena, to include more general notions such as notion of physical laws, causality and conceptions about science and scientific method.

Second, the expression does not convey the idea of rigidity that the word framework does. Since the form of organization of cognitive context is still an open issue in psychology, a more open and less committed expression seems preferable.

Third, the expression "children's science" stresses the
Kellyan metaphor "man-the-scientist" in the school context, what is compatible with the current constructivist trend in science education research. Its use symbolizes the assumption of scientists-like characteristics of children, such as the search for sense, structure and order; the strive for predictions and control; the influence of existing conceptions in the meaning and interpretations of phenomena.

I also discussed some features of "children's science" such as:

a) The spread over a large number of phenomena
b) The existence of general patterns
c) The persistence in relation to traditional teaching
d) The relation with past scientific ideas

The review of the literature showed that a) and c) are relatively well accepted features, and b) a possibility needing further exploration. In relation to d) the most that can be said is that in some cases "children's science" recapitulates past "scientists' science".
CHAPTER FOUR

CURRICULAR SCIENCE
4. CURRICULAR SCIENCE

4.1 Introduction

In Chapter 1, the expression "curricular science" was introduced in order to mean particular versions of scientific knowledge enshrined in curricular materials, such as those produced by curriculum development groups (e.g. the Nuffield schemes) and textbook writers. This constitutes a restricted conceptualization of the notion of curriculum, which in its broadest sense encompasses all the planned and organized experiences pupils encounter in a school (not considering the unplanned hidden curriculum).

When considering "curricular science" in the conceptual framework used in this thesis, I will be having in mind mainly the notion of curricular materials, which are, anyway, the most tangible component of a wider conception of curriculum. It is also the most common way in which the expression has been used in the context of science education.

In describing some general features of "curricular science", in this chapter, I will adopt, for the sake of presentation, the usual distinction between the "traditional curriculum" and the developments which arose from the so-called "curricular reform movement". The latter was started in the mid 50's and blossomed in the 60's in the U.S.A., exerting a strong influence on its British counterpart.
4.2 The Traditional Curriculum

In a review, primarily concerned with the American context, school science, before the curriculum reform movement, is characterized as taught in a prescribed and authoritative manner (Sabar, 1979). The main sources of teaching were single author textbooks and the curriculum was based, largely, on a consensus developed by specialists. Organizing concepts and generalizations were included because they were seen to be true knowledge. Sabar links that approach with the social ideology of the American society during the late 30's and 40's, according to which individuals were expected to grow by conforming their aspirations to those of the social groups they belonged to. The school, based on discipline and conformity, was designed, therefore, to "help" young people to become adjusted to the demands of an industrial society.

In the British scene (ASE, 1979; Tomley, 1980) science curricula in the 50's reflected mainly the attitudes and values of the public and grammar schools and their close and exclusive links with the universities. Science education was subject focused and content oriented, being essentially conceptualized in terms of O and A-Level courses in biology, chemistry and physics:

"In the grammar schools, the main concerns of both students and teachers were related to the processes whereby the young could be socialized into the thought and behaviour patterns of the 'elders', a highly professional activity governed by a tightly hierarchical relationship between the pupil, the teacher and the university administrator .... The former tradition placed a high premium on academic scholarship, involving a deep and systematic concern for the content of science; a concern with the latest develop-
ment in the subject; and a search for the ways whereby new knowledge could be incorporated into teaching schemes."

(ASE, 1979, p. 13)

Parallel to this trend the modern secondary schools that resulted from the 1944 Education Act, as an answer for the growth in demand for a technically educated workforce, started by the mid 50's to establish their own approach to science teaching (ASE, 1979). Teacher training colleges which usually provided the teachers for the modern secondary schools were sufficiently isolated from the academic tradition of the universities in order to develop their own solution to the social and educational problems of the schools they served. That solution reflected an overt concern with the child as the central forces for educational planning, a preoccupation with the science of everyday things and everyday life and an active concern with the existing theories of child psychology and learning. The modern secondary tradition was, however, short-lived, lacking status, support and clear articulation. Within a few years, pressure from parents and teachers led most of these schools to adopt watered-down versions of the grammar school courses.

The assumptions underlying the traditional curriculum are still strongly present in science education. In terms of "curricular science" they are represented by textbooks showing a strong content-examination orientation (e.g. Abbot, 1978; Nelkon, 1978). These materials, although apparently neutral in terms of teaching-learning methodologies, can be regarded as, being at the same time, one of the products of, and one of the instruments by means of which a "Trans-
mission" view of knowledge reproduces itself. According to this view (Pope and Keen, 1981) pupils are seen as passive receivers of information rather than active participants in the construction of their knowledge.

They also tend to project a superseded empiricist view of scientific knowledge, which, as pointed out by Cawthron and Rowell (1978) dominates school science. For instance Abbot (1978) states:

"The nature of physical knowledge
In physics, certain properties of matter are measured and the results examined to see if there is any mathematical relationship between them. It is important to grasp the true meaning of the equations we find in a physics book. They do not tell us what things are in themselves, but are simply a convenient way of expressing the laws governing this behaviour. This is the main purpose of science, to seek out the laws of the universe and, if possible, to express them in precise mathematical form."

(Abbot, Ordinary Level Physics, p. 3)

And in Nelkon (1978) we found that:

"Scientific Method
In ancient times people believed something simply because a famous person said it. A good example occurred in the case of falling objects. A famous Greek philosopher called Aristotle said that heavy objects always fell to the ground faster than light objects. This was believed for nearly 2000 years.

In the 17th century, however, someone performed a single experiment. He dropped a heavy and a light object from the top of a tall building. (Legend says that the building was the Leaning Tower of Pisa in Italy, which still exists). He observed that, contrary to what Aristotle thought, the heavy and the light object both reached the ground at the same time. Aristotle's theory was therefore wrong."

(Nelkon, CSE Physics, p. 3)

In the last quotation a single experiment is seen as responsible for the overthrow of a longheld theory. Although Galileo never did this experiment (Cooper, 1935), the myth
serves the function of presenting an image of Galileo as an empiricist. That image, which is pervasive in "curricular science" (see Section 10.4.3 for another example) has been discredited by philosophy and history of science (Section 10.2.3).

4.3 The Curriculum Reform Movement

4.3.1 U.S.A. The roots of the curriculum reform movement, in the U.S.A., can be traced back to the post-war dissatisfaction with the quality of schools and their approaches to learning. According to Sabar (1979) this uneasiness was compounded by the pressure and involvement of the scientific community, concerned with the increasing gap between the advances made in "real science" and the stagnation of school science; by the developments in the behavioural sciences; and by the then new concern with curricular theory as expressed by the work of R. Tyler and H. Taba.

The movement gained momentum (though it was not caused by) with the pioneer launching of the Soviet "Sputnik". The feeling that the U.S.A. had been overtaken by the U.S.S.R. in the spacial race, was capitalized by the interested groups, based in prestigious university departments, which, on the occasion, were granted substantial injections of funds.

Examples of direct result of the movement are curricular projects like the PSSC (Physical Science Study Committee), CBA (Chemical Bond Approach), BSCS (Biological Sciences Curricular Studies) for the high school and SCIS (Science Curriculum Improvement Study) and SAPA (Science A Process
Approach) for the elementary school. Late offsprings of the movement include Harvard Project Physics and IPS (Introductory Physical Science).

In general, these projects were nationally founded and the curricular development teams were carefully selected among university or college lecturers, based on a university department and headed by an eminent scientist. They constitute examples of a "centre-to-periphery" model: the central team is at the hub of a wheel, with communication going via spokes to the schools located on the rim (Yeoman, 1980). Although differing in form and origins, the new curricula showed some common points (Sabar, 1979):

a) They were centered on the subject matter, with an integrated science approach at the elementary level and a separate discipline approach at the secondary level.

b) The materials were tested and evaluated.

c) Teachers received special preparation for implementing the programmes.

d) Strong emphasis was placed on the active involvement of children in handling materials and apparatus, in a "discovery learning" approach.

e) A variety of media was used (printed materials, laboratory kits, audiovisuals, games).

Although a lot of resources and effort had been concentrated on the dissemination of these projects, their use in schools did not reach the intended level. One reason for this
was that the majority of them were directed towards the more academically oriented pupils. On the other hand it is recognized that they exerted an influence on the materials affected by traditional commercial publishers (McConnell, 1982).

A basic feature of the programmes developed during the curriculum reform movement in the U.S.A. was their emphasis on the "pure structure of the discipline", with very little attention being paid towards technological applications and the related personal and societal problems (Hufstedler and Langenberg, 1980). This aspect has come under heavy criticism in recent years and some studies seem to suggest that, during the 80's, the American tendency will be in the direction of developing science curricula for secondary schools emphasizing the interactions among science, technology and society (Gaskell, 1982; McConnell, 1982).

4.3.2 Britain. The science curricula developments that took place in Britain in the past 20 years were influenced by a variety of sources, among them being the ASE policy documents of 1957 and 1961, the American developments mentioned above, and the establishment of the Nuffield Foundation and Schools Council as funding agencies (ASE, 1979). In spite of relying more on the participation of school teachers in their elaboration stage than their American counterparts, the British projects did not differ radically from them (Tomley, 1980). The major Nuffield projects, for instance, were discipline-centered curriculum developments, showing a belief in the subject matter disciplines
and reflecting the values of the time and the power of the subject associations, professional institutes and university departments. One result of this set of values was that the materials were initially aimed at the O-Level pupils (20 to 30% of the school population) rather than the reforming secondary school science as a whole.

The already quoted ASE (1979) consultative document presents a general analysis of the science curricula developments of the 60's in Britain, concluding that the new programmes, in their different ways, espoused some aspects of the earlier tradition. The main aspects mentioned in the document are discussed below.

a) Nature of knowledge. The curriculum reform of the 60's adopted the existing assumption which considers school science to be a fixed body of knowledge, related to and derived from "real science", which young people used to acquire in order to understand the world, and which they must master in order to become a scientist. This view can be linked to writings of Hirst, who stressed the objective and publicly recognizable aspects of knowledge and its separate disciplinary character (Hirst, 1965).

b) Content. Content is largely prescribed and the higher the age group and the more academic the pupil, the more prescribed is the content for most of British schemes. Changes in content, when happened, reduced the content related to technological applications and social aspects of science. It also highlighted the boundaries between the individual sciences and between the sciences and other forms of knowledge, resulting
in that secondary science, at least in the upper levels, has become more isolated from the totality of the school curriculum. It showed a strong classification of knowledge, in Bernstein's (1975) terminology. Few notable exceptions to the pattern described above are mentioned ("Nuffield Junior Science", SCISP and "Nuffield Working With Science").

Commenting specifically on the Nuffield Physics curricula, Baker (1973) observes that the O-Level project aimed at making physics more accurate, up-to-date and more alike the activity of physicists; on the other hand, it removed some of the "useful physics", with the teachers' guides showing little concern with issues like scientists' social responsibility. With regard to the A-Level material, it is suggested that, although including more references to the outside world, both in readings and problems, the general atmosphere does not seem radically different.

It is relevant to notice that, even enthusiasts of the Nuffield schemes agree with some of the points made above. Lewis (1973) points out that Nuffield O-Level did little to show the social implications of physics. Ogborn (1978), an influential member of the team of curriculum planners for A-Level Nuffield Physics, admits that "we did it too little rather than too much" to give an engineering flavour to the course, and that "appreciating the wider significance of science proved to be easier to write down than to achieve, a failing perhaps connected to the minor importance we gave to the historical perspectives".

Apart from the already mentioned SCISP, attempts to intro-
duce science, technology and society issues in school science, have been directed to the sixth-form and present to be part of general studies, rather than integrated with the scientific disciplines (Solomon, 1980; Lewis, 1981).

c) Teaching-Learning Strategies. The major Nuffield projects embraced pupil practical work and guided heurism, linked to a partial acceptance of Piagetian notions of stages, as guidelines for classroom work (ASE, 1979). Both Nuffield and Schools Council developments are criticized in the document for not acknowledging the psychology of individual differences and for not considering alternative strategies based on psychological models which take into account the personal interpretations of meanings, and the role of language in mediating the individual's growing understandings of the world.

When the function of practical and experimental activities is considered, it is observed that although some schemes (e.g. Nuffield A-Level Biology and Physics) present genuine experimental investigations in the form of project work, many of the Nuffield courses have spawned contrivances designed to produce the "right" answer nearly every time.

d) Nature of Scientific Knowledge. With regard to the view of scientific method assumed by the British projects, the analysis presented in the ASE document, classifies some of the projects (e.g. SCISP, CESIS, Nuffield Secondary Science) as conveying an inductivist view, some (e.g. Nuffield O and A-Level schemes) as conveying a hypothetical-deductive approach, and others (e.g. Scottish Integrated Science;
Working With Science) as neither. The general conclusion in the ASE (1979) document is that, often, scientific method is ill defined, with most projects avoiding commitment of the pupils to any particular view of methodology, with the consequent danger of creating the false impression that the neat framework, in which the subject is presented, reflects the manner in which the knowledge was first obtained. The point that the Nuffield schemes did not succeed in articulating scientific method or seriously raising philosophical questions about it is also expressed by Baddeley (1980).

Stevens (1978), however, points out that the Nuffield schemes tend to assume explicitly a superseded empiricist view of the nature of scientific knowledge. In these schemes, scientific theories are seen as speculative models created in order to explain observational data, which are considered theory-free. The theory-ladeness of observations, assumed by modern philosophers of science (Chapter 2) does not seem to have been incorporated in these developments.

This empiricist view of scientific knowledge is reflected in the way that practical work is introduced to the pupils. For instance, in Revised Nuffield Physics, one of the curricular materials examined in Part B of this thesis, inductive discovery is a common procedure, and not a few sequences start by inviting pupils to perform "free" and "open-ended" observations (e.g. "Find out all you can about steel springs"). Furthermore, it is explicitly stated to them that by following such approaches they are emulating scientists at work.
4.4 Summary

In this chapter I considered some general features of "curricular science". The so-called "traditional curriculum" and the "curriculum reform movement" were considered. In relation to the former, it was stressed that it was oriented towards content, and tended to reinforce a "Transmission" view of knowledge. It was noticed that it assumed a superseded empiricist view of scientific knowledge.

In relation to the materials developed in Britain during the 60's, it was stressed that in general they:

a) were subject centered and showed a strong classification of knowledge.

b) followed a discovery learning approach, with little consideration of the role of language in learning.

c) tended to assume an empiricist view of scientific knowledge, in which theory-neutral observations are privileged.
CHAPTER FIVE

TEACHERS' SCIENCE
5. TEACHERS' SCIENCE

5.1 Introduction

When presenting the conceptual framework in Chapter 1, the expression "teachers' science" was introduced in order to characterize the teachers' viewpoint about science conceptions and about the nature of scientific knowledge, as displayed in a particular instructional situation.

It is important to draw attention to the word "particular" in the former paragraph, because it reflects the contextual nature of "teachers' science". What the expression is supposed to mean is not the actual knowledge possessed by the teacher, but rather his or hers translation of "curricular science" (and "scientists' science") that takes place in a specific instructional context. A teacher who accepts and is quite conversant with a sophisticated quantum mechanical model of the hydrogen atom, for instance, may use a simplified version of it when teaching A-Level students, and an even simpler planetary model with younger pupils. Sometimes, of course, "teachers' science" can represent the teachers' actual beliefs.

The fact that "teachers' science" is related to an instructional context implies that studies which can throw some light on its nature are those involving the observation of real classroom settings, particularly the ones focussing on the intellectual transactions between teachers and pupils. In this chapter I review some of these studies, which were considered relevant enough to illuminate aspects of
"teachers' science". The relatively small number of studies reviewed is explained by the fact that most of classroom observation studies have concentrated on the socio-emotional climate of the classroom, with emphasis on the organizational, procedural and disciplinary aspects of the classroom processes rather than in the intellectual transactions (Hacker, 1980). Furthermore, only a part of classroom studies were directly aimed at the investigation of science teaching.

In terms of methodology, classroom observation studies fall roughly either to the "coding-scheme" tradition, which gained impetus after Flanders (1970) pioneering work in the early 60's in the U.S.A., or in the "naturalistic" approach involving the analysis of audio and/or video recorded lessons. These methodologies will be discussed in detail in Chapter 7, and at this stage it is sufficient to state that the methodologies do affect the nature of the findings. Coding-schemes studies have disclosed general teaching styles and naturalistic studies have concentrated on more detailed analysis of the language of teaching. The first approach is best exemplified in Britain by the work of Galton and Eggleston discussed in Section 5.2, and the second by the work of Barms discussed in Section 5.3.

In general, both traditions tended to assume an equivalence between "teachers' science" and "curricular science". Recent studies, reviewed in Section 5.4 show however, that at least in the case of new curricular developments, this assumption cannot be granted.
5.2 Styles of Science Teaching

Galton and Eggleston (1979) investigated the style of 84 science teachers (33 biologists, 21 chemists and 30 physicists) by observing them when interacting with pupils in the penultimate year of O-Level. They used an observation schedule (STOS - Science Teaching Observation Schedule) consisting of 23 categories, specially designed for the recording of the intellectual interactions which take place during science lessons (Eggleston, Galton and Jones, 1975). The schedule was designed, according to its developers, to reflect some of the intentions of the Nuffield O-Level Schemes in Biology, Chemistry and Physics, such as the importance placed upon the processes of science - observing, making inferences, formulating hypotheses - rather than simply acquiring and remembering information. As such the schedule was designed having in mind the cognitive aspects of science teaching, taking no account of managerial and affective interactions.

The observation schedule is divided in two sets of categories. The first accounts for "teacher talk" and comprises seven categories of questions, four of statements and four of directives; the second accounts for talk and activities initiated and/or maintained by the pupils. It was noticed that the most frequently observed categories were "teacher directs pupils" and "teacher makes statements" indicating little pupil autonomy in the science lessons observed. Although differences between teachers were noticed, it was observed that the imparting of factual content predominated, and that pupils initiated and main-
tained categories were used much less than teacher directed ones. Although being cautious in comparing the findings with similar studies elsewhere, the authors suggest that some American studies using similar methodologies also indicate a high incidence of teacher description and teacher explanation in science lessons with little attempt to evaluate and theorize about observed data and different sources of evidence.

Apart from the general trends mentioned above, three different teaching styles were identified in the study (Galton and Eggleston, 1979; Eggleston and Galton, 1979).

Type I (Problem Solvers): the initiative is held by the teachers, who nevertheless challenge the pupils with questions in both practical and theoretical contexts. A large part of the questions reflected a form of problem-solving approach, being of speculative and observational character. In summary, the lessons are based on enquiry which imposes some intellectual demands on the pupils, but initiative and control rests in the hands of the teacher. About 50% of the sample fell in this group and style I was most frequently observed in chemistry and physics lessons.

Type II (Informers): characterized by the relatively infrequent use of questions, except those demanding recall and application of factual information. A high incidence of statements of fact and directives to sources of facts finding by the teacher was also noticed. The lesson as a
whole is characterized by factual acquisition and little emphasis on practical laboratory work. About 33% of the sample fell in this group and it was the most frequent style observed in biology lessons.

Type III (Enquirers): characterized by pupil initiated and maintained behaviour, towards designing experimental procedures, inferring, formulating and testing hypotheses. Practical work centered on pupil enquiry is common and teacher direct influence less pervasive. About 18% of the teachers sampled fell in this category.

In another study using a coding-scheme, different from STOS, Kerry (1981) observed four different teachers in sixteen double lessons. The lessons included first, second and third year science classes. The results show that the science teachers spent a considerable amount of time in managing overtly the classroom and the pupils. A considerable amount of time was also spent in short contacts with groups of pupils performing experiments. During these contacts the teachers were, in general, more concerned with the experimental procedures rather than with discussing their implications, and no real cognitive demands were placed on the pupils. When teacher talk to the classroom was observed, it was commonly concerned with information giving. Questions asked by the teachers were usually of lower order, demanding recall and comprehension. Higher order questions involving application, analysis, synthesis and evaluation accounted only for 3% of the total transactions in the lessons, with the level of
pupils' answers mirroring the low level of teacher demand. Only 10% of the transactions observed were about stimulating pupils' thinking, while 34% were about informing and 56% were concerned with managing the class and individual pupils. It is also suggested that many classroom opportunities for stimulating pupils' thinking were neglected.

In a different type of research concerning teaching styles (Barnes and Shemilt, 1974; Barnes, 1976), teachers of third-years classes in eleven secondary schools were asked to write about the written work they used to set. One pattern found, when teachers of different subjects were compared, was that science teachers were, in general, situated near the "Transmission" end of a Transmission-Interpretation continuum. According to this scale "Transmission Teachers" perceive their task as transmitting knowledge and testing whether the pupils have received it; "Interpretation-Teachers" in their turn perceive their task to be the setting up of a dialogue in which the learners can reshape their knowledge through interacting with others. Barnes hypothesizes a relationship between (1) the teachers' view of knowledge; (2) what he values in the pupils; (3) his view of his own role; and (4) his evaluation of his pupils' participation. These factors are summarized below:
The Transmission Teacher ... | The Interpretation Teacher ...
---|---
(1) Believes knowledge to exist in the form of public disciplines which include content and criteria of performance | (1) Believes knowledge to exist in the knower's ability to organize thought and action
(2) Values the learner's performances insofar as they conform to the criteria of the discipline | (2) Values the learner's commitment to interpreting reality, so that criteria arise as much from the learner as from the teacher
(3) Perceives the teacher's task to be the evaluation and correction of the learner's performance, according to criteria of which he is the guardian | (3) Perceives the teacher's task to be the setting up of a dialogue in which the learner can reshape his knowledge through interaction with others
(4) Perceives the learner as an uninformed acolyte for whom access to knowledge will be difficult since he must qualify himself through tests of appropriate performance | (4) Perceives the learner as already possessing systematic and relevant knowledge and the means of reshaping that knowledge

Extracted from Barnes (1976) pp 144-45

Pope and Keen (1981) comment on the fact that teachers have their own implicit views of the nature of knowledge and pedagogical practice. "Transmission-Teachers" adopt what they call a "Cultural Transmission" perspective on education, while "Interpretation-Teachers" present a "Constructivist" perspective. Freire (1972) dubbed the "Cultural Transmission" perspective as the "Banking" concept of education, according to which students are seen as the depositaries and teachers the depositors of knowledge.
5.3 The Language of Science Teaching

One of the major limitations of coding-schemes methodologies, such as the one employed in the study of Galton and Eggleston, is that in the coding process the real utterances of teachers and pupils are missed. Therefore, no detailed examination of what has really been said is possible.

An example of how this unavailable information can be detrimental to the analysis of results is provided by the study described in the last section. Galton and Eggleston classified about 50% of their samples of teachers as "Problem-Solvers" based on the fact that the majority of their questions were of speculative and observational character. Apart from the fact that the questions themselves are not open to further scrutiny, since they have not been recorded, nothing is said about the nature of pupils' answers. More important, no examination is possible of the treatment given by the teacher to those answers. The possibility exists therefore, that, even assuming that the questions were formally open-ended and speculative, pupils' answers were not treated in accordance, that is, only those answers leading to a swift flow of the lesson towards the teachers' transmission aims were considered and positively valued. That this pattern is likely to happen in science lessons will be demonstrated in the case studies to be presented in later parts of this thesis. It should also be noticed that even the quantitative reliability of observation schedules has been questioned. Dunkerton (1981) points out, for instance,
that observations using STOS may be underestimating the frequencies of some categories by as much as 85%.

In order to avoid the limitations of observation schedules, some studies of classroom interaction have resorted to the analysis of transcripts of lessons, making possible the examination of details of the real utterances emitted. The work of Barnes (1971) is classical in this sense. Although the sample of lessons and teachers analysed were limited and small and only first year lessons were observed, the conclusions are worth being reviewed. Not all lessons observed were concerned with science, but one third were, and most of the examples illustrating the study are derived from these lessons. Barnes does not draw specific conclusions for different subjects, therefore it can be assumed that the general comments made do apply to the language of "teachers' science".

The study was mainly concerned with the effect of teachers' language on pupils and with the teacher's use of a style of language not familiar to pupils. He points out that many teachers present a language of instruction which is alien to their pupils. Barnes talks about a "gulf of understanding" between teachers and pupils, which is not always bridged by the former in their desire to teach the terminology of the subject, which for him became a familiar and even unconscious form of language. One typical example is the case of a teacher asking a group of pupils about a test-tube of milk and using a language of chemistry to suggest that milk is an example of suspension of solids in a liquid. From the teacher's talk it is clear that he sees before him
a good and useful illustration of the concept of suspension. His pupils, however, dependent as they are on their own experience, use a different framework and see milk in terms "bottle", "shake" and finally "cheese". Barnes then observes that "the teacher, frightened by his sudden glimpse of the gulf between them, hastily continues with the lesson he has planned".

Barnes sees the language of instruction as falling in three main categories:

a) Specialist language presented. This includes cases in which the teacher presents specific terminology related to the subject because he is aware of the potential barrier that can be created to the pupils' understanding. Barnes points out that the introduction of specific terminology seems to have for many teachers a value of its own, and not always the substitution of a technical form for a more colloquial one fulfils the function of helping pupils' understanding. The situation is illustrated by a dialogue about the respiratory system during which the word "windpipe" advanced by a girl is substituted by the word "trachea". Although the everyday language term was perfectly adequate for explaining the phenomenon under discussion, the teacher felt the urge to initiate the pupil in the more esoteric subject matter terminology.

b) Specialist language not presented. Either because the terms have already been introduced, or because the teacher is not aware that he is using them.
c) **The language of secondary education.** This includes forms of language that, although not specific to particular subjects, are not part of everyday outside school speech. Most of the time teachers are not aware of the register of the language they use and do not make a conscious effort to elucidate it. To learn it is apparently part of the hidden curriculum of secondary education. Expressions like "tend to be", "approximate", "is quite apparent" and "the point I would like to make" fall in this category.

It is also suggested by Barnes that apart from allowing teachers to express the concepts of their subject more precisely the language of instruction also fulfils, due to its conventional nature, the sociocultural function of supporting their role as teachers. These conventions are likely to be foreign to pupils, and teachers being used to operate within these linguistic styles can fail to see that a pupil has understood a concept if the explanation is not couched in the conventional terminology. The reverse can also happen: the use of a technical term by a pupil can conceal a lack of understanding.

In his study Barnes paid special attention to the forms of questions asked by teachers. He concluded that "very few questions were asked because the teacher was truly ignorant of the answer and wanted to know". Most of the time questioning fulfilled the sociolinguistic function of keeping the presentation flowing. Furthermore, entirely open questions were extremely rare. Usually, the follow-up of questions framed in open terms, showed the teacher admitting only the "right" answer.
Barnes calls them "pseudo-questions". In this issue, Barnes' analysis of classroom language seems to support the views of those who compare classroom discourse to a "verbal game" or "ritual", in which defined roles are assumed by the participants (Sinclair and Coulthard, 1975; Stubbs, 1976; Edwards and Furlong, 1978).

5.4 Teachers' Science and Curricular Science

Discussing some implications of their research, Galton and Eggleston (1979) draw attention to the evident disparity between the principles guiding the development of new science curricula, such as the Nuffield O-Level schemes (emphasis on higher cognitive skills operating in a framework of guided discovery), and the style of teaching adopted by more than 80% of the teachers observed. This divide, between the teachers' traditional pedagogical practice and the principles orientating the development of modern curricula, may have been one important factor preventing a wider implementation of schemes moving away from the traditional.

Recent research on the introduction of new science curricula in school indicates that even when the new curricular materials were adopted, teachers tended to follow ad hoc strategies which lead to the use of the new materials without a re-orientation of their pedagogical practice (Olson, 1982a). He to a large extent, blames curriculum developers for adopting a
mechanistic conception of teacher behaviour and failing to recognize some of the pressures school teachers are faced with in their work, such as examination demands. Moreover, he argues, in general, innovators failed to communicate, in a language accessible to teachers, the philosophy of the new curricula, and to provide enough pedagogical guidance.

In a study that investigated eight postgraduate science teachers using the Schools Council Integrated Science Project (SCISP), Olson (1982b) reveals the difficulties faced by them in adopting the enquiry and discussion oriented pedagogical directives of the curriculum. The teachers perceived these directives as ineffective in coping with the examination demands and as threatening to their influence, control and authority in the classroom. He argues for a humanistic and constructivist approach, taking into account the ways teachers perceive and construe their roles, to be adopted by curriculum innovations. Similar problems are related by Brown and McIntyre (1982) in relation to the introduction of Scottish Integrated Science (SIS) project. They comment that although SIS has been a remarkable example of success of curriculum development, being adopted by 80% of secondary schools in Scotland, the extent to which the intended classroom innovations have been implemented have been rather more modest. The fact that the adoption of the curriculum was not necessarily made on a voluntary basis may be a factor to explain this observation.

In one of the case studies to be presented in this
thesis (Chapter 12) a situation will be shown in which, although Nuffield O-Level materials were used as the basis of the course, the teacher's style was basically a transmission one.

The research reviewed in this section seems to justify the proposed consideration of "curricular science" and "teachers' science" as related but separate entities, and to support Hamilton's insightful observation that:

"When any curriculum - however 'teacher proof' it may be - is translated into classroom practice, it takes on a reality of its own. Occasionally it may match the expectations of the curriculum planners but more often than not it develops in a variety of forms, some intended, some unimagined. Clearly the impact of an innovation can be surely modified by the milieu in which it is used and by the uses to which it is put. In an extreme case 'innovation without change' may result."

(Hamilton, 1976, p. 196)

5.5 Summary

In this chapter I considered some aspects concerning the nature of "teachers' science". Research reviewed suggests that, in spite of the curriculum reform movement pleas for less directive and more inquiry oriented approaches to science teaching, most of what happens in secondary school science classroom can be accommodated in a "Cultural Transmission" framework. It also indicates that the linguistic registers employed by science teachers, do not always help to foster pupils understanding.

If those considerations are linked to the fact that pupils bring to the classroom some already formed personal
perspectives about physical phenomena - "children's science" - the possibility arises that those perspectives are not given due consideration. The case studies, dealing with classroom negotiation of knowledge, presented later in this thesis illustrate this possibility.

It was also indicated that teachers' personal perspectives do influence the way in which they translate the intentions of curricular developers into classroom practice.
CHAPTER SIX

STUDENTS' SCIENCE
6. STUDENTS' SCIENCE

6.1 Introduction

In the conceptual framework presented in Chapter 1, the expression "students' science" was introduced in order to account for the outcome of the interaction between "teachers' science" and "children's science". Although acknowledging that in science courses pupils interact with other sources of information apart from the teacher (e.g. textbooks, other pupils), the instructional situation is usually mediated by the teacher. This fact justifies the instructional situation to be, at first approximation, conceptualized as the interaction between the two forms of knowledge mentioned above.

Before the current wave of research on "children's science", outcomes of learning were usually characterized in terms of "right" and "wrong" conceptions, usually identified in post-test situations by means of nomothetic questionnaires. With the more constructivist view that typifies a considerable part of recent research in science education (see Chapter 1) came the realization that "children's science" plays a greater role in the way pupils incorporate new knowledge to their existing views.

Nevertheless, research in the area concentrated mainly in identifying conceptions held before formal teaching than after. As it was already shown in Chapter 3, investigations with older subjects demonstrate that "children's science" can persist in spite of formal teaching, but little attention has been given to the details of the outcomes of science teaching.
6.2 Outcomes of Science Teaching

One recent attempt to classify outcomes of science teaching in general categories is provided by Gilbert, Osborne and Fensham (1982), and Gilbert, Watts and Osborne (1982). Analysing data from research using Interview-about-Instances (Osborne and Gilbert, 1980) and Interview-about-Events (Osborne, 1980) they identified at least five patterns of outcomes. The patterns and examples presented below are extracted from Gilbert, Osborne and Fensham (1982) and Gilbert, Watts and Osborne (1982).

a) The Undisturbed Children's Outcome. Some children have an undisturbed viewpoint despite formal teaching. In this case it is common for the learners to have incorporated some language of science to describe the viewpoint, which, nevertheless, remained essentially unaltered. One example of this outcome is the case of a 15-year-old, doing O-Level integrated science, advancing the same answer that a 6-year-old and a 13-year-old, when asked if there was any force on a man in a satellite orbiting the earth:

"No, there is no gravity up there."

In relation to the situation presented, ideas about force and gravity taught in the science class seem to have had no impact on the 15-year-old viewpoint.

b) The Two Perspectives Outcome. The student basically rejects the "teachers' science" as something that can be accepted in terms of how to view the world, but considers
it as something that must be learned for examination purposes. This pattern is illustrated by the answer given by a 17-year-old sixth-former when asked for a definition of force:

"Oh now I've got it ... a force is an action or reaction (laughs) that's what they (teachers) always give us. (What does it mean?*) Well they normally give us examples that are easy to explain ... but I don't get it ... if I push the wall I can't see how it can possibly push me back."

Although the student seems to have "learned" the standard explanation that "to each action corresponds a reaction", he finds it difficult to apply it, in order to analyse everyday phenomena.

c) The Reinforced Outcome. The dominance of the pupil's prior understanding can often lead to unintended uses of what is being taught. One common case is where concepts defined in science in a particular way are used to mean something different. For example, a 15-year-old explaining the appearance of drops of water outside a jar containing ice:

"Through the glass ... like diffusion through air and that ... well it isn't got there any other way (a lot of people I have talked to have been worried about this water ... it troubles them*) Yes, because they haven't studied the things like we have studied (what have you studied which helps?*) things that pass through air, and concentrations, and how things diffuse."

In this case the notion of diffusion, learnt in the

* Interviewer
context of movement through air and water, has been applied to explain movement through glass; the concept of diffusion reinforces the "children's science" explanation of the phenomenon.

d) The Mixed Outcome. In this pattern students hold ideas that are not interpreted and may be self-contradictory; the learner's views are a mixture of "children's science" and the teacher's views. This case can be illustrated by the explanation provided by a 14-year-old when confronted with a mixture of ice and water due to the defrosting of ice:

"I thing it is the same atoms in the ice before and now they are unfrozen in the water (What else is there beside the atoms?* The stuff that freezes?*) no ... I don't know ... yes ... no ... it's all atoms but the atoms are just frozen."

The student applied the idea of conservation of matter between change of phases, but the microscopic change in structure was interpreted as a change in the properties of the atoms themselves.

e) The Unified Scientific Outcome. In this case the student successfully mastered the conceptions he is supposed to have learned. His views regarding the phenomena in question, are closely aligned to "curricular science". For example, the answer given by an 18-year-old sixth-former when asked about the forces acting on a golf ball after being hit by a club:

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* Interviewer
"No there's only gravity here ... as any applied mathematician would know ... the force ended when it left the club ... and there's an air resistance of course so that the resultant force is back this way when you add the two."

One possible argument that could be raised in relation to the way by which the outcomes described were determined, is that the students were not interviewed before the topics had been taught. Therefore their prior knowledge and the answers they would have given if asked similar questions before teaching took place is something which had to be conjectured. Nevertheless, the categories seem sound enough to be considered as a system to be tested and, possibly expanded in studies using a research design with more control over the variables.

One example of such a case is a quite old study by Fleshner (1963). Russian schoolchildren, aged between 11 and 13 years, were interviewed about their ideas of "weight" before and after being taught the topic. Four patterns of outcome were identified in the study. Three of the patterns were similar to the Undisturbed, Mixed and Unified outcomes described above. The fourth group of children presented a reaction in the post-interviews, which I would suggest be called "The Inhibited Children's Science Outcome". This pattern shows children starting an explanation by employing their prior knowledge ("children's science") but suddenly coming to a stop, realizing to be on the wrong track. They were not able, however, to produce an explanation which satisfied them and decided not to give any. Typical statements of pupils presenting this outcome are:
"I don't remember and I don't want to talk nonsense."

or

"I forgot about what we learned. Why say it wrong?"

6.3 Summary

In this chapter some possible patterns of outcomes of science teaching were presented. Five of them were identified in Gilbert, Osborne and Fensham (1982) and in Gilbert, Watts and Osborne (1982):

a) The Undisturbed Children's Science Outcome
b) The Two Perspectives Outcome
c) The Reinforced Outcome
d) The Mixed Outcome
e) The Unified Scientific Outcome

A sixth pattern is presented in a study carried out by Fleschner (1963), which could be named

f) The Inhibited Children's Science Outcome

It was suggested that the amount of research focussing on the outcomes of science teaching, from a constructivist perspective is still very reduced. Further studies are needed in order to corroborate and expand the categories so far described.
CHAPTER SEVEN

PRESENTATION OF THE CASE STUDIES
7. PRESENTATION OF THE CASE STUDIES

7.1 Introduction

In the previous chapters of this thesis I introduced and discussed, in a general way, a framework according to which science education is conceptualized by considering different forms of knowledge, their interactions and their transformations. The framework was advanced as a proposed conceptual tool and descriptive language to be shared by teachers and researchers in science education.

In the next six chapters four case studies are presented, and in them some aspects related to the everyday practice of physics teaching are analysed from the point of view of the framework adopted. In Case Studies I and II (Chapters 8 to 11) the framework is applied comprehensively, and the analysis is centered around two topics which are usually considered in school science physics at CSE and O-Level. Case studies III and IV (Chapters 12 and 13), in their turn, consist of the analysis of two instances of classroom interaction involving practical work. Since Case Studies I and II are more complex, in the sense that their scope is wider, in this chapter I will concentrate on the discussion of their form of presentation. The form of presentation of Case Studies III and IV are discussed in their respective chapters.

In Case Studies I and II, the conceptual framework described in Part A of this study is illustrated by applying it in the analysis of two topics of secondary school physics. My aim, in presenting them is twofold. On the one hand they
are intended to illustrate, with concrete instances, the forms of knowledge previously discussed at a more general and abstract level. In this sense the presentation has a clarificational purpose. On the other hand the case studies do highlight some problems with regard to the teaching of the topics considered. Thus I expect that the presentation can serve some practical purpose.

The two case studies consist basically of a critical analysis of curricular materials and instances of classroom interaction. The conceptual framework is brought into action by:

a) informing the analysis of "curricular science" with results derived from a study of "scientists' science" and "children's science".

b) conceiving the classroom interactions during science lessons, at least as far as content is concerned, as an interaction between "teachers' science" and "children's science".

c) informing its analysis with results derived from the considerations of item a) above.

The topics around which the case studies are centered are "Light and Colour" (Chapters 8 and 9) and "Force and Movement" (Chapters 10 and 11). The reasons for choosing these topics were various:

a) Both are commonly taught in physics courses at CSE and O-Levels, and therefore the results of the analysis can be instructive to practising teachers;
b) They are topics in which children are likely to develop early intuitive conceptions and therefore the interaction between "children's science" and "teacher's science" could be illustrated;

c) In the case of "Force and Movement", in particular, there is strong evidence that "children's science" tends to recapitulate conceptions that were produced in the historical development of "scientists' science". There is, therefore, a need for teachers to have a greater awareness of that fact;

d) Both are topics which are treated by most science curricula, and therefore an analysis of "curricular science" could be undertaken;

e) I had the opportunity to observe an experienced physics teacher in action when presenting these topics. Thus some problems that even experienced teachers face, when presenting those ideas, could be illustrated.

7.2 Form of Presentation

The presentation of Case Studies I and II follows a similar sequence:

1. Scientists' Science: a summary of the historical development of scientific ideas concerning the topic. The historical development offers a baseline for the analysis of the transformation of "scientists' science" into "curricular science". In the case of "Force and Movement", in particular, the presentation also aims to show parallels between "children's science" and historically earlier scientific ideas.
2. **Children's Science**: a summary of the literature concerning alternative conceptions related to the topic. It provides a background against which "curricular science" and the interaction between "teacher's science" and "children's science" are analysed.

3. **Curricular Science**: an analysis of some textbooks' presentation of the topic. For the present study I considered the following texts:


- **CSE Physics** (Nelkon, 1978): a traditional approach to CSE Physics

- **Nat Phil 3,4,5** (Jardine, 1973a, 1973b, 1974): a traditional approach, though more historically illustrated


   The sample of exemplars of "curricular science" does not claim to be inclusive, but is, nevertheless representative. Revised Nuffield Physics, with its heuristic orientation is a departure from the traditional, and is a typical example of developments following the curricular reform movement of the 60's (Chapter 4). Nat Phil, although still in the traditional approach in terms of content presentation is more historically illustrated than usual textbooks. The two books representing the traditional approach of content
presentation are probably the most popular ones in their class* and were the ones indicated by the teacher observed in Case Studies I and II.

4. Analysis of a lesson extract: an analysis of transcripts of tape recorded lessons. Sociolinguistic and content aspects of the presentation of "teacher's science", and its relation with "curricular science" and "children's science" are considered.

For the two case studies which follow immediately the sequence 1 to 4 described above is divided into two chapters. In one items 1 to 3 are considered (Chapter 8 for Case Study I and Chapter 10 for Case Study II); in the other item 4 is considered (Chapter 9 for Case Study I and Chapter 11 for Case Study II).

In the presentation of the case studies the emphasis will be on the critical analysis of the curricular materials and of the instances of classroom interaction, and suggestions for alternative approaches will be rather implicit in the critique. Their explicitation and development will be considered in the final chapter of this study.

The next section consists of a discussion of the methodology used in observing and analysing the lessons, which constitute a central component of the following case studies.

*I was informed by the Publishers Association (personal letter, Nov. 1981) that there were no figures available concerning sales of physics textbooks. Dangerfield (1981) reports that a survey considering every secondary school in Staffordshire showed those two to be the most commonly used ones. Informed contacts with teachers suggest that the same can be true for the rest of the country.
7.3 Approaches to Classroom Observation

The major approaches to the study of classroom interaction, from a linguistic point of view, can be briefly described under the following headings (Open University, 1979):

a) **Coding Schemes:** sets of categories designed to code and classify classroom language. Usually, a trained observer sits in the back of the classroom and codes the interactions at fixed time intervals, as they occur. This sort of approach has been traditionally associated with the work of Flanders (1970), although a large number of different observation schedules have been developed (Simon and Boyer, 1970). A version especially adapted to the observation of science lessons in the U.K. was developed by Eggleston and Galton (1979); the main results of their study were discussed in Chapter 5.

The coding scheme approach is traditionally quantitative and allows for broad trends of teaching styles to be detected when large samples are observed. The fact that the code is made "in loco", often means that the actual content of classroom language is missed. Some of the consequent problems had been commented upon in Chapter 5. There are no reasons, of course, for not tape-recording the lesson in order to recupe-rate the missing utterances, but a detailed analysis of the material would certainly impose, from a practical point of view, restrictions on the samples to be studied. This would lead to a restriction on what advocates of the approach see as its major disadvantage.
The limitations of coding-scheme approaches have been pointed out by supporters of classroom studies following an "anthropological" orientation (Hamilton and Delamont, 1979) and by those concerned with classroom language (Barnes, 1971; Stubbs, 1975). As one of them stated:

"Most of the studies, however, restrict themselves to statements about whole lessons, and do not examine the details of the ebb and flow of activity during the parts of the lesson. Quotations of the actual words used are hardly to be found; writers tend to use made-up exchanges to illustrate their meaning. The desire to make general and quantifiable statements has directed the attention of most investigations away from the considerations raised in this paper."

(Barnes, 1971, p. 12-13)

Limitations of this sort directed some researchers on classroom studies to a more detailed study of classroom language, such as "insightful observations" and "analysis of discourse".

b) Insightful Observations: such studies involve the detailed observation and commentary of recorded lessons, demanding close attention to the details of classroom language. In this approach attention paid to matters of detail and the preoccupation in capturing the actual language displayed in classroom discourse leads the advocates of the approach to sacrifice quantity (in terms of large samples) to the needs of qualitative aspects. The investigation of the characteristics of "teacher's science" and its interaction with "children's science" in classroom contexts has to be based in some sort of detailed analysis of the actual language employed by teachers and pupils.

Insightful observation in Britain is usually associated
with the work of Douglas Barnes, some features of which had been presented in Chapter 5. Barnes' description of teachers' language was restricted to selective commentary of passages in lessons. Some of the limitations of the approach have been pointed out by Barnes (1971) himself. Language, he states, is described in impressionistic terms because no operational definitions exist and therefore it has been difficult "to define the categories in such a way that the analysis can be reproduced by another investigator".

c) Analysis of Discourse: this pays close attention to the actual forms of language used, mainly from a sociolinguistic, rather than from a pedagogical, perspective. Although using coding categories, the coding is performed "a posteriori" and is based on the transcripts of recorded lessons. It offers a useful descriptive approach and it is represented by the work of Sinclair and Coulthard (1975). Since the preoccupation is primarily with the sociolinguistic functions of classroom language, the actual content of the utterances is not discussed in this sort of analysis.

The system of categories proposed by Sinclair and Coulthard was developed from the observation of a limited number of lessons, during which the interactions observed were restricted to formal lecturing by the teacher to the class. Therefore, its use is properly restricted to this sort of situation. Since the instances of classroom interaction presented in Case Studies I and II occurred within this type of teaching situation the system was employed. The system is also employed when similar situations occur in Case Study III. A summary of the system of analysis proposed by Sinclair and Coulthard (1975), is presented as an Appendix to the thesis.
7.4 Method of Analysis

In the analysis of the lesson extracts, as included in Case Studies I and II, I attempt to combine the systematic power and preoccupation with sociolinguistics aspects of classroom language, with the preoccupation with content analysis that typifies less structured approaches such as insightful observation. This combination reflects my concern with both the form and content of classroom discourse.

The first step in the analysis was the application of Sinclair and Coulthard categories to the material transcribed in order to identify the general sociolinguistic pattern of the observed lessons. According to the scheme employed, a lesson, when following a formal lecturing mode, consists of a sequence of major units - transactions - which in their turn are seen as composed of more basic sociolinguistic units - exchanges, moves and acts (see Appendix ). In a second step the transactions were used as units for comment on the content and pedagogical aspects of the interactions. The presentation consists then of a series of transactions, each of which is followed by a commentary. The format of presentation of the transcripts is different from the one used in Sinclair and Coulthard (1975). This is due to the fact that their format, although feasible in a book, would cause practical difficulties if followed in a thesis presentation. The format adopted here is illustrated in the Appendix.
CHAPTER EIGHT

CASE STUDY I: LIGHT AND COLOUR

(Scientists', Children's and Curricular Science)
8. CASE STUDY I: LIGHT AND COLOUR (Scientists', Children's and Curricular Science

8.1 Introduction

In this first case study the framework presented in Part A of this thesis is applied in the analysis of the topic "Light and Colour", which is usually treated by most school physics courses, and included in the majority of CSE and O-Level textbooks. The presentation follows the pattern already described in Section 7.2. Some additional remarks are, however, needed.

Some science curricula today, when illustrating alternative scientific theories about physical phenomena, do mention the controversy between the corpuscular and wave models of light. PSSC (1960) Physics and Revised Nuffield Physics constitute good examples in which both models are presented in order to prepare the way for the introduction, at the end of the course, of the quantum-mechanical synthesis.

Although related to that major controversy, mainly after the developments which occurred in the seventeenth century, theories about colour have their own history of disputes. These became quite acute, with the divide, in the nineteenth century, between theories emphasizing physical aspects and theories emphasizing physio-psychological ones. The final part of Section 8.2, which presents a historical overview of conceptions about the nature of light and colour, concentrates on this divide. When analysing curricular materials in Section 8.4, I will make the point that this aspect of theories about light and colour is absent in
"curricular science" presentations. It will be seen that a particular view - Young's trichromatic theory - advanced at the beginning of the nineteenth century, is presented as the accepted explanation for what is still today an issue under study.

The presentation of the historical overview is selective, the emphasis being placed on theories about the nature of light and colour. Therefore, important aspects related to geometrical properties of light behaviour will not be specifically discussed.

The presentation of "scientists' science" conceptions about the nature of light starts with some ancient views. Although some would object to the classifying of these views as "scientific", I decided to include them for various reasons. First, they help to put latter developments in perspective by providing a historical background. In the second place, some of them are paralleled by "children's science", a point which will be stressed in Section 8.3. And finally, they represented sophisticated attempts to understand the world, and therefore can be considered, at least, protoforms of "scientists' science".

8.2 Scientists' Science

8.2.1 Ancient Conceptions. Although the concern with light and its associated optical phenomena was common to the great ancient civilizations in general, the roots of the Western tradition in this field lie, as part of a more comprehensive cultural heritage, in the Greek world. According to Ronchi
(1970) the Greek philosophers were less interested in determining the nature of light than in explaining the mechanism of vision, a concern that can be explained by their preoccupation to understand man and his faculties.

One of the earliest lines of thought is credited to the Pythagorean tradition (Ronchi, 1970), according to which vision was due exclusively to an invisible emanation which came out from the eyes, and, by touching the objects, revealed their shape and colour. This theory was quite influential and became part of geometry, with the definition of "visual ray", emitted by the eye and following a straight line.

Systematic doctrines of light and vision were also proposed by the atomists. Although differing, sometimes in matters of substantive detail, all the atomists shared the belief that the phenomenon of vision could be explained by the mediation of material effluences of corpuscular character (Lindberg, 1976). Different to the Pythagoreans, for the atomists the emanations were conveyed from the visible object to the eye.

Democritus (460 BC) believed that light consists of indiscernable round particles, travelling through the air, from the luminous source to the observer's eye. The visual image, however, was not supposed to be formed directly in the eye but in the air, compressed by the combined effect of the eye and the corpuscular emanations from the object seen. The visual image consisted of this compressed air, which was assumed to be solid and variously coloured (Lindberg,
An influential version of atomistic conceptions about light and vision was the one advanced by Epicurus (342-270 BC) and later popularized by Lucretius (d.ca. 55 BC). According to Epicurus, colour and form were part of the nature of objects. All existing bodies were thought of as continuously emitting images ("eidola") similar in shape and colour to the solid bodies, but more tenuous than them (Ronchi, 1970). These images were able to impress our eyes and souls, the latter in dreams (Tonnelat, 1964).

Plato, in his turn, believed that a stream of rays was issued from the observer's eye and, after coalescing with the sunlight, formed a single homogenous body which encountered particles emanated from the observed objects (Lindberg, 1976). These particles were assumed to be black and white, having different sizes; colour vision was explained by different motions performed by these particles (Tonnelat, 1964). According to Ronchi (1970), Plato's assumption of emanations, both from the objects and from the eye, must be interpreted as indicating a belief that both external and internal (psychological) agents were needed in order to explain visual perception.

The necessity of corpuscular emanations, which characterized the models described above, was rejected by Aristotle (384-322 BC), who presented an account of vision as part of his psychological theories. He accepted the necessity of a physical mediator between visible objects and the observer, attributing this function to the medium
between them. For him the medium of sight was the "transparent", a quality found in the air, water and some solid objects. Light was a state of the "transparent", activated by the presence of fire (one of Aristotle's four basic elements); when this state was activated the objects became visible through the transparent medium. Colour, in its turn, was thought to be a property of the surface of objects, which had the power to produce qualitative changes in the transparent medium, leading to their perception (Lindberg, 1976).

During the Middle Ages most of the important contributions to the study of optical phenomena were developed in the Islamic world (Ronchi, 1970; Lindberg, 1976). The original and new conceptions produced, however, concentrated on aspects related to geometrical optics and perspective, rather than on theories concerning the nature of light.

As far as the phenomenon of colour was concerned, medieval theories reflected basically the ancient assumption that light and colour were distinct entities. Colour was supposed to be a quality or property of the surface of objects, made visible through the action of light.

In the Renaissance new ideas started to appear, and the first hints at the possibility of a wave theory of light were presented by Leonardo da Vinci, who, considering the similarity between sound echoes and the reflection of light, suggested an analogous behaviour for light and sound (Harvard Project Physics, 1968). The rainbow and its colours, which received increased attention during the
Middle Ages, was already, in the sixteenth Century, explained by refraction and reflection of the sunlight in the raindrops, indicating that a closer relationship between light and colour was beginning to be explored (Bouma, 1971). Kepler, for instance, defined colour as "potential light", and assumed that light was colourless, only acquiring colour when reflected by, or travelling through, a coloured body (Ronchi, 1970).

8.2.2 The Seventeenth Century. During the seventeenth Century the unification between light and colour was completed. At the beginning of that century light was "colourless" and "light and colour were two different things" (Ronchi, 1970), and by its end the Newtonian model, according to which white light was composed of different colours, was beginning to dominate. Although the name of Newton is usually associated with the transition, his way was paved by other scientists such as De Dominus (1564-1624), Descartes (1596-1650), Grimaldi (1618-1663) and Hooke (1635-1703), who studied the production of colours in rainbows, glasses filled with water and prisms (Sabra, 1967; Ronchi, 1970). In these cases the phenomenon of refraction was involved, and the precise formulation of the law of sines by Snell and Descartes provided the tool for a mathematical approach to the problem.

Grimaldi, in particular, strongly defended the idea that light rays were also endowed by an undulation of very high frequency that enables them to stimulate the sensation of colour; light was no longer a "colourless something". The idea, however, was not easily accepted:
"What has been said so far seemed to be quite sufficient to demonstrate the truth of our Proposition. But in discussing several times this question with men of great learning, I discovered that more than once they made recourse to the evidence of the eyes which according to them revealed colour as being something permanently attached to bodies which are invisible and not self luminous, and as something really different from light; it was not possible by making use of any argument whatsoever to move them from this sacred altar to which they were clinging."

(Grimaldi, quoted in Ronchi, 1970, p.146)

An important analysis of the problem of colours, using a wave model, was presented by Hooke in his Micrographia, which appeared in 1665 (Sabra, 1967; Ronchi, 1970), and in which an elaborate account of the colours appearing in thin transparent plates - later known as Newton's rings - (such as soap bubbles, glass blown in very fine sheets and metallic surfaces) was proposed. Hooke assumed that white was the effect of an undisturbed motion or pulse, in which the wave fronts were perpendicular to the direction of propagation. Colours were produced when such pulses were disturbed as a result of refraction (the prism) or the combination of pulses reflected by the lower and upper faces of thin plates. In those disturbed pulses the wave fronts were oblique to the direction of propagation; in the oblique wave front the part which first met the refracting surface would be "weaker" than the part which follows, because the former will prepare the way for the latter.

The sensation of colours was then explained by Hooke:

"Blue is an impression on the Retina of an oblique and confus'd pulse of light, whose weakest part precedes, and whose strongest follows ... Red is an impression on the Retina of an oblique and confus'd pulse of light, whose strongest part precedes, and whose weakest part follows."

(Hooke, quoted in Sabra, 1967)
The other colours were explained as resulting from the effect on the retina of pulses focussed between the extremes red and blue. In Hooke's model, colour is clearly an effect generated in the retina by the light pulses, and not a quality of the object being observed, and the propensity to generate colour was acquired by the pulses when passing through prisms, thin plates, water drops, etc.

8.2.3 The Newtonian Influence. Newton's initial interest in colours was associated with the problem of chromatic aberration effects on lenses of non-spherical shapes. Then, according to his letter to the Royal Society in February 1671:

"... I procured me a Triangular glass-Prisme, to try therewith the celebrated Phaenomena of colours. And in order thereto having darkened my chamber; and made a small hole in my window shutes, to let in a convenient quantity of sun light, I placed my Prisme at its entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasing diversion, to view the vivid and intense colours produced thereby; but after a while applying myself to consider them more circumspectly, I became surprised to see them in an oblong form; which according to the received law of Refraction, I expected should have been circular ..."

(Newton, quoted in Ronchi, 1970, p.160)

Newton explained this surprising result by assuming that light consists of rays with different degrees of refrangibility (indices of refraction), each of which associated to a different colour. He also assumed the rays to be "possibly" constituted of "globular bodies" of different masses, which were therefore subjected to different deviations (Ronchi, 1970). The fact that a second prism was able to reconstrue the original beam, generating a round (and not
refracted) image was presented by him as confirming his explanation.

The Newtonian model differed in two important ways from the existing ones. Unlike Hooke (and also Huygens) Newton used a corpuscular model. Although he claimed that it was just a hypothesis, which he would relinquish if presented with a better alternative, he adhered to it in quite a dogmatic manner; his explanation of refraction which appeared in the Principia, was based on a corpuscular view since the rays of light were assumed to obey the laws of particle dynamics (Sabra, 1967).

The second point of departure was Newton's view that white light was a composed entity. Rays with different refrangibility (particles with different mass) were already existent in white light, and not created in the prism. The function of the prism was to sort out the different rays which could be recombined by means of a second prism. Newton was very committed to this conception, which he regarded not as a hypothesis, but as a definite result, based on experimental data. That was another important point of disagreement between Newton on one side and Hooke and Huygens on the other (Sabra, 1967).

It is important to stress that Newton made clear that colour is a perception, and pointed out that when he mentioned coloured light or coloured rays, he was only expressing himself in a manner of speaking, and not "philosophically and properly":

"The homogeneal light and rays which appear red, or rather make objects appear so, I call rubrific or red-making; those which make objects appear yellow, green, blue and violet, I call yellow-making, green-making, blue-making. In them there is nothing else than a certain power and disposition to stir up the sensation of this or that colour."

(NEWTON, QUOTED IN RONCHI, 1970, P.170)

The Newtonian conceptions about light and colour were generally critisized by Huyghens and Hooke, who committed to a wave model of light, reacted strongly to the corpuscular theory proposed by Newton. The corpuscular model had to assume that the light particles moved faster in a denser medium, such as water or glass, than in air, in order to explain refraction, and that was an anti-intuitive proposition. They were also never convinced by Newton's arguments in favour of the composite nature of white light (Sabra, 1967). Furthermore, Newton never succeeded in giving a satisfactory account of the phenomena of colours in thin plates (Newton rings) even when he incorporated in his pure corpuscular theory, the idea of a vibrating ether (the theory of fits). Diffraction, a phenomenon already noticed by Grimaldi, and double refraction, were also poorly accounted for by Newtonian optics (Ronchi, 1970).

In spite of these drawbacks, with the publication of Newton's "Opticks" in 1704, and in part due to the influence of his theory of mechanics, his conceptions on optics gained the acceptance of a major part of the scientific community during the eighteenth century. As Ronchi (1970) points out:
"Perhaps the simplicity with which Newton's theory explained the best-known elementary phenomena of light, such as reflection, refraction, and the production of colours, conquered the majority of minds. This left unexplained the complex phenomena of diffraction and double refraction ...."

(Ronchi, 1970, p. 199)

According to Kuhn (1977a), during the eighteenth century, Newton's "Opticks" provided the paradigm in this field. For instance, physicists sought evidence of pressure exerted by light particles, a line of research not hinted at by wave theory. Kuhn regards the Newtonian framework as the first nearly uniformly accepted paradigm in optical physics. The emergence of the Newtonian paradigm changed the field:

"Since Newton, education and research in physical optics have normally been highly convergent. The history of theories of light does not, however, begin with Newton. If we ask about knowledge in the field before his time, we encounter a significantly different pattern - a pattern still familiar in the arts and in some social sciences, but one which has largely disappeared in the natural sciences. From remote antiquity until the end of the seventeenth century there was no single set of paradigms for the study of physical optics. Instead, many men advanced a large number of different views about the nature of light. Some of these views found few adherents, but a number of them gave rise to continuing schools of optical thought. Although the historian can note the emergence of new points as well as changes in the relative popularity of older ones, there was never anything resembling consensus. As a result, a new man entering the field was inevitably exposed to a variety of conflicting viewpoints; he was forced to examine the evidence for each, and there always was good evidence. The fact that he made a choice and conducted himself accordingly could not entirely prevent his awareness of other possibilities. This earlier mode of education was obviously more suited to produce a scientist without prejudice, alert to novel phenomena, and flexible in his approach to his field."

(Kuhn, 1977a, p. 231)

Ronchi (1970), using more passionate discourse, makes a similar point:
"For those interested in the function of dogmatism in science, it is worth noting that the Newtonian theories of the eighteenth century constituted a real and true dogma. The revolutionaries of the seventeenth century had struggled against the dogmatism of the Peripatetics to establish a rational method and a clear critical mentality in the scientific field. The result had been obvious. The dogmatism of the Peripatetics was supplanted by the dogmatism of the Newtonians which, unfortunately, was even stricter and more domineering than its predecessor. The Peripatetic dogma was clearly stated and was used as a method, while the Newtonian was not called dogma but was considered to be the result of experimental and rational investigations and, as such, was considered to be unquestionable. In practice it was forbidden to criticise it or to lay any stress on phenomena which did not come within its general framework. From this it appears as if the scientific world is destined to pass from one dogma to another, just as if dogmatism were an absolute necessity."

(Ronchi, 1970, p. 220)

If the word "dogma" is substituted by "paradigm" the quote could be Kuhn's. The original edition of Ronchi's book was published in Italy in 1939.

In a situation like the one described by Ronchi and Kuhn, it is not perhaps surprising that criticisms of the Newtonian paradigm came from men who were not trained to be physical scientists.

8.2.4 The Nineteenth Century.

a) The Wave Model. The Newtonian paradigm was challenged in the early nineteenth century by Thomas Young, an English linguist, physician and physiologist. Not being a physicist, he was not tied to the Newtonian paradigm, and therefore was more free to propose divergent explanations for the problems which the corpuscular model failed to solve (Ronchi, 1970).

In his now famous double-slit experiments, performed between 1802 and 1804 he showed that the patterns of interference observed could be interpreted by assuming a trans-
universal wave model, while they were incompatible with a corpuscular one. He was also able to measure the wavelengths associated with different colours, from his initial theoretical supposition.

Young's results, supporting a wave model of light propagation, were received with hostility by the British scientific establishment, strongly committed to the Newtonian paradigms in optics and mechanics (Ronchi, 1970; Berns, 1973). One of his articles was not accepted by any periodical, and he was forced to publish it himself, as a pamphlet. To the accusation that he had been too critical of Newton's ideas and experiments, presuming errors that a man like Newton could never have made, he answered:

"But much as I venerate the name of Newton, I am not therefore obliged to believe that he was infallible."

(Young, quoted in Ronchi, 1970, p. 240)

Young's views, however, started to be considered in a different light after Fresnel's wave theory was accepted in France in the late 1810's. Fresnel, like Young, was not a physicist by training and spent the first ten years of his professional life as a civil engineer involved in road construction (Ronchi, 1970). His theories, applying a mathematical wave model to the phenomenon of diffraction were received in a more supportive way by French academics. That is not to say that all of them were easily converted, and actually some important scientists like Poisson and Biot remained attached to the corpuscular model in spite of Fresnel's successes. The support he received from other members of the community, such as Arago, was enough for his
views to be discussed and to be considered as plausible alternatives to the corpuscular theory.

The successes of Young and Fresnel's wave theories in dealing with diffraction of light, coupled with the determination of the velocity of light in liquids in the middle of the nineteenth century (found to be less than in air and therefore contrary to Newton's assumption), led to the substitution of the wave model for the particle one.

The wave model of light became the paradigm accepted during the second half of the last century. Maxwell's theoretical synthesis, which integrated light, electricity and magnetism in a common wave theory, and Hertz's experimental work, consolidated the new paradigm. Light appeared to be definitely explained as a part of the electromagnetic spectrum, able to sensibilize the normal human eye, with wavelengths ranging approximately from $4 \times 10^{-7}$ m to $7 \times 10^{-7}$ m. In this model the sensation of different colours is associated with different wavelengths.

b) Colour Vision. Newton's approach to the problem of colour was strongly criticized by Goethe in a book published in 1810. He was a writer and a poet, and a well known representative of the Romantic School in literature, which had links with the German Natural Philosophy movement. The latter defended the search of great unifying principles which could provide a picture of nature in its wholeness, instead of the analysis of natural phenomena in contrived laboratory experiments. It is agreed that this movement was influential in the formulation of the principle of
conservation of energy (Raman, 1975).

For Goethe, the Newtonian approach to the study of natural phenomena, postulating a neutral observer as part of an observer-observable duality was not acceptable. He argued that man is part of nature, and in observing nature, nature is observing itself, and that the more direct the observation, the closer to the truth (Bouma, 1971). Therefore, if white light appears to our consciousness as a simple and unique sensation, it must be considered as a simple and unique entity, the spectrum of colours resulting from the effect of the prism on pure light. Moreover, argued Goethe, colour is a subjective idea, which can be imagined even with closed eyes, and therefore could not be characterized by refrangibilities as Newton did.

Coming from literary, rather than scientific quarters, Goethe's ideas were not well received by the scientific community, which considered them as a return to a sort of subjectivism that science had been liberated from (Ronchi, 1970).

A more "scientific" approach was presented by Young who advanced a trichromatic hypothesis, according to which colour vision was explained by considering the existence of retinal receptors with different sensitivity to different wavelengths. He postulated that these receptors were basically sensitive to wavelengths corresponding to the red, green and blue colours. According to his theory a yellow perception was assumed to result from the simultaneous stimulation of the "red" and "green" receptors, the
equal stimulation of the three types of receptors resulting from the sensation of white (Bouma, 1971).

In summary, Young transferred to the eye the results of experiments of additive colour mixing, which are today common in school science. At this point, argues Ronchi (1970), the phenomenon of colours started to be shifted from the domain of physics to the domain of physiology.

Young's trichromatic theory of colour vision was ignored for almost fifty years before being adopted and developed by Helmholtz and his collaborators, mainly in its mathematical and experimental aspects. The theory became known as the Young-Helmholtz theory and constituted a guide for research until recently (Padgham and Saunders, 1975). That is not to say, however, that it did not have its critics.

The criticisms to the theory came both from the areas of physiology and psychology. The former was based on the lack (until recently) of evidence to support the three retinal detectors; on the psychological side, it was difficult to reconcile the theory with the fact that four colour sensations are actually experienced and qualitatively distinguished - red, yellow, green and blue (Padgham and Saunders, 1975). For instance, although the mixing of green and blue lights produce a sensation which can be rightly described as blueish-green, the mixing of red and green light produces a sensation of yellow, which cannot be described as reddish-green.

In order to accommodate these facts a psychologically oriented theory was proposed by Hering in 1870 which considered four primary colours (experienced by the observer as a single
sensation): red, green, blue and yellow. According to the theory the basic feature of colour vision is three opposing processes, a red-green, a yellow-blue and a white-black. These processes are in equilibrium, but they can be displaced by the action of light, leading to the combination between colours of different pairs, but not of the same pair; thus the theory is known as "Opponent Colour Theory" (Bouma, 1971). It explains, for instance, why red-yellowish sensations are possible, but not reddish-green ones. The theory, however, was complicated for explaining the laws of additive colour mixing.

8.2.5 The Twentieth Century

a) Wave-Particle Duality. The wave model of electromagnetic radiation was shaken by Einstein's interpretation of the photoelectric effect in 1905, experimentally confirmed later by Millikan in 1916 and Compton in 1923. According to that interpretation, light is supposed to consist of photons, a corpuscular-like entity, with different colours being associated with photons of different energy.

The most popular position among modern physicists is to accept the so-called wave-particle duality as expressed in the quantum mechanics paradigm; they being complementary ways of describing the physical world. The apparent contradiction between the two models lies, not in nature itself, but in the limitations of our conceptual apparatus which is only able to model, visually, the processes involved in the phenomena described above by using either a wave or a particle model. Mathematically, the descriptions can be related,
with the energy of photons being expressed in terms of wavelengths (or frequencies) of the corresponding radiation. The choice of the model to be used depends on the experimental situation involved.

b) Colour. As far as the specific problem of colour is concerned, basic research moved from the field of physics to the field of physiology and psychology. Physicists will rather conceptualize their problems in terms of wavelengths or photon energies, than in terms of colours.

The physical problem of measurement of colour was practically solved in 1931, with the CIE (Commission Internationale de l'Éclairage) definition of a standard observer and three standard illuminants and standard primary colours (Edwards, 1975). It has been accepted, since the mid-nineteenth century, that any three colours (and not only red, green and blue) can be combined to match any colour of the spectrum, provided that the three primaries chosen are mutually independent (one of them cannot be matched by combining the other two). It is interesting to note that the three colours chosen as primaries by the CIE are not part of the visible spectrum (Feynman, Leighton and Sands, 1963).

The problem of colour vision, however, is still an open one, and the field was for a long time divided between modern versions of physically oriented Young-Helmholtz trichromatic theory and modern versions of the psychologically oriented Hering's opponent colour theory (Padhgan and Saunders, 1975). In the middle ground a compromise between the two
approaches emerged in the so-called zone theory (Edwards, 1975). According to it, the Young-Helmholtz theory is applicable as far as the analysis of the absorption of light by photoreceptors in the retina is considered. Although the process is not yet completely explained, there is some photochemical evidence which seems to support Young's hypothesis of receptors more sensitive to the red, green and blue spectral regions. In a second stage, these inputs are coded on their way to the brain. This coding seems to be better explained by assuming a pattern similar to the one suggested by Hering.

The situation is such as if the two models have been vindicated in relation to two different functions (the reception of electromagnetic radiation in the retina and the sensation of colours). The details of the links between the two stages is, however, a problem of which very little is known (Open University, 1981).

8.3 Children's Science

The most remarkable aspect of children's alternative conceptions of light and some associated phenomena like colour, is the reduced amount of published research, mainly when compared with more explored areas as mechanics and heat. This lack of research becomes more surprising when it is considered that vision is the channel through which the majority of people acquire, from an early age, most of the information about the physical world.
In my literature survey I was able to find only three papers on the theme, which are reviewed below.

Guesne (1978) interviewed a sample of about 20 children (ages 13-14 years) of a French secondary school, ranging from the lowest to the highest ability levels. The interviews concentrated on aspects related to the mechanisms of seeing, intrinsic properties of light (e.g. retilinear trajectory propagation in space, intensity), interaction of light with opaque objects (e.g. mirror, sheet of paper) and the action of a lens on light.

According to the results a typical interviewee can be portrayed as:

"he sees objects because they are lit and because his eyes have then the power to 'see'; coming from the source, light 'settles' on the object and the eyes collect information from over there. His model of vision is coherent with the model he has of light and the latter can explain the former; light means intense light, something dazzling or illuminating, whereas no violent feeling is linked to vision. The child cannot think he is receiving something (light) in his eyes, if he does not imagine that light could exist outside any perceptible effect, consciously discerned".

(Guesne, 1978, p. 265)

Guesne observes that in the children's answers there was a noticeable sense of activity - it was they who searched visually for the observed light. She points out that this idea is close to Platonic and Pythagorean theories of vision which assumed a power emanating from the eyes (Section 8.2.1). She also comments on the fact that the everyday language tends to reinforce the idea of an active eye and a passive object (e.g. "the eye examines").
Stead and Osborne (1979) explored New Zealand science students' conceptions related to light, such as transmission, sources and reflectors and vision. In the first stage the Interview About Instances method (Osborne and Gilbert, 1980) was used to interview 36 students (9-16 years), none of which had studied light in the previous 12 months, if at all. Although some students presented, in analysing some of the instances, a concept close to the scientific one, others simply did not conceive light as travelling at all, and for others the distance travelled varied between one meter and infinite. Those differences seemed not to be age related in the sample.

The categories in which students' conceptions were classified as a result of the interviews were used to guide the construction of a multiple choice test (the possible answers were matched to the four major categories) and the test administered to 144 Form 2 students. In general, a higher percentage of students chose the "non-scientific" answers, with the percentage choosing each category depending on if the example involved a situation in daylight or night. At least one half of the sample held the idea that light did not travel away from the source or reflector in the daytime. In this case it is reasonable to suppose that they will attribute an active role for the eye as described by Guesne.

A slightly revised version of the test was sent to volunteer teachers in widely spread New Zealand schools and administered to 235 Form 3 students who had recently studied a unit on light. The pattern of responses was basically
similar to those obtained in the first application of the test.

According to the authors of the report "both the qualitative and quantitative method produced evidence that many students of different ages, and with different amounts of formal tuition on light, did not see light as travelling far from a source or reflector during the day. Most students saw light as travelling further at night. Few students had a concept of light travelling that matched the scientific concept and that was constant over all the ten instances".

The fact that Form 3 students, who had received formal teaching on light, presented concepts of light travelling similar to those of Form 2 students, who had not received formal teaching on light, led Stead and Osborne to conclude that the teaching had not significantly moved the students' concepts towards the scientific one, probably because teachers had, incorrectly, assumed that their students believed that light travels great distances, and no teaching was specifically directed at this aspect.

Jung (1981) describes his investigations of children's understanding of virtual image. In a pilot study students (ages 13-14 years) who had been taught elementary optics, as image formation by mirrors, were asked to observe a distant light source through a double slit, and to report and explain what they saw.

Although he did not expect an explanation in terms of patterns of interference, he hoped for an application
of the scientific framework of image formation previously taught. More than 50% of the students (total number not presented) reported that they saw the source of light radiating sideways and "only one boy was able to trace the phenomenon correctly back to a deflecting influence of the 'screen', as they called the double slit".

The "sideways radiation" is an interesting interpretation, which supports the interpretative nature of sensations. I find it difficult to understand why Jung expected the children to explain the phenomenon in terms of image formation and why he thinks that to trace the information back to the deflecting influence of the double slit is correct from the physical (scientific in his terminology) point of view. Image formation is usually explained, for the age group considered, in terms of the geometry of retilinear propagation of rays of light, assuming at least implicitly a corpuscular model, and the double slit observations can only be explained by a wave model, as firstly done by Young.

More acceptable are Jung's investigations with mirrors, in which more than 90% of a sample (total number not presented) of 12 year-old boys located their images on the surface of a mirror and not behind it because no light passes through the mirror and therefore one cannot see behind it. Even the majority of older children (ages 14-15 years) is reported by Jung to hold a similar view.

Another widely expressed view detected by Jung was that a bright spot can be seen in a mirror whatever the
position of the observer (as far as he is not behind it),
the justification being that although the light is reflected,
it is always lying on the mirror surface.

As it can be seen, the area of children's conceptions
about light is still an unexplored ground and conceptions
about some important phenomena have not been investigated
at all. In none of the studies that I have reviewed is any
investigation about children's conceptions of colour
reported.

It seems reasonable, for instance, to suppose, as Jung
does, in the beginning of his paper, that people tend to
consider that what is perceived as "a given in itself, i.e.
something that exists in its own right irrespective of the
fact of being perceived". If this idea is extrapolated to
colour vision, colour is likely to be considered as something
that an object possesses, as an intrinsic quality. As it
was seen (Section 8.2.1) this conception was held by
Aristotle and accepted throughout the Middle Ages. It is not
difficult to imagine how contradictory with this conception,
the usual curricular experiments of colour subtractive mixing
can be.

It can also be speculated that for children, in general,
and for most adults: white light is light in its purest
state, which is transformed when passing through some media,
such as prisms and transparent coloured objects. This was
a common view before Newton's theory of light (Section 8.2.3).
And, after all, white is a symbol of purity and goodness (e.g.
wedding dress). According to this hypothesis, school children
will tend to explain the school science demonstration involving a projector and coloured filters by assuming that a filter adds its colour to white light. For holders of such an alternative conception a red filter would look red, not because wavelengths (or photons) corresponding to other colours have been absorbed by the dye, but because the filter transmitted its redness to the pure light. The possibility of this alternative framework is speculated on in the Revised Nuffield Physics Curriculum (Section 8.4.3).

In order to test this speculation a study was conducted by myself and Mr. D.M. Watts in which 146 pupils at the end of their third-year (i.e. aged 13-14) were asked to observe a demonstration of light passing through coloured slides, and explain (in writing) why they saw a coloured light when the slide was kept in front of the torch.

A preliminary analysis of the answers showed that nearly half of the sample gave explanations according to which the slide "changes" the ordinary light (white) into coloured light. About 70% of those children did not explicitate the process of transformation, e.g.:

"It is red because the light has hit the red slide and come on red because the light changes."

The other 30% of this group (≈15% of total sample) described the colouring process as hypothesized. Some answers of this group:

"All the slide does is colour the light, changing the colourless white light to red."

and
"When you shine a torch through a piece of glass the light you see is clear. Then when you cover the torch with a red slide a red light appears. It is because the red slide sort of in a way dyes the light rays and lets out a beam of red light."

About 13% of the children answered in terms of a projection mechanism. In this case, it is not so much that the light is transformed but that it makes the colour to come out of the slide, e.g.:

"Because the light shines through the slide, which is red, and the colour of the slide is projected along with the light of the torch."

and

"The light shines through the red slide and it projects the colour onto the screen."

Near 30% of the sample answered in a quite non-committal way of the sort:

"Because the beam of light is going through a red slide."

This sort of answer did not tell very much about the conceptions held by the children. In an interview the pupils could be probed further and it is likely that a number will come out with answers which could be fitted in one of the frameworks described above. It can also be speculated that at least some of the children who said that the white light "changes" when passing through the slide, without expliciting the process, if asked to elaborate their views, would advance the mechanism of the white light being "coloured" by the slide. Further investigation on the issue is needed, but the results described support the view that for most of the children the ideas of the composite nature
of light and of filtering processes are strange to their more intuitive explanations.

Children's previous experience with paints (common in primary schools) can also interfere with their understanding of the mixing of coloured light experienced late in the secondary school. I would expect them to be puzzled by the fact that a mixture of red, green and blue lights is white (they will possibly see black as the natural result) and that yellow results from the combination of red and green light. I would see Hering's psychological model (Section 8.2.4) as more compatible with their conceptions.

8.4 Curricular Science

8.4.1 The Sequence of Presentation. In the four textbooks analysed in this study (see 7.2) there is a chapter in which the topic "light and colour" is discussed. Since the topic is treated in different places in the texts, a summary of the context in which the phenomenon is considered is necessary in order to put the matter in perspective.

Abbot's Ordinary Level Physics deals with the problem of colour in "Chapter 25 - Dispersion and Colour", which is placed at the end of the Optics unit in the book. The four previous chapters in this unit are concerned with geometrical optics only, and the physical nature of light is not discussed. In Chapter 25 the phenomenon of dispersion is presented as a consequence of the fact that "different colours" have different refraction indices, and the treatment is purely geometrical. The relation between colour and wave-
length is introduced in the following chapter, in which waves are discussed. Light is then explained as being of an undulatory nature and part of the electromagnetic spectrum. Some properties of light explainable by a wave model (e.g. interference and diffraction) are discussed. The photoelectric effect is mentioned in Chapter 45, in the Atomic and Nuclear Physics unit of the book, but the challenge presented to the wave model by Einstein's interpretation of the effect is not discussed. In this sequence of presentation the wave model of light is privileged, as it was in the nineteenth century paradigm.

Nelkon's CSE Physics also introduces the topic at the end of the Optics unit, which consists of seven chapters. "Chapter 20 - Colours of Light - The Spectrum" is the sixth in the unit, which, like in Abbot's, presents a mainly geometrical treatment of light. Differently to Abbot, however, geometrical optics is preceded by a chapter on waves in which the idea that light is an electromagnetic wave is introduced. The model is not used in the further sections and even in the chapter on colour, the relation between colour and wavelength is not explicitly presented. The particle model of light and the photoelectric effect are not discussed in the book. Again, as in Abbot's the wave model is privileged.

Jardine's Nat Phil treats light, initially in "Chapter 2 - Light and Sight", which is part of a unit in wave motion,
the first of Nat Phil 3*. The phenomenon of colour is discussed in a section of this chapter from the perspective of a wave model. Light is revisited in Nat Phil 5, in a unit that is basically concerned with the wave-particle duality and models of light, but colour is not specifically treated. The treatment in Nat Phil 5 is illustrated with some examples from history. Some Greek theories of light are mentioned and the wave-particle controversy in the seventeenth century considered. These issues, however, are only discussed in Nat Phil 5, and therefore pupils not pursuing physics up to Scottish H Grade will only have been presented to the wave model.

Revised Nuffield Physics introduces the topic colour in "Chapter 3 - Light and Colour" of Year 3. This chapter follows one in geometrical optics; and although the first chapter of the text deals with waves, colour is treated without reference to models of light. At the end of Chapter 3, an optional introduction to the wave and particle theories of light is presented. The theme is considered again in Year 5, in which the wave model of light is developed and contrasted with the photon theory in Chapter 11. As in Jardine's text, the idea of "models" and the illustration of their role in physics, by using theories of light, is a central concern in the late stages of the course.

Although the general context in which Light is con-

*Nat Phil curricular consists of a series of three books. Nat Phil 3 is the first of the series. Nat Phil 3 and 4 cover the O Grade of the Scottish syllabus, and Nat Phil 5 the H Grade.
sidered varies in the texts analysed - for Nuffield and Jardine the role of models in physics is basic, whereas Abbot and Nelkon do not consider that aspect - the sections dealing specifically with colour have very much in common. The topic is treated without strict adherence to any model. This commonality is reflected in the fact that the pattern of presentation is similar, for the chapter devoted to colour, in all the texts. Some aspects of that pattern of presentation are discussed next.

8.4.2 Newton's Experiments With Prisms. All the four texts introduce the topic by referring to the phenomenon of dispersion and Newton's experiments with prisms are discussed. In general Newton's contribution is presented a-historically. He is considered to be the first to have investigated the issue in a serious way.

Abbot's O-Level Physics states that the phenomenon of colours appearing when white light passes through fragments of glass was known for centuries, but was not investigated systematically until Newton. It is correctly pointed out that Newton's interest in removing the chromatic aberration from telescopic lenses directed his attention to the problem.

The primacy of Newton's work is also stressed in Nelkon's CSE Physics:

"The prism experiment outlined here was first performed by Sir Isaac Newton in Cambridge in 1666."

(p. 334)
in Jardine's Nat Phil 5:

"In 1666 Newton discovered that when a shaft of sunlight passed through a prism it produced the same range of colours."

(p. 128)

and in Revised Nuffield Physics Year 3:

"that (dispersion) must have been seen but Newton thought about it."

(p. 90 Emphasis added)

In none of the books, Newton's predecessors in the study of this particular phenomenon are mentioned (Section 8.2.2). The idea transmitted is that Newton was the first scientist to devote himself to the problem, a point that Newton himself makes clear that he was not, in the presentation of his paper to the Royal Society, by stating:

"... I procured me a Triangular glass-Prisme to try there-with the celebrated Phaenomena of colours."

(quoted by Ronchi, 1970, p. 160)

On the other hand, the textbooks analysed do not stress the real novelty provided by Newton, which was his interpretation of the phenomenon in terms of composite nature of the solar rays. The revolutionary character of that notion, in Newton's times, is not discussed. The results of the study conducted by myself and D.M. Watts, described in Section 8.3, suggest that for a number of pupils this can be a revolutionary notion as well.

The phenomenon of dispersion of light is explained in all the textbooks with reference to different indices of refraction of "different colours", leading therefore to
the formation of the spectrum. This form of presentation of
the prism experiments can lead to the idea that the rays
which compose the white light are themselves coloured.
The "post-office" analogy presented in Revised Nuffield
Physics can serve as an example:

"He (Newton) wanted to show that a prism is not a colour
factory that manufactures lots of colour but only a
colour-sorter-like the sorting office for letters in
the post office."

(Revised Nuffield Physics, Pupils' Text, Year 3, p.91)

To talk about the "colours of white light" or to
refer to the "sorting out" effect of the prism is of common
usage even among scientists. Newton himself used this sort
of terminology, and certainly it is easier to say simply
"green light" when meaning "wavelengths (or photon energies)
which induce the sensation of green". The problem is that
in none of the texts it is clearly mentioned that colour
is a sensation, and that the rays are not coloured in them-
selves.

8.4.3 The Mixing of Colours. After demonstrating that
white light is composed by seven "colours" (red, orange,
yellow, green, blue, indigo, violet), this knowledge is
applied to explain results derived from experiments on
additive and subtractive colour mixing. The presentation
is centered around the aspects discussed below.

Colour of objects: This is explained in terms of absorption
and reflection of different "colours of white light".
According to this explanation a white light looks white
because it reflects all colours and a black object absorbs them all; a red object reflects only red light, and so on. In none of the books examined the idea of photons being absorbed or reflected is mentioned. This sort of explanation can be in contradiction with a possible alternative conception held by children according to which colours are inherent properties of objects (Section 8.3).

**Primary and secondary colours:** Experiments with colour filters and projectors are discussed in order to present the idea that white and other different colours can be composed by using red, blue and green coloured lights. The colours obtained by their combination are referred to as the secondary colours, yellow, cyan and magenta (Jardine prefers to use turquoise instead of cyan). The combinations are illustrated by diagrams and colour equations (Fig. 8.1).

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**Fig. 8.1 Additive Colour Mixing**
It is not stressed, however, that a larger variety of hues can be obtained by varying the relative amount of each primary. The fact that any set of three mutually independent colours can act as primary colours is not mentioned.

Only Revised Nuffield Physics mentions explicitly the fact that what is usually referred to as blue, in terms of primary colour lights, is in reality a saturated blue, almost violet, corresponding to one of the extremes of the visible spectrum. The text in question calls it "true blue", and states that what is normally called blue in everyday language, is what, in the context of additive coloured light demonstration, is defined as the secondary colour cyan.

The distinction described above may be seen at first look, as complicating the matter, but due to it Revised Nuffield Physics is the only text among the ones examined to offer an acceptable explanation for the fact that the mixing of yellow and blue paints produces a green hue. This is a well known fact for secondary school children, and the standard example in textbooks for introducing the idea of subtractive mixing of colours in pigments.

The explanation presented by Revised Nuffield Physics is internally coherent: what is being mixed in the case of paints is actually yellow and cyan, and since the first reflects green and red, and the second reflects green and blue, the only reflected colour is green. The solution presented by Jardine's Nat Phil 3 is similar in spirit, since
in it, turquoise and yellow paints produce green when mixed, but it has the weakness of calling turquoise what children normally know as blue.

On the other hand the solution proposed by Abbot's O-Level Physics and Nelkon's CSE Physics lacks coherence. Since they have not distinguished between the blue in paints (cyan for Nuffield) and the primary blue light ("true blue" for Nuffield), the case has to be explained by stating that the blue paint is actually not pure blue, but also reflects green. The explanation is confused, contradicting previous statements, as the following quotation illustrates:

"Although the mixing of blue and yellow lights creates whiteness, the mixture of blue and yellow pigments (paints) produces a green. This is because the results of paint mixture are due to a subtractive process. Blue paint absorbs all light except blue and green. Yellow paints absorb all light except yellow, orange and green. The only light reflected by both yellow and blue pigments is green, and this is the resulting colour seen."

(Nelkon's CSE Physics, p. 340)

But, according to what has been previously stated in the same text, the result of green and blue light is cyan and therefore it is contradictory to state now that blue paint reflects green and blue, unless the blue of "blue paint" is different from the blue of "blue primary light colour".

Filters: A basic apparatus for colour experiments with light in school science is the projector with coloured filters. Abbot's O-Level Physics, Nelkon's CSE Physics and Jardine's Nat Phil 3 assume that a colour filter is understood by pupils as absorbing some colours and letting others through. Only Revised Nuffield Physics takes into account the possibility that school children can have an alternative framework,
according to which the filter adds its colour to the white light, and the point is explained by using an analogy:

"Some red dye has been melted into the plastic. Does that dye paint all parts of the spectrum red or does it just cut out other colours and leave only the red that was always there in the white light? Is it a 'colour-ADDER' or a 'colour-SUBTRACTOR'?

Why is your sheet of red plastic called a 'filter'? What do filters do in coffee machines, chemical experiments, or public water supplies? What does a scratch filter do in a record player?

(Revised Nuffield Physics, Pupils' Text Year 3, p. 93)

8.4.4 Colour Vision. The issue of colour vision is treated explicitly only in two of the texts examined - Nelkon's CSE Physics and Jardine's Nat Phil 3. In the first, an explanation based on the Young-Holmhloltz tichromatic theory is presented. The fact, however, that this physically-based explanation has been since the beginning contested by proponents of psychologically-based theories is not commented upon. In the second text it is pointed out that colour vision is a complex phenomenon which depends not only on the nature of the light entering the eyes but also on psychological and physiological factors. His presentation concentrates on some examples in which colour perception is altered by the effect of past experience and background illumination. In spite of stressing some psychological components of colour vision, Jardine does not mention the fact that the actual mechanism of colour vision is, still today, a matter of research.
8.5 Discussion

This section is aimed at the discussion of some aspects of the curricular treatment of the topic under analysis. These although already mentioned, deserve further comments. The discussion also intends to illustrate how a consideration of "scientists' science" and "children's science" can inform the analysis of "curricular science".

8.5.1 Historical Treatment. The historical (or rather a-historical) treatment of the topic has been criticized in connection with the presentation of Newton's works with prisms. The texts analysed, even the historically illustrated Jardine's Nat Phil, seem to be mainly concerned with stressing the untrue notion that Newton was the first to seriously study the production of colours by prisms. On the other hand, they do not sufficiently point out his real contribution - the analysis of white light in its components, and the final integration between light and colour.

From a constructivist point of view, in this particular case, this treatment is detrimental to teaching. As was suggested, a significant number of children do hold the conception that white light is pure light. A respectful treatment of pre-seventeenth century theories could indicate to the children (and to teachers) that their explanations ("children's science") were once similar to the accepted ones ("scientists' science"). A behaviourist would perhaps argue that such an approach would reinforce "wrong" conceptions. As a constructivist I prefer to entertain the idea that what will be reinforced are the pupils' awareness and
confidence in their power of construction. The Newtonian explanation can then be introduced as a different way of constructing the same phenomenon.

But if science presents instances in which conceptual frameworks are radically changed (revolutions) it also presents periods during which constructions are adhered to (normal science). In this case too the curricular treatment fails to treat history appropriately. Apart from a brief hint in Jardine's Nat Phil 5, no reference is made in the texts examined, to the fact that, in spite of its inadequacies, the Newtonian optical paradigm dominated the field during about one hundred years. This fact could be used to illustrate the almost dogmatic character of normal science and the idea that scientists will adhere to paradigms, which although successful in some aspects, will still have to be vindicated in others. It could also be used to illustrate the notion that experiments (even in science) are interpreted and construed from the point of theoretical frameworks. These two points are, however, contrary to the empiricist view which characterizes "curricular science": scientific knowledge is supposed to be based exclusively on neutral experimental evidence.

8.5.2 Classification of Knowledge. The theoretical notion of "classification", introduced by Bernstein (1975) is clearly exemplified in the textbooks' presentation of light and colour. "Classification" refers to the strength of boundaries between educational subjects, and the presentation of the phenomenon of colour in the textbooks examined can be regarded as showing
a strong "classification". Colour, which in the end is a sensation, is treated mostly as a purely physical phenomenon. Abbot's O-Level Physics and Revised Nuffield Physics do not treat colour vision, and the limitations of the treatment presented in the other two texts had been pointed at in Section 8.4.4. This limited treatment can be explained by the fact that research on colour has shifted from the field of physics to the field of physiology and psychology - modern physicists prefer to talk in term of "colourless" radiation and its associated wavelengths and photonic energies. Therefore colour vision is regarded by curriculum developers and textbook writers as a topic to be treated in biology and not in physics.

The limitations introduced by the strong "classification" of knowledge are evident in the present case: by treating colour from a physical point of view, its sensorial nature is not stressed (e.g. the textbooks convey the idea that the waves and photons themselves are coloured (see 8.4.2)). Furthermore, the impression is left that colour had been successfully explained in terms of physical theories. As it has been argued, this is true for "colourless" radiation, but, in treating colour, the boundaries between subjects must be necessarily broken. As Feynman, a Nobel Prize physicist, rightly recognizes:

"The phenomenon of colors depends partly on the physical world. We discuss the color of soap films and so on as being produced by interference. But also, of course, it depends on the eye, or what happens behind the eye, in the brain. Physics characterizes the light that enters the eye, but after that, our sensations are the result of photochemical-neural processes and psychological responses. There are many interesting phenomena associated with vision which involve a mixture of physical phenomena and physiological..."
processes, and the full appreciation of natural phenomena, as we see them, must go beyond physics in the usual sense. We make no apologies for making these excursions into other fields, because the separation of fields, as we have emphasized, is merely a human convenience, and an unnatural thing. Nature is not interested in our separations, and many of the interesting phenomena bridge the gaps between fields."

(Feynman, Leighton and Sands, 1963, p. 35-1)

8.6 Summary

In this chapter I have presented:

1) An historical overview of the development of conceptions concerning the nature of light and colour ("Scientists' Science").

2) A review of the literature on alternative conceptions about light and colour ("Children's Science"). Some results of research carried out by myself (and M.D. Watts) were also included.

3) An analysis of textbooks' presentation of the topic of "Light and Colour" ("Curricular Science").

It is shown with the use of examples from these reviews and analysis, that:

a) There are aspects in which it can be suggested that "children's science" parallels ancient conceptions.

b) There are aspects of "children's science" that are not in general taken into account in the curricular presentations (e.g. colour as a quality of objects; white light as "pure" light; the nature of colour filtering). Only one of the materials (Revised Nuffield Physics) considers the possi-
bility of children's alternative conceptions about filtering.

c) The curricular treatment of light and colour is faulty from an historical point of view. It was argued that this can be detrimented to teaching from a constructivist perspective. It also conveys a superseded view of the nature of scientific knowledge.

d) The curricular treatment of colour presents a strong "classification" which limits the explanation of colour vision.

e) Only one of the materials (Revised Nuffield Physics) provides a satisfactory explanation for colour mixing. The explanation presented in two of the textbooks, lacks internal coherence by failing to take into account the difference between the curricular and everyday language use of the word "blue".
CHAPTER NINE

CASE STUDY I: LIGHT AND COLOUR

(Analysis of a Lesson Extract)
9. CASE STUDY I: LIGHT AND COLOUR (Analysis of a Lesson Extract)

9.1 Introduction

The lesson extract analysed in this section consists of a 30 minutes sequence dealing with additive mixing of colours, and it was conducted with the help of a projector and coloured filters. In the previous lessons (not observed) the unit of optics was presented following *Nelkon’s CSE-Physics*, which was one of the texts the pupils had access to (the other was *Abbott’s O-Level Physics*). The lesson immediately following was the last one dealing with light and during it the pupils had the chance to handle some apparatus in a non-structured way. They were not supposed to report on the task and the objective was, as the teacher told me, "to let them play with the equipment" (projector and filters, prism, spectrometer).

The extract analysed refers to the first half of double period lesson. In the second part of the lesson subtractive mixing of colours was considered, and the presentation followed the pattern criticized as lacking coherence in Section 8.4.3.

The group observed consisted of 25 pupils (15 boys and 10 girls) of a fourth-year and the teacher was an experienced one (more than 10 years of practice). She had been recently appointed head of department and two years before the observations had been awarded a M.Ed. in science education.

The analysis follows the pattern already described in Section 7.4. It consists basically of a socio-linguistic part following Sinclair and Coulthard scheme (see Appendix I), and a series of comments. Both parts are integrated in the presentation, with the comments following each identified
transaction. The transactions are presented in a temporal order, and it should be assumed (unless otherwise stated) that one follows immediately the other.

Symbols used: T) Teacher Ss) Various pupils B) Boy ) A pupil (Non-identified sex) G) Girl NV Non-verbal reaction

9.2 The Analysis

 TRANSACTION 1

001 B Fr T). OK ..... act 001 m
002 E O . we want to look at the combination of colours 002 ms
003 Re-1 O . if I ask you what the primary colours are? ..... 003 el
004 p . I can get two different sort of answers always 005 cl

B). Blue red and yellow 006 rep
B). Blue 007 rep
B). Yellow yellow 008 rep
Ss). Red blue and yellow 009 rep

004 E O T). Now 010 m
. people who are saying red blue and yellow what makes you view those as primary colours? 011 el

A Ss). (NOT AUDIBLE) 012
. Paints 013 rep
F T). Yeah 014 e
. you can mix the coloured paints to give you all the other colours ... 015 com

TI is an introductory transaction in which the teacher shows an awareness of the fact that some pupils tend to think on the mixing of colours in terms of coloured paints. She brings that point in scene by eliciting the idea from the pupils in Exchs 002 to 004. Although prompting and clueing were needed in Exch 003, the elicitation is unproblematic and the teacher can proceed.
TRANSACTION 2

005 B Fo T). But today we are more in ... the stage lighting business the disco lighting business and we'll be looking today not at paints to begin with ... but at coloured light .. and try to sort out whatever other special meaning for what we call the primary colours when we're talking about coloured light .. 016 ms

006 I O if you're putting .. coloured lights together like stage lighting then .. the combination that gives us white is what we call the primary colours ... 017 i

007 E O now .. this might come up not only in stage lighting disco lighting where else do we mix coloured lights? to .. give us you may not be aware that you're mixing coloured lights but there's another area that takes quite a lot of your time in the course of the day I suspect for some of you where colours are put together to give you a whole range of colours anybody can tell me? 018 m 019 s 020 e1 021 cl 022 p

A B). Telly 023 rep

F T). Television colour television is what I am thinking of 024 e

008 E O do you know the three colours that we use in .. colour television? 025 e1

A B). Green 026 rep B). Red blue and green 027 rep

F T). Red blue and green ... those are the colours used there 028 e

009 B Fo and we'll look at red blue and green to give us today coloured lights of red blue and green so if we could ...... if we could skip the paints for the moment and look at those later they are rather more complicated .. and look to begin with at coloured light and how we can add them up and the effects that we can get 029 ms 030 com 031 ms

T2 can be regarded as the complement of T1. Here the teacher communicates to the class what would be the theme of the lesson: properties of coloured lights instead of coloured paints. This is accomplished by two meta-statements, first in act 016 and then reinforced in act 031. It is interesting to note that in act 016 the teacher uses a metaphor - "stage lighting business", "disco lighting
business" - which she created. The reasons by which the metaphor was used can only be speculated. It could have been used to stress the fact that the lesson will deal with light rather than with pigments, helping the students to change their mental setting from the latter to the former or just to indicate some practical implications of the topic to be studied.

The first teaching exchange of the transaction (Exch 006) is informative. The definition of primary colours presented by the teacher is limited both in terms of "scientists' science" and "curricular science", since the primary colours can generate a wider variety of hues apart from white. The information is completed in exchanges 007 and 008, with the teacher using the eliciting pattern. The questions are closed and factual, and their aim seems to be to involve the group in the teacher's line of presentation. This is clear in acts 020 and 021, where the possible answers to the question (act 020) are restricted by the clue which follows it (act 021).

TRANSACTION 3

| 010 | B | Fo | T | Now there will be a slight pause because it takes. a little while to set this particular lot up | 032 ms |
| 011 | D | 0  | can I have a stand please? | 033 d |
| 012 | Ch| 0  | and it .. is the one with some bits on it? ...... | 034 ch |
| 013 | D | 0  | and may I have the blinds down please? | 035 d |

(Pupils close blinds)

| 014 | D | 0  | can you move that table near the back there? | 036 d(n) |

(Pupils moving the table)
(T. mounting apparatus) 2:50 min
TRANSACTION 4

O15  B  Fo  T). I'm just setting this
      . can we look at the arrangement ....

O16  I  O  . hum ...
      . we're using just one projector .. with a sort of
      triple slide to produce us red green and blue
      lights

O17  E  O  . what's the purpose of the mirrors then?
      . can you see this sort of arrangement

A  B). To reflect the different colours on to the screen

F  T). OK?
      . we've got .. then a mirror for each colour .. to
      give us three beams of light onto the screen ..

O18  E  O  . and .. how will we shift the beams around?

A  B). The screws

F  T). OK?
      . if you just turn around the mirrors .. we .. can
      play with them

TRANSACTION 5

O19  B  Fr  T). Right

O20  D  O  . somebody put that slide in ..
      . so that it will .. give us .. a green beam of
      light to go over to various places just down ....

A  ). NV
A transaction consisting of straightforward directive exchanges involving a boy who is handling the apparatus. The directions given consist of physical manipulation of pieces of equipment and although the manipulation is done by a pupil, the teacher controls verbally the pace and sequence in which they are performed.

TRANSACTION 6

025 Oth  
  T). I find this projector ... yeah I mean who have designed it .. I can't imagine what .......... .......... really is we don't want some shadows on the board in this minute .. we can manage without one or two fingers  
  (Pupils talking between themselves while the teacher tries to set up the apparatus - (40 s))  
  062 z  
  063 oth

026 Oth  
  T). This is one of these demonstrations that is OK if you've got you know an hour to set it up before the class comes in .......... right .......  
  (Teacher trying to adjust apparatus (1:10 min))  
  064 z
T6 can be seen as an "accident" in the sequence planned by the teacher. The apparatus failed to work as expected, and the teacher is trying to sort out the problem. Acts 062 and 064 were classified as asides since the teacher seems to be talking to herself (or perhaps to the observer) rather than to the class.

Act 063, however, does not fall neatly in any of the types proposed by Sinclair and Coulthard. Formally it resembles a comment, but its function is really, without being explicitly repressive, to show disapproval towards one (or more) pupil's action, with the aim to stop it. There are no categories in the scheme to deal with this sort of behaviour control employed by teachers.

**TRANSACTION 7**

<table>
<thead>
<tr>
<th>027</th>
<th>E</th>
<th>0</th>
<th>T). Now it's OK</th>
<th>065 z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>. let's get rid of the blue for a minute</td>
<td>066 z</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>. Arnold what were we saying we wanted what is our condition for three lights to be primary lights?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>...............</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>0</td>
<td>Make white</td>
<td>068 rep</td>
</tr>
<tr>
<td>F</td>
<td>T</td>
<td>0</td>
<td>They make white</td>
<td>069 e</td>
</tr>
</tbody>
</table>

| 028  | D | 0 | . so put them all together and see .. what we get | 070 d(n) |
| A    |   |   | ). NV | 071 rea |

| 029  | P-I | 0 | B). Blue | 072 i |

| F    | T | 0 | Between them .. you're looking at the screen actually | 073 com |
|      |   |   | . some of us are looking at the screen ... | 074 z |

| 030  | E | 0 | . how am I doing then? ............... | 075 el |

| A    | B | 0 | Got white | 076 rep |
|      | B | 0 | Yellow    | 077 rep |
|      | B | 0 | Yellow    | 078 rep |
|      | S |   | (Laugh)  | 079 oth |
The teacher aims to demonstrate to the pupils that the mixing of the primary colours give white, but the apparatus fails to produce that result.

The transaction starts with a closed factual question (act 067) involving the recall of an information presented previously in the lesson (act 017). In a following exchange an answer based on observation is required and although one pupil gives the theoretically expected answer (act 076), the teacher seems to agree with the other two (acts 077 and 078) answers. This is evident from the way she "blames" the apparatus, and again it is difficult to say if in act 081 she is just talking to herself or justifying her position to the observer.

Being unable to produce the desired phenomenon she decides to transfer the problem to the next lesson (act 082) and to start a different point. The problem, however, would have been easily dealt with if the teacher's definition of primary ("teachers' science") had been more complete (see comment on Transaction 3).
The attention of the teacher is suddenly caught by the shadows produced when one of the pupils puts his hand in front of the projector.

Apart from the directive exchange (033) most of the acts in this transition do not allow for a classification according to the scheme being used. Acts 084, 090 and 091 for example are pupils' comments which are aside to the development of the lesson and therefore would not be well represented as parts of P-I or P-E exchanges.

The scheme, as it stands, does neither include collective reactions like "laughing" (acts 085 and 089) as one of its categories; nevertheless, that seems to be an important verbal reaction in the context of classroom discourse.
TRANSACTION 9

035 B Fr T). Yeah .. all right OK
036 D O . how are we getting all those different colours?
. shall we have one hand in for start ..... 092 m
037 E O T). Now
. we really ... it would help if we ..
. hum what did we start of with?
A . NV 095 rea
038 E O T). What colours have we got there? ..
A B). Red blue and green 099 rep
F T). Red blue and green 103 e
039 I O . and we've now added .. what we could describe as
. a pinky red yeah? and a bluey green ...
103 i
040 P-I O B). Magenta 104 p-i
F T). Hum yes 105 acc
041 E O . pinky red called?
A B). Magenta 107 rep
F T). Magenta 108 e
042 E O . bluey green?
A B). Turquoise 110 rep
F T). Turquoise 111 e
. I would call it turquoise you would call it
. turquoise and we all know what we mean 112 com
043 E O . what do you think the examiners call it?
A B). Bluey green 114 rep
F T). Cyan ...
. I mean it's obvious isn't it? who ever heard of
. anything called cyan C ... Y .. A .. N 116 com
044 E O . have you ever heard? no?
A B). No 118 rep
F T). Me neither 119 com
045 B Fo . turquoise to you and me .. but .. get used to cyan
. perhaps it is because they can't spell cy can't
. spell turquoise .. but for the same reason they
. call it cyan ..
. it's that bluey green colour
. I suppose I will try to call it cyan to get you
. used .. to it .. 123 com
In the beginning of the transaction the teacher appears to be somehow undecided about the way in which she should develop this part of the lesson. In Exch 036, the first teaching exchange of T9, act 093, an elicitative, is immediately cancelled by act 094, a directive. The indecision is also apparent in Exch 037 in which act 097 is left uncompleted, another case which does not appear in the scheme proposed by Sinclair and Coulthard.

I can only speculate about the reasons for this insecure start. T7 was a transaction in which the demonstration did not work as planned, and after giving up, the teacher had to start a new line of presentation. The new line was hinted at by the effect of the pupils' hands in front of the projector, and she had to replan her route, which she managed to do, but at the cost of two false starts in Exchs 036 and 037.

The rest of the transaction consists basically of eliciting exchanges which seems to be the way of presentation favoured by the teacher. As in previous transactions the questions are closed and factual or purely rhetorical as in act 118, serving the purpose of involving the class in the presentation, and controlling the pace and sequence of the lesson.

The sequence of exchanges 039 and 038 serves as an illustration of the points made above. In Exch 039 the teacher is in the middle of an informative act (103) when one pupil advances an unsolicited information (act 104). The teacher acknowledges the information without commenting
(act 105) and immediately reestablishes her control by asking a question (act 106) whose answer is the information advanced by the pupil.

Exchanges 042 to 045 show the teacher presenting (using eliciting exchanges) scientific terminology by contrasting it with everyday language, and adopting an ironic view in relation to the former (acts 113, 116, 117, 119, 120).

In spite of the irony the message to the children is clear: the new term is part of what they are expected to learn (acts 115 and 123) by the examiners, even if an equivalent one exists in everyday language.

**TRANSACTION 10**

<table>
<thead>
<tr>
<th>046</th>
<th>E</th>
<th>O</th>
<th>T). Hum ..</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>where does the magenta come from? 124 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>what combination do you think gives you magenta? 125 el</td>
</tr>
<tr>
<td>A</td>
<td>B)</td>
<td>Red and blue 126 el</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>T)</td>
<td>Red and blue 127 rep</td>
<td></td>
</tr>
</tbody>
</table>

| 047 | D | O | so could we have this nice early thing back 128 e |
|     |   |   | so could we have this nice early thing back 129 d(n) |
| A   | ) | NV |
| F   | T) | Thank you 130 rea |

| 048 | E | O | hum |
|     |   |   | that magenta hand 131 e |
|     |   |   | what do you think is shining on the magenta hand?... 132 m|
| A   | G) | Green and blue 133 s |
|     | B) | Green 134 el |
|     | B) | Blue 135 rep |

| 049 | Re-i | O | T). Hands from magenta coming on the screen 136 rep |
|     |     |   | what do you think magenta is a combination of? 137 rep |
| A   | G(2) | Red and blue 138 s |
| F   | T) | Red and blue 139 el |

<table>
<thead>
<tr>
<th>050</th>
<th>E</th>
<th>O</th>
<th>so what can we see on the palm of his hand if we look here? what? 140 rep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>so what can we see on the palm of his hand if we look here? what? 141 e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>so what can we see on the palm of his hand if we look here? what? 142 el</td>
</tr>
</tbody>
</table>
In this transaction again the teacher uses eliciting exchanges as a form of presentation of knowledge. As in T9, pupils' answers are complemented by comments (act 148) and a summing up conclusion (act 149).

The elicitation is unproblematic in Exch 046, but Exchs 048 and 050 show the main drawback of this form of presentation. The answers to the question presented in Exch 048 are not the expected ones, and instead of investigating the reasons for it, the teacher changes the wording of the questions (act 139) which becomes similar to the first question of the transaction (act 126); not surprisingly she now gets the correct answer and proceeds with the questioning.

The wording of the following question makes it similar in spirit to the one presented in Exch 048 and again the answers are either incomplete (acts 144 and 145) or show a lack of understanding (acts 143 and 146). Instead of
investigating the problem, the teacher seems to consider the combination of the two incomplete answers as making a correct one, and complements the presentation with a comment (act 148) and a conclusion (act 149).

As far as the teacher's purpose is concerned the transaction could be terminated at that point but an input from one pupil added three more acts to it. The pupil's input although having the form of a P-I exchange, does not actually represent an attempt of contributing to the theme of the lesson; it is rather a joke which is accepted in good spirit by the teacher (act 152). Since the contribution does not actually represent relevant information, as far as the concepts presented are concerned, I decided not to classify the exchange as a P-I one.

**TRANSACTION 11**

<table>
<thead>
<tr>
<th>Time</th>
<th>Role</th>
<th>Action</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>053</td>
<td>D O</td>
<td>T) Hum...</td>
<td>can we have the turquoise cyan hand back please?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>NV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>T) Yeah</td>
</tr>
<tr>
<td>054</td>
<td>E O</td>
<td></td>
<td>the turquoise cyan what do you think that's a combination of?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>G) Green and blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>T) Yeah blue and green</td>
</tr>
<tr>
<td>055</td>
<td>E O</td>
<td></td>
<td>so ... the part of which lies on the way?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B) Red</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>T) Red</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>there we are stopping the red getting to the screen and only getting the blue and green this cyan hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>056</td>
<td>Ch O</td>
<td></td>
<td>he's got a blue thumb there has he? can you see a blue tip of the thumb?</td>
</tr>
</tbody>
</table>
The teacher continues to use the elicitation approach. The questions are all closed, but two of them (acts 172 and 188) require some reasoning on the part of the pupils. Their answer to the question presented in act 171 is unsatisfactory, and the reaction of the teacher indicates her displeasure with this. This sort of act, which represents an instance of the teacher verbally (and rather gently) controlling the
behaviour of the group is not accounted for in Sinclair and Coulthard's categories.

Exchs 057 and 060 cannot be classified either according to the scheme. As Exch 052 in T10, they formally resemble P-I but, the pupils' input is a joke, rather than a relevant piece of information for the development of the lesson. This sort of contribution seems to be an important factor for the creation of a relaxed, though formal, atmosphere in this particular classroom.

Exch 061 presents an illustrative example of how an eliciting exchange can be used as an instrument for the control of attention on the part of the teacher. Act 188 is uttered in a way in which it can be a starter either for an eliciting exchange or an informative one. The direction to be taken by the exchange is totally under the teacher's control, and until it is made clear the group has to wait in attentive expectation.
I was thinking perhaps you need a good balance of brightness, you know, a good balance so that each gets their oar in and each of the red blue and green, it seems to me that if anything the blue is a little bit weak on the brightness or intensity.

But if we remove the red we are left with?

The magenta cyan combination of the primary colours blue and green. OK? the primary colours blue and green combine to give us turquoise or cyan which is known as a secondary.

Pretty obvious the next one. I'll give you an easy one next. Let's get rid of that one. Which was the other one we're talking about that was the easy one?

Magenta.

Yeah. Let's just see the lamp on I'm getting the mirrors in the place. All right. Right here we come. Pretty magenta. Go away green.

OK? ... Magenta-ish coming in there. So primaries red and blue combining to get what is named as a secondary. The magenta.

Any guesses for red and green? Who's been fairly observant while we've been doing this? I think I'm going to take the blue on that side.


Taking bets on the red and green.
... there's the cyan on the bottom there's a turquoise colour ...  232 com

070 E O  who's been observing to notice the other secondary colour light?  233 cl
A Ss) .. Yellow  234 rep
B). Yellow  235 rep
F T). That still surprises me my eyes can't .. or perhaps is my brain my eyes are seeing that but my brain can't .. get used to the idea that red and green .. give us yellow ... (smile) ..  236 com

071 E O  hum ..  237 m
. except if you think through the spectrum ... think through the spectrum ....  238 s
. what is the sort of average of red and green? .....  239 cl
...

072 Re-i O  yeah you've got what? red ....  240 cl
073 Re-i O  going through the spectrum ....  241 cl
074 Re-i O  rainbow  242 cl
A B). Orange  243 rep
B). Red orange  244 rep
B). Red orange ..  245 rep

075 Re-i O  T). Dear me
. yeah .. do go on  246 z  247 p(n)
A B). Ah .. red orange yellow green  248 rep
F T). Oh well done red orange yellow green blue indigo violet  249 e

076 I O  . yellow comes sort of between .. red and green so perhaps .. our well it's really our brain responds to the average of .. red and green and sees it as the yellow .. that's how we respond to the sort of combination or average of the red and green  250 i

077 E O  . what's ... apart from them looking different colours .. hum if we thought about radiations before
. what we thought of being different about red and green?
. or you know .. the different colours ... they have different?  251 s  252 cl
A B). Wavelengths  253 cl

078 Re-i O  T). Or? ...  254 rep  255 cl
A B). Frequencies  256 rep
F T). Frequencies .. different wavelengths or frequencies .. and the yellow comes in between in wavelengths and frequencies between red and green .. so that perhaps is why that combination we recognize as the .. yellow.. 257 e

079 B Fo  . so there's your .. two previous combining to give the yellow as the .. hum secondary there ..  258 com
The transaction is again basically composed of eliciting exchanges, in which the answers given by some pupils are complemented by the presentation of "teachers' science", either as comments in follow-up moves (Exchs 065, 066, 070, 078) or by informative exchanges (064, 076).

Only one of the questions presented by the teacher (act 196) can be considered an open one. The teacher, however, although acknowledging the possibility of different answers to the question (act 202), does it only in passing, and does not discuss the alternatives offered by some pupils (acts 199 and 201 for example). Instead of asking the pupils to elaborate their answers, or at least commenting on them, the teacher immediately presents her view in an informative act (act 204). In this way, a relatively open question is treated by subsequent teaching acts as an almost closed one. It is interesting to notice in this particular presentation of "teachers' science" the use of a metaphor - "a good balance (of colours) so that each gets their oar in" (act 204).

The sequence of Exchs 067 to 070 shows the teacher using eliciting acts to involve a larger number of pupils in the presentation, and for controlling the attention of the group. The right answer has been elicited in the beginning, but the teacher keeps pressing for more pupils to utter the correct word.

The sequence of Exchs 071 to 075 shows a case in which an everyday language word is used as a clue after failed attempts to elicit an answer. In this case the meaning of the word
"spectrum" (acts 238 and 241), a typical expression of scientists', curricular and teachers' science, is not known or at least not recalled by the pupils. As soon as the teacher changes the word to rainbow (act 242), the sequence of colours is recited by one pupil. But rainbow and spectrum are not synonymous, and although their meanings overlap, the differences are not discussed, probably because for the teacher's immediate purposes they are not relevant. The sequence is followed by an informative exchange (076) summarizing the teacher's view.

The explanation presented by the teacher when discussing the fact that red and blue lights are experienced as yellow when mixed is an example of mismatch between "teachers' science" and "scientists' science". The problem of colour perception is still an unsolved one, and the perception of yellow has been a matter of dispute between physically and psychologically orientated colour theorists (Sections 8.2.4 and 8.2.5). The problem, however, is not treated in the textbooks followed by the teacher - and is not considered in "curricular science" in general (Section 8.4.4) - and the teacher had to develop her own explanation, which in this case is incorrect: if the same reasoning (averaging of wavelengths by the brain) is applied for the mixing between blue and red, the expected result would be something in the middle region of the spectrum (yellow-greenish) and not magenta. It must also be noticed that the explanation advanced by the teacher is presented in a rather tentative way as the use of the word "perhaps" in acts 250 and 258 shows.
TRANSACTION 13

080 D O T). Can you just see them and I'd like you to draw and colour up...
what I'm about to do in a way.. come on where is the blue one
that's the classic colour triangle as it's known
and I would like you.. preferably before Friday
I don't mind as long as it is by next Wednesday when we'll be going on.. I'd like you please to
.. draw yourselves up a colour triangle like that and colour it up.. in.. those colours given

081 E O . hum.....
what's the one you won't be able to mix with your
colours to give the results that you get with the light?.....

A B). Blue and white
B). White
G). Green and blue

082 I O T). Hum...
no way will you.. sort of mix on paper a red and green pencils to give you yellow.. so that is a
coloured light triangle and hum pick yourselves up I think.. to get a.. better demonstration of it pick yourselves up the colours the pinky magenta colour.. and the turquoise and the yellow and use those in those sections

083 E O .. and what's in the middle of your triangle?
A ). White
F T). OK?
leave it showing as white

084 D O also would you just make yourselves a little table of the way the primaries combine.. to give the secondaries...

085 Ch O OK?...
086 E O so give me a first colour equation
A Ss). Red and green gives yellow

087 Re-i O T). We can have other ones can't we?...
088 Re-i O .. you can get it
A B). Yes.. blue plus.. blue plus green gives cyan

089 E O T). Red?
A ). (NOT AUDIBLE)
F T). OK red plus green equals yellow

090 E O .. and you've got your.. other little colour equations...
red and blue gives you magenta?...
The directive exchanges of this transaction (Exchs 080 and 084) are different than the ones before and the ones presented by Sinclair and Coulthard in the sense that they do not demand an immediate response, but are rather setting up a task to be performed in the future as homework.

It is noticeable, on the other hand, how the attentive demands imposed, by the teacher's presentation, on the class can suffer rapid changes in relative short periods of time. Act 263 for instance is a directive, and 265 an elicitation, the transition being marked by 264. The answers presented by some pupils are followed directly by an informative act (270), which in its turn, is immediately followed by another elicitation. A large proportion of pupils' attention, I would guess, has to be directed to those socio-linguistic demands, rather than to the understanding of their content.
<table>
<thead>
<tr>
<th>Time</th>
<th>Line</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>094</td>
<td>B Fr</td>
<td>T). Hum ..........</td>
</tr>
<tr>
<td>095</td>
<td>E O</td>
<td>so what was that rubbish in that film we saw last week? ....</td>
</tr>
<tr>
<td>096</td>
<td>E O</td>
<td>what we've got here? ....</td>
</tr>
<tr>
<td>A</td>
<td>B). Magenta</td>
<td></td>
</tr>
<tr>
<td>B). We've got the secondaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>097</td>
<td>E O</td>
<td>hum ..</td>
</tr>
<tr>
<td></td>
<td></td>
<td>anybody think what in the film we saw was .. to my mind ... rubbish in that film there?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what did they say/</td>
</tr>
<tr>
<td>A</td>
<td>B). Too long</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>T). We've got the secondary colours OK?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>magenta yellow and .. cyan turquoise</td>
</tr>
<tr>
<td>098</td>
<td>E O</td>
<td>what did they say about magenta plus yellow .. plus cyan or turquoise on bluey green? they said it was black</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what we've got here?</td>
</tr>
<tr>
<td>A</td>
<td>Ss). White</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>T). A much nicer white in fact than we had before</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and to my mind that .. this I mean I can see .. I believe this but they don't believe though .. I</td>
</tr>
<tr>
<td>099</td>
<td>E O</td>
<td>well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>can you think what they might have been doing?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what are we doing here? ...</td>
</tr>
<tr>
<td>100</td>
<td>E O</td>
<td>hum .....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>yeah we are .......... OK we've got ... hum ..... three separate simple rays ..</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what's the magentaearing?</td>
</tr>
<tr>
<td>A</td>
<td>B). Red and blue</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>E O</td>
<td>T). And what's the yellow?</td>
</tr>
<tr>
<td>A</td>
<td>B). Red and green</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>E O</td>
<td>T). Cyan?</td>
</tr>
<tr>
<td>A</td>
<td>B). .. Green and blue</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>Ch O</td>
<td>T). OK?</td>
</tr>
<tr>
<td>104</td>
<td>E O</td>
<td>so ..</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what are we in a sense putting together when we put all this together? ....</td>
</tr>
<tr>
<td>A</td>
<td>.) (NOT AUDIBLE)</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>T). Two reds .. two greens two blues</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>six colours as you say ..............</td>
</tr>
</tbody>
</table>
we won't worry with this triangle for recording this is just because we've got it really and it's pretty
... now ...
but we're putting together in the middle there in effect two reds two blues two greens hum you've got in other words if we think through our spectrum again red orange yellow green blue indigo violet you've got red from one end of the spectrum blue from towards the other end of the spectrum and green in between we are putting a representation of all the spectrum together and we recognize it as white that in a sense give us the all range of wavelengths and frequencies and we recognize that combination as white so here we are getting in a sense a couple of red wavelengths a couple of green wavelengths a couple of blue wavelengths and our eyes respond to that in our brain and we see it as the whole spectrum as though all the wave frequencies were there so we see it as white in the same way as we would if we've got all the spectrum all the wavelengths all the colours and here we are adding all those wavelengths and frequencies together and seeing them all together reflecting them all off a good white screen so that we're getting the whole range to our eyes and we therefore now see them as white
.
I suspect what they were doing how could you ...
if you if I gave you out bits of this sort of film how do you think they are putting them together to get their black ........
yeah (lowering) .. if you put your magenta filter then your yellow filter then what ...

what does a magenta filter do to the light you're offering it what ...
A B). Reflects off it  
G). Reflection  
B). Let the magenta  
B). Gets through  
B). Let through the yellow  

If we take the magenta let's take the magenta on its own ...
that piece of plastic in there is letting through what? what we're ending up?

A )). Red and blue  
F T). Red and blue  

what's that bit of plastic jelly stuff doing? what else would the white light be offering it really in the way of primary colours..
A) Green
B) Green

F T) Green

111 E O what it has done to the green
A B) Blocked it
B) Subtracted

F T) Blocked it.....

112 E O what do you think it may the way of that hum .... might be use? blocked it? stopped it? ...
A B) Distorted it

F T) Distorted it?.....

113 I O may I try absorbed? .. can you get used to absorbed please (laughing)
I sorry .. it is a language lesson isn't it?

114 I O it's absorbed .. the green has been stopped .. blocked taken in .. absorbed by the chemical dye we've got in there .. it picks up the green and absorbs it stops it .. so only the red and blue get through ..

115 E O what colour has been absorbed by the cyan .. filter
A B) Green
G) Red

F T) Yeah .. red

116 E O and by the yellow?
I somebody else

A ) Blue

F T) Good .. blue
I red and green are getting through so we see the combination of yellow

117 I O that particular chemical dye in there the molecules in there are picking out and absorbing just .. the .. blue so that they are taking in the blue wave-length the blue frequency ....

118 E O right hum ....
I and .. that .. can you think again if you put the three filters these three secondary filters if you put them one up to the other in front of the light
I if you put in the magenta .. that absorbs? ..... 380 e

119 Re-i O if you put in the magenta in the magenta it absorbs?
A G) Green
B) Green

F T) Green
I so it takes the green out ..

120 E O if you then out in the yellow that absorbs?

This quite extended transaction shows the teacher using again mostly eliciting exchanges. In this case, the main aim of the questioning is to generate, from the class - or that part of the class involved in the dialogue - the answer to a question posed in the beginning. The sequence of eliciting exchanges follows a socratic approach, in which the bits of information elicited, if logically organized, should lead to the solution of the "problem" presented by the teacher. The end result, however, is not successful.

The "problem" is posed, in the very beginning (acts 299 and 306), in a very general and open way; the pupils have practically to guess what the teacher has in mind, and not surprisingly she gets only a general and out-of-context answer (act 308). Although the question posed by the teacher is open in its form, it is clear from the rest of the exchange...
that she had a very specific aspect in mind, and I would speculate that the out of context answer given by the boy in act 308 is a "good-mooded" form of defence. He probably knows that this is not the sort of answer wanted by the teacher, and in one sense is signalling to her to narrow the focusing of the questioning.

By acknowledging the answer in relative good mood, she seems to have accepted the message and in exchanges 098 to 104 she presents a series of factual and closed questions, followed by an extended piece of information (Exch 105). It is interesting to notice that in the informative exchange the explanation is given totally in terms of specialists' language.

In Exch 106 the teacher attempts to return to the initial problem, now more explicitly defined (act 338) but fails to generate any answers. She recognizes that the problem is difficult for the pupils (act 342) and starts a sequence of socratic types of questioning.

The questions presented by the teacher in the sequence of exchanges 108 to 122, should "logically" lead to the correct answer to the problem initially proposed. In practice it does not happen, and the final answers presented by some pupils (acts 393 to 395) demonstrate that the principles underlying the mixing of coloured light has not yet been understood by them. The teacher recognizes the point (act 396) and gives up (act 397) the attempt of eliciting the answer from the pupils. She decides to present it as a piece of explicit information (acts 398 and 399).
The sequence of eliciting exchanges discussed in the paragraph above was interrupted on two occasions by informative exchanges (Exchs 113, 114 and 117). Exchange 113 is particularly interesting because it shows the introduction of specialists' terminology - "absorb" - for replacing children's terminology - "blocked", "subtracted", "distorted" (acts 358, 359, 362). The teacher treats the case as a problem of changing of language (acts 364 and 365). It certainly is, at the surface, a problem of language, but at a deeper level, it can be a conceptual question: are the pupils using the words "blocked", "subtracted" and "distorted" in the same sense that the teacher is using the word "absorb", or are the different terms an indication that alternative frameworks are held by these pupils with relation to the phenomena discussed? The way in which the transaction ended (discussed above) seems to support the second hypothesis. If this is so, I would speculate that in future these pupils are likely to employ the new word without changing their frameworks.

It is also possible that part of the children have problems in conceptualizing the question in terms of absorption of colours by the dye, because they tend to see a filter as a colour-adder, and not as a colour absorber (see Section 8.3).
9.3 Discussion

The aim of this section is to summarize and to extend some of the points disclosed in the analysis of the lesson extract. In the discussion I will consider initially aspects related to the form of the interaction and afterwards aspects related to its content.

9.3.1 The Form of Interaction. The lesson was formally conducted with the teacher lecturing to the class as a whole, and no opportunity being offered for inter-pupil discussion. Without being openly authoritarian, the teacher managed to exert disciplinary control over the group, and the atmosphere was relaxed and friendly.

The teacher fully controlled the flow of knowledge during the interaction, which rather than being described as an instance of "negotiation" can be seen as an example of "presentation" of knowledge by the teacher. The different types of exchanges identified in the analysis of discourse are summarized in Table 9.1.

<table>
<thead>
<tr>
<th>Type of Exchange</th>
<th>B</th>
<th>E</th>
<th>Re-i</th>
<th>I</th>
<th>Ch</th>
<th>D</th>
<th>P-I</th>
<th>Oth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (%)</td>
<td>12</td>
<td>45</td>
<td>10</td>
<td>10</td>
<td>04</td>
<td>13</td>
<td>02</td>
<td>04</td>
</tr>
</tbody>
</table>

Table 9.1 Frequency of Types of Exchange

Most of the exchanges (96%) were identifiable according to the categories proposed by Sinclair and Coulthard, and
the few which were not, consisted of instances related but not relevant to the topic being taught (e.g. jokes). The high percentage of identified exchanges (and moves and acts) allows to conclude that the system adopted was adequate for the task.

The predominant mode of interaction was the elicitation which accounts for 55% of the exchanges, when "Re-initiation Exchanges" are also considered. The elicitation mode of interaction follows in general the pattern:

Opening (by teacher) → Answering (by pupil) → Follow-up (by teacher)
A Question → A Response → Evaluation and/or Comment

Although "follow-up" moves are optional in the "eliciting exchanges" in the present case they were present in the majority of them. Sinclair and Coulthard (1975) comment on the fact that "eliciting exchanges" are the most typical in formal lessons. This form of interaction places the control of what is presented in the teacher's hand, and it can be considered a form of presentation of "teachers' science". The questions were not actually aimed at disclosing pupils' ideas or to challenge their views, since only the "right" answers, i.e. those contributing to the following of the teacher's discourse were considered, and commented in the "follow-up" or in following "information exchanges". Since the main aim of the questioning was to exert control over the classroom attention and over the flow of information, most of the questions were closed and factual. Even those apparently open-ended were treated in the "follow-up" as closed (e.g. Exch 063).
The form of interaction described below allows for both a disciplinary and knowledge control on the part of the teacher. Using Bernstein's (1975) concept of "framing", which refers degree of control over the selection, organization and pacing of the knowledge exchanged in the pedagogical relationship, it can be said that the pattern of sequences of elicitations disguises, under a superficially enquiry format, a strong framing of knowledge on the part of the teacher. In Barnes' terminology the teacher would be classified as a "Transmission-Teacher", at least in this particular lesson (Section 5.2).

From a constructivist perspective some critiques can be raised against this form of interaction. A first aspect to be noticed is the passive role assumed by the pupils: only 02% of the exchanges directly relevant to the topic being taught were pupil-initiated, and they were not properly considered by the teacher. Other cases of pupil-initiated exchanges consisted of jokes. The pupils' answers to the questions were not elaborated sentences, consisting mostly of very short utterances (one or two words or a very short sentence). The shortness of pupils' answers can be seen as a requisite for the swift flowing of the teacher's presentation. Furthermore, "wrong" answers, i.e. those not contributing to the flowing of the presentation, were not explored, and the views of those not answering at all (a majority) not questioned.

In these circumstances it is not surprising that alternative conceptions were not explicitly voiced during the
interaction. It can be argued that they were not given the chance to emerge, and that the interaction between "teachers' science" and "children's science" took place in the pupils' heads rather than in open discussion.

9.3.2 The Content of the Interaction. The teacher's presentation followed closely the pattern suggested in the textbooks for the introduction of additive mixing of colours. In two instances, however, differences between "teachers' science" and "scientists' science" were noticed.

The first case occurred in the very beginning when the teacher defined primary colours as "the combination that gives us white" (Exch 006). The definition is incorrect since a set of primary colours can produce a large variety of hues apart from white. This point is mentioned explicitly in one of the textbooks followed (Nelkon's CSE Physics) and hinted at in the other (Abbot's O-Level Physics). Had the teacher given a more general definition of primary colours, she could have explored it when the demonstration failed to produce the planned result (white) in Transaction 7.

The teacher also conveyed the idea that "red, green and blue" is the only acceptable set of primary colours, an idea that although not in accordance with "scientists' science" is implicit as well in the curricular materials examined.

The second instance of divergence between "teachers' science" and "scientists' science" was her explanation of the yellow sensation at the end of Transaction 12, a typical case of a sophisticated alternative framework presented by the teacher. This point of the lesson would have been a
good moment for discussing the difficulties faced by theories of colour vision and to consider the fact that this is, still today, a case in which consensus was not reached. But again, this is not an issue considered in the curricula examined. The same as "curricular science", "teachers' science" showed, in this case, a strong "classification" of knowledge.

9.4 Summary

This chapter complements Chapter 8 in the presentation of an illustrative example in a case study format in which the forms of knowledge described in Part A of the thesis are used in the analysis of school science presentation of "Light and Colours". In the present chapter an extract of a lesson dealing with additive mixing of colours was analysed using both Sinclair and Coulthard's scheme for analysis of discourse (form of the interaction) and insightful observation (content of the interaction).

It was shown that:

(a) The particular interaction was a case of "Transmission-teaching" with a strong "framing" (control of knowledge) on the part of the teacher.

(b) The interaction could be characterized as the presentation of "teachers' science", rather than negotiation of knowledge, that is, open interaction between "teachers' science" and "children's science".

(c) Questioning was used by the teacher as a form of control over the nature and pace of knowledge presented and
not in order to explore children's views.

(d) In some aspects "teachers' science" was not in accordance with "scientists' science". These happened in cases not properly dealt with by "curricular science".
CHAPTER TEN

CASE STUDY II: FORCE AND MOVEMENT
(Scientists', Children's and Curricular Science)
10. CASE STUDY II: FORCE AND MOVEMENT (Scientists', Children's and Curricular Science)

10.1 Introduction

This chapter and the next one may be considered in conjunction. As with the previous two chapters, they consist of the presentation of a case study in which the conceptual framework, described in Part A of the thesis, is employed in the analysis of a topic of school physics.

The relation between force and movement, from an inertial point of view, is basic for the understanding of Newtonian mechanics at a conceptual level. Newtonian mechanics is regarded as one of the foundations of secondary school physics, hence the importance of considering the topic.

The present chapter consists of an overview of the historical development of conceptions relating force and movement ("scientists' science"); of a review of research on alternative conceptions about the topic ("children's science"), and of a critical analysis of curricular materials ("curricular science"). Chapter 11, which follows, presents the analysis of a lesson extract in which the topic is treated.

10.2 Scientists' Science

Conceptions concerning the relationship between force and movement can, historically, be divided into four major groups: the Aristotelian view, the "impetus" theory of the
Middle Ages, the inertial view as expressed by Newton's first law of motion and the Einsteinian view. This is, of course, a rough generalization, since representative workers within these different groups were not uniform in their interpretations. There are intermediate figures, like Galileo, whose conceptions represented the transition between the medieval Impetus theory and the Inertial conception of motion. Nevertheless, the division can be a useful device in helping to conceptualize major stages in the development of the concept of force, especially in its relation to movement.

10.2.1 The Aristotelian View. Aristotle's ideas concerning motion were part of a broader perspective which can be described as the Aristotelian two-sphere universe (Kuhn, 1977b). This conception considered a finite and completely full universe limited by a sphere of stars. The majority of its interior was supposed to be filled with a single element, the aether, aggregated in a set of nestling shells containing the planets. The sphere of stars formed the outer surface of that aggregate of shells, and the sphere containing the moon (the lowest planet) formed its inner surface. The earth rested in the centre of this universe.

The aether was considered to be the celestial element, filling the space between the sphere of the moon and the sphere of the stars. It was pure, unalterable, transparent and weightless, constituting the substance from which the planets, the stars, and the shells accounting for their motions, were made. The sublunary region was filled with
the four Aristotelian elements: earth, water, air and fire. At every point of this universe some sort of substance was present, and matter and space were inseparately linked, with the result that the very notion of a vacuum was an absurd in terms.

Motion was considered differently with regard to the celestial and sublunary regions. In the former, which was eternal and changeless, motion was supposed to be perfect, that is, uniform, circular and perpetual. Terrestrial or sublunary motion, in its turn, was divided in natural and violent. Natural motion was the motion directed to the "natural places" of objects. In the case of rocks and earthly materials, that teleological destiny was considered to be the centre of the universe. That explained the fact that the Earth (composed of rocky and earthy materials) occupied this position. Natural motion was, therefore, governed by the space geometry alone, and not by the mutual relation between bodies. According to the Aristotelian view, a stone falls naturally towards the Earth, not because it is attracted by it, but because the Earth occupies the centre of the universe. By the same token a moving Earth was inconceivable in the Aristotelian universe. That point of view was incorporated in the Ptolemaic paradigm which dominated astronomical research until the Copernican revolution (Kuhn, 1977b).

All motions which were not natural, were considered violent in the Aristotelian framework, and since, unless it is pushed or pulled, a body will move straight towards its natural position and then rest there, a force was
necessary to move terrestrial elements from their natural place, like for instance the motion of a chariot.

Franklin (1978) represents Aristotle's law of motion by:

\[ \text{Velocity} = \frac{\text{Force (motive power)}}{\text{Resistance}} \quad \text{or} \quad V = \frac{KF}{R} \]

where \( F \) is the motive power urging the body to move, and \( R \) stands for the resistive medium through which the body passes.

Aristotle himself never stated his law of motion in this concise mathematical form. He rather discussed, separately the changes of velocity due to changes in the moving force or in the resistance of the medium. But it can be argued that the mathematical expression presented conveys the meaning of Aristotle's statements. There are two basic aspects of the Aristotelian physics of motion, symbolized in the expression, that must be stressed.

First, the idea that force and velocity are directly associated, that is, for a body to have a velocity a force must be being exerted. Second, the impossibility of a void existing in the Aristotelian universe, expressed by the resistance in the denomination of the equation. The implication is that, in the void, resistance must be zero and the velocity would be infinite, which is impossible since the motion would be instantaneous. That was the argument used by Aristotle to argue for the impossibility of a void, which was a fundamental feature of his finite and filled universe.

Aristotle's theory of motion explained quite well the
movement of bodies lying on a surface, but could only offer a complicated and rather unconvincing explanation for the motion of projectiles. In this case, no visible mover exerting a force on the projectile was present, and Aristotle amended the theory by conceiving the disturbed air as the source of a push, after the contact between the object and the thrower ceased (antiperistasis theory), as illustrated by Fig. 10.1.

According to Kuhn (1977b) Aristotle was aware of the weakness of this extremely artificial and ad-hoc solution but for him the point was not very important. Projectile motion was considered as a case lying outside his general framework, probably because it might have created difficulties to his theory.
10.2.2 Impetus Theories. These weaknesses constituted, however, the foci for medieval commentators on his theories of motion. Following the scholastics method of analysis, in which arguments and counter-arguments were advanced in relation to specific aspects of Aristotle's views, particular inadequacies were highlighted even by scholars pledging an allegiance to the general Aristotlelian view of the world (Kuhn, 1977b).

The most important early medieval critic of the antiperistasis explanation was John Philoponus who lived in the sixth century A.D. (Franklin, 1978). He proposed that an impressed force or borrowed power was transmitted by the thrower to the projectile, rejecting the idea that a medium can both sustain and resist the motion of a projectile. He also argued for the possibility of motion in a void, assuming, however, that the impressed force was of a self-expanding nature, in order to disallow the possibility of infinite motion.

A similar view was held by some Arab scientists in the Middle Ages, among them Avempace (1106-1138) whose views were introduced in the West through Averroes' comments on Aristotle's physics, a standard text among medieval scholars. Franklin (1978) represents Philoponus' and Avempace's theories of motion by the equation:

\[ V = F - R \]

where \( V \) = Velocity, \( F \) = Force, \( R \) = Resistance of medium. This equation allows, at least hypothetically, for motion in a void.
The discussions about the possibility of motion in a void and about the very existence of a void reached their peak in the 13th century. Some scholars maintained that God was restricted by the laws of Aristotelian physics when creating the universe and that position prompted a reaction of the Church, condemning 219 Aristotelian theses which could be used to cast doubts upon God's omnipotence, in the Edict of Paris issued by Bishop Tempier in 1277 (Wallace, 1981). Among the condemned prepositions was one stating that God could not move the universe with rectilinear motion because a vacuum would result.

Although being, in its origins, a conservative and dogmatic theological move, the Tempier's Edict is regarded by some historians of science as providing a stimulus for scientific speculation since it obliged a more serious reflection on the concepts of space, time and motion (Dijksterhuis, 1961). Few authors, however, will go as far as Pierre Duhem, one of the pioneers of studies into medieval science, who considered 1277 as the birthdate of modern science (Wallace, 1981).

The scholastic criticism of the Aristotelian theory of projectile motion culminated in the formulation of the "impetus" theory in the 14th century by scholars based in the University of Paris. Jean Buridan, one of the leading members of this group asserted that, when a stone, or other projectile, is launched:

"(The projector) impresses a certain impetus or motive force into the moving body, which impetus acts in the direction toward which the mover moved the moving body, either up or
down or laterally or circularly. And by the amount the mover moves that moving body more swiftly, by the same amount it will impress in it a stronger impetus. It is by that impetus that the stone is moved after the projector ceases to move. But that impetus is continually decreased by the resisting air and by the gravity of the stone which inclines it in a direction contrary to that in which the impetus was naturally predisposed to move it. Thus the movement of the stone continually becomes slower until the impetus is so diminished or corrupted that the gravity of the stone wins out over it and moves the stone down to its natural place."

(Jean Buridan, quoted in Kuhn, 1977b, p. 120)

Buridan's "impetus", differently from earlier versions was not self-expanding, and, unless resisted, could make motion endure forever. He also presented a quantitative description by equating the quantity of impetus with the product of the body's speed by its quantity of matter, a concept very similar to the concept of momentum in modern science (Kuhn, 1977b).

Nicole Oresme, one of Buridan's students, continued his master's work, and actually employed the concept of "impetus" in order to demonstrate the possibility (although not the necessity) of the Earth having a diurnal rotation. Oresme's counter-arguments to Aristotle's and Ptolemy's theories, considered an inertial solution to the problem of an arrow thrown vertically. They were very similar to the ones used later by Galileo to defuse anti-Copernican "proofs" of the immobility of the Earth (Kuhn, 1977b). With Buridan and Oresme, terrestrial dynamics started to be used in cosmological arguments, a movement in the direction of a unique physics to describe earthly and celestial movement. It must be stressed, however, that:
"Impetus dynamics is not Newtonian dynamics, but by pointing to new problems, new variables, and new abstractions impetus dynamics helped to pave the way for Newton's work. Before the impetus theory both Aristotle and experiments testified that only rest endures. Buridan and some other impetus theorists declared that, unless resisted, motion too will endure forever, and they thus took a long step toward what we now know as Newton's First Law of Motion."

(Kuhn, 1977b, p. 122)

By the end of the fourteenth century "impetus" dynamics had replaced Aristotelian dynamics. and during the during the next two following centuries it was taught and used by the principal medieval scientists; Galileo learned it from Bonomico at Pisa (Kuhn, 1977b) and it was Galileo who was to provide the final and crucial link between the "impetus" theory and Newtonian mechanics.

10.2.3 Galileo. The role played by Galileo in the development of dynamics is still today a controversial matter in modern philosophy and history of science (Shapere, 1974; Finocchiaro, 1980; Wallace, 1981). According to Ernst Mach (1960), the influential nineteenth century positivist philosopher, Galileo must be regarded as an empiricist, who made a sharp break, both in content and methodology (the former as a result of the latter) with the pre-existent tradition. From this point of view, which nowadays has in Drake (1970) its best known supporter, Galileo formulated originally and in a form equivalent to Newton's first law, the principle of inertia, establishing the equivalence between uniform retilinear motion and rest.

At the opposite end of the spectrum, Pierre Duhem, at the turn of the century, argued that practically all the ideas attributed to Galileo had already been discovered in
the fourteenth century by the "impetus" theorists, and that he was at best a propagandist for what had already been accomplished (Shapere, 1974). Far from being the empiricist pictured by Mach and Drake, according to Duhem's view Galileo followed a rationalistic approach. Anti-empiricists images of Galileo are also pictured by Feyerabend (1975), Kuhn (1977b) and Koyré (1978) amongst others, and with the changing of perspective which took place on philosophy of science (Section 2.2.4) the traditional image of Galileo as the father of the empirical inductivist "scientific method" was reconsidered. Philosophers and historians of science today seem, in general, to accept that Galileo's theories were developed not based on observational results, but in spite of them. As Koyré stated, after pointing out that most of the so-called Galileo's experiments were in reality "thought" experiments:

"One could say, applying to Galileo the saying of a modern physicist, that he had no confidence in observations which had not been verified theoretically."

(Koyré, 1978, pp. 67-68)

With regard to the role played by Galileo in the formulation of the principle of inertia, an intermediate view between that of Mach and Duhen was proposed by Koyré (1978). It seems to be generally accepted that Galileo was influenced by the "impetus" theories as Duhen argues (Dijksterhuis, 1961; Clagett, 1959; Moody, 1975; Wallace, 1981), but his "impetus" evolved from the almost Parisian view expressed in his early works, like "De Motu" (circa 1959) to a nearly Newtonian perspective as expressed in his more mature
"Dialogue Concerning the Two Chief World Systems", published in 1632. This evolution was influenced by Galileo's adherence to Copernic平ism and by his attempts to solve the physical problems posed by the new cosmology (Feyerabend, 1975; Koyré, 1978).

The main purpose of the "Dialogue" was to defuse arguments against the motion of the Earth, which were presented by the defenders of an Earth-centred cosmology. One of the most serious arguments was that, in a moving Earth, a body released from a certain height would fall behind the perpendicular from the point of release to the ground. Galileo's solution to this problem postulated an independence between the vertical and horizontal motions of the body and a conservation of the horizontal "impetus" (the famous Galileo's principle of independence of movements). But at this stage "impetus" had acquired a new meaning for Galileo (Koyré, 1978). It was no longer the "motive force", causing the object to move, but motion in itself, an idea very close to the modern concept of momentum.

In one of his classical "thought experiments" in the "Dialogue" Galileo introduces the idea of conservation of motion by arguing that a ball moving in a horizontal plane will remain in a state of uniform motion unless resisted by external impediments. This notion of perpetually conserved motion in an idealized frictionless plane represented a sharp departure from the fourteenth century theories. First of all Galileo presented it as a case of motion which was neither violent nor natural, breaking therefore with the old Aristotelian separation; motion became a state in itself.
Furthermore, being a state which is conserved, motion for Galileo, or more precisely uniform motion, was located at the same ontological level as rest (Koyré, 1978). The ontological equivalence between uniform motion and rest, as states which tend to be conserved, meant that, as rest, uniform motion itself need not be explained. Using Toulmin's (1961) terminology not only rest, but now also uniform motion, became an "ideal of natural order", and only what deviated from these ideals required an explanation.

Although inertial ideas are important in Galileo's work, he never explicitly stated a "Principle of Inertia" as expressed in Newton's First Law. The first to clearly state it was Descartes (Kuhn, 1977b, Koyré, 1978), twelve years after Galileo's "Dialogue". Nevertheless, Galileo's physics was so impregnated with it that Newton attributed the credit for its discovery to Galileo.

10.2.4 The Newtonian Picture. The final step towards a fully inertial perspective in mechanics was to be provided by Newton. The first of his famous three laws of motion, presented as axioms at the beginning of the Principia, states that:

"Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed on it."

(Newton, quoted in Dijksterhuis, 1961, p. 466)

This axiom is followed by his famous second law of motion stating the proportionality between the "change of motion" and the "motive force impressed", and by his axiom
stating the equality between action and reaction.

Differently than his forerunners, however, Newton started his work in an almost fully accepted Copernican universe. By combining his three axioms on motion with the laws of planetary motion developed by Kepler, he derived the law of universal gravitation. He was therefore able to develop a quantitative cosmology that proved to be extremely successful. The far-reaching effects of the Newtonian synthesis helped his theory to overcome the initial reactions of the Cartesians (who would not accept the action through distance implied by the law of gravitation) and to establish it as the undisputed research paradigm in mechanics during the eighteenth and nineteenth centuries. The developments in mechanics which took place during these two centuries, like for instance Lagrange's formalism, reflect only the articulation of the paradigm, in the Kuhnian sense (Section 2.3.3), without changes in its basic principles.

The practical utility of the Newtonian laws of motion did not prevent scientists from interpreting them in alternative ways. O'Sullivan (1980) identifies four different interpretations, three in the framework of classical mechanics and one relativistic. Although pointing out that Newton himself was ambiguous towards what conceptual interpretation he adopted, O'Sullivan seems to attribute to Newton the interpretation that the second law was a law of nature, capable of being directly tested by experimental techniques. According to this interpretation that was the reason for Newton stating the first and second laws separately, the first being a definition of an inertial frame
of reference, and the second a statement about the behaviour of the real world on inertial frames of reference.

O'Sullivan points out that a different interpretation was the one provided in the nineteenth century by Kirchhoff, and adopted by Sommerfield, Mach and Hertz, according to which the second law is to be regarded as a definition of force. The result of this interpretation is an axiomatization of classical mechanics, its results following from this definition rather than from experimentally deduced laws of nature. In this view the first law is clearly a special case of the second.

The third classical interpretation mentioned by O'Sullivan (1980) sees the phenomenon of inertia as a result of the interaction between an observed body and the rest of the mass of the universe. In this framework an inertial frame is defined as having no acceleration with respect to the smeared out mass of the universe and Newton's first law is again a particular case of the second hardly needing to be separately stated.

10.2.5 Relativity. The conceptions embodied in the Newtonian theory of mechanics passed through a major revision with the development of Einstein's theory of relativity. In the "special theory" presented in 1905 Einstein's aim was to reconcile Maxwell's laws of electromagnetism with the possibility of performing covariant transformations (no change in the form of the laws) among frames of reference moving with constant velocity in relation to each other. Newton's laws of motion were covariant under such changes of systems
of reference, but the same was not true for Maxwell's theory.

According to Einstein's special theory of relativity, the laws of electromagnetism can be shown to be covariant if some fundamental concepts of classical mechanics are re-interpreted. In particular, concepts like time intervals and distances, which in the Newtonian framework are absolute, became relative to the system of reference considered, and the speed of light in turn into an absolute concept and upper limit. One consequence of this re-interpretation is that the mass of a particle, which is an absolute property of the particle in the Newtonian paradigm, becomes associated with its speed through the relation:

\[ m = \frac{m_0}{\sqrt{1 - v^2/c^2}} \]

where \( m_0 \) is the rest mass of the particle and \( c \) the speed of light.

One usual procedure after the advent of relativity has been to re-interpret the laws of classical mechanics according to Einstein's theory. Newton's second law of motion and the principle of conservation of momentum are assumed to be valid provided that the law of motion is expressed in its differential form \( F = \frac{dp}{dt} \) (which actually is equivalent in principle to the way Newton expressed it) and momentum is relativistically defined as

\[ p = \frac{m_0}{\sqrt{1 - v^2/c^2}} \]

which is completely different from the Newtonian expression of momentum \( p = mv \).

According to this interpretation, which represents the positivist view of scientific progress (Section 2.3.3e), the laws classical mechanisms are considered to be special cases of the laws of special relativity, when the velocities
are small compared to the speed of light.

The reduction of the laws of relativity to the laws of classical mechanics have been strongly criticized by Kuhn (1970a) and Feyerabend (1975). They argue that the theory of relativity represents an ontological breakdown with the pre-existing paradigm and therefore the two theories should be considered irreducibly. They point out that, although employing apparently the same concept (e.g. mass, time, force), the meanings of these are so different that any reduction is spurious. Newtonian mechanics and relativity are to be considered, therefore, mutually exclusive paradigms.

In 1916 Einstein presented a generalization of his theory, in order to include accelerated frames of reference. In the general theory of relativity the concepts of gravitation and acceleration are unified under the so-called principle of equivalence. The main consequence of the general theory is that Newton's gravitational theory is replaced by one in which the concept of a force is not necessary, and the motion of bodies is related to the configuration of the space, which is considered to be distorted by the presence of massive bodies. The general theory is in accordance with results predicted by Newton's gravitation theory in general, and in the very few cases in which both theories disagree in their predictions (precession of the perihelion of Mercury; deflection of light rays near strong gravitational fields; the shift towards the red of light near gravitational fields) the experimental results have
favoured Einstein's general theory.

10.3 Children's Science

The area of mechanics has certainly been the one in which the majority of studies on alternative conceptions have concentrated. Inside this area, the relationship between force and movement has been thoroughly explored and there is convincing evidence to support the statement that school children, and even some university students with a background in physics, tend to use pre-Newtonian ideas when analysing movement.

Driver (1973) employing a micro study method observed closely a small group of 11 and 12-year-old pupils during an introductory physical science course, during which topics like balancing systems, centres of gravity, the law of moments, action and reaction and the relation between force and tension were introduced. A number of alternative frameworks were identified, among them one implying that a constant force will cause a body to move at constant speed.

Lebou-ted-Barrel (1976) describes a study in which a written questionnaire containing 10 questions was applied to more than five hundred high school students (age 11-16 years) who had not yet taken a course in Physics, concluding that "the physical notions are physical notions only by name (force, power, speed ...). There is no rigid correlation between the common use and the scientific concept." What is
being called scientific concept, is in this case the Newtonian picture of mechanics.

Watts (1981, 1983) interviewed pupils (age 11-18 years) using the Interview-About-Instances approach (Osborne and Gilbert, 1980) in order to explore their conceptions of "force". He was able to detect eight different alternative frameworks. One of the common frameworks evident in the interviews was that forces are required to cause and maintain motion.

Watts and Zylbersztajn (1981) used a questionnaire, in a multiple-choice-with-explanation format, in order to assess the popularity of some particular alternative frameworks related to the concept of force derived from a study of literature. 125 pupils at the end of the third year of secondary school (age 14 years) from four comprehensive schools participated in the study. Six of the twelve questions presented aimed at surveying the association between force and movement, the first three asking about forces on a stone thrown vertically upwards in the air, and the other three asking about forces on a cannon ball in flight from muzzle to ground. The responses to these questions indicated that about 85% of the pupils associated force and motion: they saw the stone as having a force upward away from the person's hand as the stone moved upward and the cannon ball was seen to have a force away from the cannon, moving it through the air.

There is evidence to suggest that the pervasiveness of this belief is not to be found only among young school children who have not been taught the Newtonian framework.
For instance, Warren (1971) presented to 148 (in 1968) and to 193 (in 1970) science and engineering university entrants a simple problem involving uniform circular motion of a vehicle, requiring the students to represent the forces acting on it. Less than a third of the students represented the resultant force as being radically inward, and about half of each group represented the resultant force in the forward direction, showing an intuitive association between force and direction of movement despite years of formal instruction in physics.

Viennot (1978) reported that several hundred students (mainly French, but also British and Belgian) from the last year of secondary school to the third year of university, showed to apply a linear relation between force and velocity when answering paper-and-pencil test focussed on their predictions about the motion of bodies. The results suggest that for many students this intuitive relationship can be expressed as $F = a V$ leading to:

- if $V = 0 \Rightarrow F = 0$ even if a (acceleration) $\neq 0$
- if $V \neq 0 \Rightarrow F \neq 0$ even if $a = 0$
- if $V_1 \neq V_2 \Rightarrow F_1 \neq F_2$ even if $a_1 = a_2$

Not surprisingly this alternative framework was more likely to emerge in situations when intuitive reasoning was required, as for instance, when students had to compare, qualitatively, the intensity of the force acting on a body attached to a spring at the same position but with different speeds. On the other hand, students tended to associate force with acceleration (as they have supposedly been taught)
when presented with an equation of motion and asked to calculate the force.

McCloskey, Caramazza and Green (1980) asked university students to draw the path which objects, constrained by a tube to follow a curvilinear path on a horizontal plane, will follow when free of the constraint. Over half of them, including many who had taken physics courses, advanced answers showing a belief that, at least initially, the objects will continue to move in a circular curved path. Interviews conducted after the experiment showed that most of the subjects who drew curved pathways held the view that an object forced to travel in a curved path acquires a "force" or a "momentum" that causes it to continue in curvilinear motion for some time after emerging from the tube. This force or momentum eventually dissipates, and the object's trajectory gradually becomes straight. According to the authors these beliefs are similar to some versions of the medieval impetus theory (Section 10.2.2), namely the self-expanding and the circular versions of it.

Clement (1982) presents similar claims based on data obtained from written tests and videotaped problem-solving interviews. 88% of a group of 34 engineering students, which took a diagnostic test at the beginning of their first semester (most of them had had high school physics although not college physics) gave incorrect answers when asked to draw arrows showing the forces on a coin moving upwards. In 90% of the cases the error involved the drawing of a force arrow pointing upwards. It is suggested that most students presented conceptions very similar to the "impetus" theory (Section 10.2.2).
It is interesting to remark that the explanations advanced by the university students of Clement's study, when solving the coin problem, are similar to the ones presented by the third-year pupils who participated in the already described Watts and Zylbersztajn (1981) study when solving the equivalent stone problem.

The studies described above support the notion that pre-Galilean ideas about force and movement are not only prevalent among school children, but also in certain cases persisting even after years of formal exposure to physics teaching. There is also evidence to suggest that, at least when projectile motion (vertical or composed) is considered, the conceptions are closer to the medieval "impetus" theories than to the older Aristotelian conception.

10.4 Curricular Science

The relation between force and movement is introduced in the four textbooks examined as part of the general treatment of Newtonian mechanics, which constitute one of the basic components of school physics. In all textbooks the relationship between force and movement is formalised in the presentation of Newton's laws of motion, particularly the first and the second. The general context and the specific patterns of presentation in the materials examined, do, in this case, show a diversity which suggested a different form of presentation of the analysis than the one adopted in the case of Light and Colour (Section 8.4). In that case the similarities in the curricular presentation made it
functional for the analysis to be centred on aspects of that presentation. In the present case, however, the diversity in the curricular presentation suggested a textbook-centred presentation of the analysis of the materials. In Sections 10.4.1 to 10.4.4, therefore, I consider each text in particular and in Section 10.5 the relevant aspects are discussed in a more global perspective.

10.4.1 Abbot's Ordinary Level Physics. Mechanics is presented in the first part of the book (13 chapters). In the first three chapters basic concepts such as mass, weight, gravity, force, speed, velocity and acceleration are introduced, preparing the way for the presentation of Newton's laws of motion (Chapter 4). Vectors are introduced in Chapter 5, and Chapter 6 deals with statics. Chapters 7 and 8 are concerned with concepts such as work, energy, power, efficiency and with the study of simple machines. Chapters 9 to 12 are concerned with the study of pressure in liquids and gases, and Chapter 13 with molecular properties of matter from a mechanical perspective.

From the point of view of the case study being now presented, Chapter 4, "Newton's Law of Motion" is central. Although this is true, some ideas concerning the concept of force and its relation to movement are presented in earlier chapters, which therefore deserve consideration. The analysis presented here is based on the material of the first four chapters of the books, since those are the ones more directly related to the topic being considered. Although concepts like energy, work, power and pressure are
important in secondary school dynamics, they are not analysed here, because usually the relation between force and movement (the topic being focussed), as expressed by Newton's laws, is taken for granted in the presentations of those concepts.

In Abbot's Ordinary Level Physics the way for the formal presentation of Newton's laws in Chapter 4 is prepared in the previous three chapters. In Chapters 1 and 2 the concepts of mass, weight, force, force of gravity, friction are introduced and illustrated; Chapter 3 in its turn deals with kinematical concepts (speed, velocity and acceleration) and with the description of motion by means of equations and graphs. Motion under constant acceleration, which is basic for curricular presentations of Newton's second law ($F = ma$) is specially considered and illustrated with the case of free fall under the action of gravity.

In Chapter 1, primarily concerned with measurements, the "mass" of a body is defined as:

"... the quantity of matter it contains, and the basic SI unit of mass is the kilogram. The standard kilogram is the mass of a certain cylindrical piece of platinum-iridium alloy kept at Sèvres."

(Abbot, Ordinary Level Physics, p. 8)

and shortly after:

"The weight of a body is the force it exerts on anything which freely supports it, and normally, it exerts this force owing to the fact that it is itself being attracted towards the earth by the force of gravity."

(Abbot, Ordinary Level Physics, p. 9)
It is important to note that although weight is defined as a "force", and "force of gravity" is mentioned, the concept of force had not been introduced formally at this stage.

Assuming that the textbook is being used linearly, that could mean that the presentation is relying on the ideas of force that pupils bring from primary and middle school. It is normally assumed that school children at that stage possess an idea of force which is associated with sensorial attributes like "pushes" and "pulls". This sensorial association is explicitly mentioned in Chapter 2. Force of Gravity, Weight and Friction. At the beginning of the chapter "force" is defined:

"What is force? The word 'force' generally denotes a push or a pull. Now it is not possible to describe a force as we can describe some material object such as an apple. We can only say what force can do. When a body is acted upon by a resultant force it will begin to move. If the body is already moving a force may alter its speed or alter its direction of motion or else bring it to rest. We therefore define force as follows: Force is that which changes a body's state of rest or of uniform motion in a straight line."

(Abbot, Ordinary Level Physics, p. 12)

The implications of the definitions are not pursued in Chapter 2 (neither is the definition justified), and the rest of the chapter deals mostly with some properties of gravitational forces, weight and frictional forces. The properties illustrated are not, however, explored in connection with Newton's first law of motion, which is implicit in the definition of force stated. Although the relation between force and motion is left to be discussed in Chapter 4, in one of the cases treated in Chapter 2, this relation is
of fundamental importance. The idea of "centripetal force" in circular motion is presented in a way that does not take into account the fact that in "children's science" force and direction of movement are closely related:

"Centripetal Force
It is important to grasp the idea that, to keep a body moving in a circle there must be a force on it directed towards the centre. This is called the centripetal force. Before Newton's times it was believed that invisible spokes radiated out from the sun and pushed the planets round. Newton's insight into the problem convinced him that a push such as this was not necessary. The planets, carrying their atmospheres with them, go on moving in their orbits because the great vacuum of space offers no opposing force to their motion. Centripetal force is, however, required to produce the continuous change of direction which occurs in the orbit and this is provided by gravitational attraction."

(Abbot, Ordinary Level Physics, p. 14)

This summary of how inertial ideas were introduced in astronomical movement does not make justice to the historical struggle between conceptions about motion that took place in the years between Copernicus' proposition of a heliocentric universe and Newton's proposition of universal gravitation (Kuhn, 1977b). It can also be expected that for children, holding a pre-Galilean framework, this short paragraph will present very little in the way of helping them to change their conceptions and grasping the idea that to "keep a body moving in a circle there must be a force on it directed towards the centre".

In the next paragraph the existence of centripetal force is demonstrated by reference to sensorial experience. Pupils are encouraged to try the classical experiment of swinging round a mass tied to a string, and it is suggested that:
"The pull in the string which is providing the centripetal force can be easily felt and we notice that it varies according to mass, speed, and path radius."

(Abbot, Ordinary Level Physics, p. 14)

The transference of ideas from this situation to the astronomical one is not immediate. Here the string can be imagined to act as the spoke which, in the previous paragraph, Newton was said to prove not necessary. Furthermore, the force that is experienced by the holding hand is not centripetal, but actually the outwards reaction of the force acting on the swinging cross. With this sort of example the conception of a (non-existent) "centrifugal force" accounting for circular motion can only be reinforced. The problems that this conception brings for the teaching of circular motion in inertial frames of reference have been discussed in several places, (e.g. Warren, 1979; Gardner, 1981).

The relation between force and movement is discussed in more detail in Chapter 4, in which Newton's laws are formally presented. The chapter starts with a brief "historical" introduction:

"The study of moving bodies begun by Galileo Galilei in Italy was continued after his death by Sir Isaac Newton in England. In 1687 Newton published a book written, as was the custom in those days, in Latin and given the title, Philosophie naturalis principia mathematica. .... The Principia, as it is familiarly called, is regarded as one of the greatest scientific works ever written. It is devoted mainly to the study of motion, particularly that of planets and other heavenly bodies. In the first part of the book Newton sums up the basic principles of motion in three laws. In this chapter we shall discuss these laws and consider some of their applications."

(Abbot, Ordinary Level Physics, p. 35)

Again, there is very little justice to historical developments in this quotation. The impression given is that
the study of moving bodies started with Galileo, who was referred to in Chapter 3 in connection with the study of falling bodies. There are no references, in all the book, to pre-Galilean theories in the study of motion. There are also no references to the interplay between developments in astronomy and in earthly mechanics which characterised the period between Copernicus and Newton.

In the rest of the chapter the three laws of motion are introduced. The form of presentation follows a similar pattern for the three: initially the law is stated (stressed in bold types) and afterwards discussed and illustrated by examples. For instance, after stating the first law as

"Every body continues in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise."

(Abbot, Ordinary Level Physics, p. 35)

the fact that is "common experience" that objects at rest do not begin to move by themselves is pointed out, and illustrated by some "parlour" tricks. This aspect of the law conforms quite well with the expectations of most people.

The troublesome part of the law is when moving bodies are concerned, as research on alternative conceptions indicates. To some extent this fact is acknowledged in the text:

"It is not immediately obvious that a body moving with uniform velocity in a straight line tends to go on moving for ever without coming to rest. The fact is that no one has yet found a means of eliminating all the various outside forces which can retard a moving body.

(Abbot, Ordinary Level Physics, p. 36)

The text goes on presenting some examples in which motion
is affected by air resistance, friction or forces like gravity. The hidden assumption of this sort of presentation is that, once aware of the effect of resistant forces, students will accept the inertial view of motion. It is stated, for instance, that:

"When a bullet is fired from a gun its motion is opposed both by air resistance and the pull of the earth. Sooner or later it returns to the earth, but it would be reasonable to suppose that, if air resistance and gravitation could be eliminated, the bullet would go on moving in a straight line forever."

(Abbot, Ordinary Level Physics, p. 36) (Emphasis added)

The reasonableness of the supposition can be disputed. Aristotle (Section 10.2.1) was quite aware of resistant forces, but argued that if they could be eliminated (and he assumed they could not) the speed of the body would increase forever. Some impetus theorists (Section 10.2.2) assumed that in the absence of other forces, a body once in movement would continue in movement, but only because the "impetus force", once imparted, would be conserved and sustain the movement; others assumed that the "impetus force" would be self-expandable, even in the absence of resistive forces. It is doubtful whether, for a large number of pupils, the simple awareness of friction would make it "reasonable" for them to dissociate force from uniform motion. But that is the essence of the first law, as the text recognizes:

"It is important to realize that, once a body is moving with uniform speed in a straight line, it needs no force to keep it in motion provided there are no external opposing forces."

(Abbot, Ordinary Level Physics, p. 36)
The idea is then summed up with the abstract concept of "inertia", which is said to describe the tendency of a body to continue in rest or moving in a straight line.

In the rest of the chapter the treatment becomes more quantitative, with the definition of the concept of momentum, and the presentation of the second and third laws, and the principle of conservation of moment. The emphasis is then turned to quantitative applications of formulae such as $F = ma$ or $m_1v_1 = m_2v_2$, as the worked examples and the questions at the end of the chapter do show.

The changing from the pre-Galilean view (force always in the direction of movement) to an inertial view of motion, apparently is not seen as very problematic. It is quite symptomatic that none of the 16 questions at the end of the chapter are directed to the assessment of the pupils' understanding of the relation between force and movement at a conceptual level. Since the importance of that understanding is mentioned in the text (see last quote), it can only be assumed that the absence of questions assessing it indicates a tacit assumption that this understanding would be unproblematic.

10.4.2 Nelkon's CSE Physics. As in Abbot's text, mechanics is presented in the first part of the book. Although in Chapter 2, Molecules and Matter, forces between molecules are already mentioned in order to explain phenomena like elasticity and surface tension, mechanics is more formally dealt with in Chapters 3 to 7. Here the order of presentation
is reversed in relation to Abbot's. Statics work and energy, and forces and pressure in fluids are introduced first, and dynamics is treated in the last chapter in the mechanics section. The logic of this pattern of presentation seems to be that, differently than in dynamics, statics can be dealt with by assuming an intuitive idea of force associated with muscular sensations like "pushes" and "pulls". As with "force", the idea of "mass" is used from an intuitive point of view in Chapter 2 and employed freely in the definition of density.

In Chapter 3. Forces and Moments Centres of Gravity, devoted to the study of statics, use is made of the intuitive association of force with muscular sensations:

"A push and pull are examples of forces. If a girl pushes a pram she feels the force exerted by her muscles, which become taut .... A boy throwing a cricket ball feels a force in the same way."

(Nelkon, CSE Physics, p. 38)

After presenting some ways in which forces can be described (tension in a rope, weight, reactions, friction) and introducing the Newton as a unit of force, the rest of the chapter is concerned with statics.

The relation between force and movement is treated formally in Chapter 7. Dynamics. The first half of it deals actually with kinematics (speed, acceleration and graphs). Dynamics is defined in the beginning of the chapter as:
"Dynamics is the study of motion and of the forces which keep an object in motion or oppose its motion."
(Nelkon, CSE Physics, p. 120)

This definition of dynamics, to some extent, matches the alternative conception which assumes a relation between force and any kind of movement, since it seems to assume that forces are needed to keep an object in motion. The introduction of the chapter ends with a "historical" note:

"The founder of mechanics is generally recognised to be Sir Isaac Newton, who published a work called Principia in 1687, in which 'Laws of Motion' were clearly stated for the first time."
(Nelkon, CSE Physics, p. 120)

If, in Abbot's text only the impression was given that the study of motion started with Galileo and reached its apex with Newton, here it is clearly stated that it was founded by Newton. As it was seen in Section 10.2, this idea misrepresents the historical development of ideas concerning motion. Certainly the subject was studied before Newton; that the previous conceptions were superseded by the Newtonian formulation is quite a different point.

The idea that a force produces a change in the movement of an object is introduced in the beginning of the second part of the chapter, which is concerned particularly with dynamics:

"Force
If you collide with someone while walking, your motion is immediately checked. A force, due to collision, thus produces a change in velocity. When a train starts from a station its velocity increases from zero. A force, due to the metal chain or link connecting the train to the engine again produces a velocity change. If a tennis or cricket ball is hit, or a football is kicked, the force at impact produces a velocity
increase. All these examples show that, in general, a force produces a change in the motion or velocity of an object." 

(Nelkon, CSE Physics, p. 134)

In the following section the idea of friction is discussed and the fact that, with reduced friction, motion tends to persist for longer, is presented. This prepares the way for the presentation of Newton's first law. The presentation of the law is supported by reference to experiments with dry ice pucks and stroboscopic photographs showing that with friction reduced to a very low level the object tends to present a uniform motion, or to remain at rest. The first law is then formally stated:

"Newton's first law summarizes experience. It may be stated: Every object continues in its state of rest or uniform motion in a straight line unless impressed forces act on it."

(Nelkon, CSE Physics, p. 137)

As in Abbot's the implicit idea in the presentation is that, once aware of the existence of frictional resistive forces, children will more easily accept an inertial conception of motion. The same sort of comments made before can be applied to the present case. As in Abbot's the concept of "inertia" is introduced:

"Newton's first law recognized that objects have a reluctance to move when they are at rest. They also have a reluctance to stop when they are moving. Objects thus have a certain amount of inertia."

(Nelkon, CSE Physics, p. 137)

After this statement, "mass" is presented as a "measure of its inertia" and the relation \( F = ma \) presented. This is followed by a short discussion about circular motion and
centripetal force. The idea that the centripetal force is directed towards the centre of movement is justified by appeal to sensorial experience:

"In the case of a stone whirled round in a circle, the force is due to the tension in the string - we can feel the force on the hand as the stone is whirled round. It is called a centripetal force because it acts towards the centre of the circle in which the stone is moving."

(Nelkon, CSE Physics, p. 139-140)

The same comment made in relation to Abbot's presentation of centripetal force is valid here. The force that a person feels when whirling a stone is actually directed outwards, being the reaction to the inwards force exerted by the person on the stone. It is not very difficult to imagine that this sort of statement can actually be quite confusing for children holding a conception linking force and direction of movement.

Again, as in Abbot's, none of the questions at the end of the chapter are directed to the probing of the pupils' understanding of the relation between force and movement, as expressed by Newton's first law. Again, it can be assumed that this understanding is regarded as unproblematic.

10.4.3 Jardine's Nat Phil. The presentation of mechanics in Nat Phil follows a rather different pattern when compared with the two texts analysed before. First of all it is presented in the form of a "spiral" approach, with the same concepts being treated in different parts of the material, at different levels. This is clearly noticed when topics presented in Nat Phil 3 and Nat Phil 4 (directed to the
Scottish O Grade) are revisited in Nat Phil 5 (directed to the Scottish Higher Grade). But even in the first two volumes, directed to the same grade, mechanics, and particularly the relation between force and movement, is not presented in linear fashion. Another aspect in which the presentation in Nat Phil differs from the two texts previously analysed is in that it follows a more discursive approach, usually illustrated by historical examples. As will be seen, however, the image of science conveyed by the historical illustrations is, to a large extent, an empirical-inductivist one.

The relation between force and movement is first discussed as early as in the Introduction (Nat Phil 3). In this chapter some basic concepts of pre-O Grade physics are briefly summarised (energy, matter, kinetic theory, states of matter, conduction and convection, work, electric charge and energy transfer). The section concerned with forces starts with a picture of a space ship accompanied by the following text:

"A space ship-coasts along merrily, its rocket motor switched off. No force is needed to keep it going. If this seems odd to you it would have seemed even more odd to Aristotle! Galileo, however would have simply uttered 'I told you so!' By carefully studying and measuring the motion of such things as a swinging pendulum or a rolling ball Galileo came to the conclusion that this was the way things are. This tendency of a body to stay put or to keep moving once started we call inertia, a word which suggests that, like some humans, things tend to resist changes of any kind."

(Jardine, Nat Phil 3, p. XIII)
(Emphasis added)

In this preliminary statement the idea of uniform motion without force is introduced as one which, although
"odd" (for us and for Aristotle), was reached by Galileo through "studying and measuring" the motion of real bodies. This empiricist view of Galileo's approach has been discredited by modern philosophy and history of science (Section 10.2.3).

Another aspect of the statement is the contraposition between Aristotle and Galileo. This is a recurrent theme in Jardine's Nat Phil: Galileo representing the modern (empiricist and scientific) approach to knowledge and Aristotle, the old (metaphysical and philosophical) one.

In the next paragraph the effect of friction is introduced:

"Our normal experiences, like Aristotle's two thousand years ago, suggest however that things do not go on moving indefinitely. They come to rest or change direction because forces act on them. Air resistance - the bombardment of air molecules - slows down an airplane and friction - the force acting between two surfaces in contact - changes the direction of a racing car. Forces are of course needed to get stationary bodies moving. It was left to the genius of Sir Isaac Newton to define force precisely and in such a way that it could be measured accurately. The unit of force we now use is named after him."

(Jardine, Nat Phil 3, p. XIV)

Here, as in Abbot's and Nelkon's texts the explanation coincides: bodies tend to present an inertial behaviour, but normally they do not because of the effect of resistive forces (see pp. 10-28 for a critique of this explanation). It is also interesting to note that as in the previous books the word "inertia" is introduced, and in this case with a strong animistic connotation ".. like some humans, things tend to resist changes of any kind".)
After a unit on wave motion and light (four chapters), the study of motion is started in a more formal way in Unit Two. Matter on the Move (1) - Mechanics and Heat of Nat Phil 3. This unit consists of six chapters: two on time measurements and kinematics, two on the relation between force and motion, one on mechanical energy, and one on heat from a kinetic point of view. The relation between force and motion is initially discussed in Chapter 7. Newton 1 - Uniform Motion (Nat Phil 3), from the point of view of the Principle of Inertia and Chapter 8. Force, Mass and Motion consists of a qualitative introduction to the second law.

Chapter 7 begins with references to Aristotle's physics and to its common sense basis:

"Aristotle and Common Sense
In his Mechanics Aristotle said that a moving body comes to a standstill when the force which pushes it along can no longer so act as to push it. It is hardly surprising that for 2000 years this doctrine was accepted, considering that it describes what happens in our everyday experience. Try pushing a box, a bicycle, or a ball. Each will come to rest soon after you stop pushing it."

(Jardine, Nat Phil 3, p. 67)

The fact that Aristotelian physics had problems in explaining projectile motion is pointed out, and some of the theories advanced by Aristotelian mentioned, such as the one based on antiperistasis (Section 10.2.1). From Aristotle's theory of motion a historical "jump" is made to Galileo. The "impetus" theory, which provided a solution to the problem of projectile motion which was accepted during the Middle Ages, and which influenced the development of Galilean physics (Section 10.2.2), is not mentioned at all.
The work of Galileo is presented after some short biographical details. It is pointed out that:

"Galileo challenged many of the beliefs of Aristotle and his followers and in particular their views on motion and gravity. He did not try to answer the question, 'Why does a body keep moving?' He simply stopped asking it! He said it was better for people 'to pronounce that wise, ingenious, and modest sentence, 'I know it not' rather than to suffer to escape from their mouths and pens all manner of extravagancies.' Suppose it was just 'natural' for a body to move as it is to stay still. Then ought we not rather try to discover what stops moving objects? If it is 'in the nature of things' to keep moving the wonder is that things ever come to rest at all!"

(Jardine, Nat Phil 3, p. 67)

In the quotation above Jardine, rightly, states one of the major differences between Galilean physics of motion, and its predecessors, i.e. a change of outlook on what was to be considered natural and therefore does not require explanation, or "ideals of natural order" (Toulmin, 1961). Only what deviates from that ideal is supposed to require an explanation (e.g. accelerated motion). With Galileo, the "ideal of natural order" included not only rest but also uniform motion. That is, an ontological equivalence between rest and motion was established (Section 10.2.3).

In the next paragraph, however, the empiricist image of Galileo appears again:

"One of the experiments Galileo used to investigate motion was not unlike the bent curtain rail illustrated in Fig. 7.2."
When the rail is bent to position ABC, a ball released at A will run down the rail and up to C which very nearly is the same height as A. With the rail bent to position ABD the ball rises to nearly the same height at D. If then, the process of unbending is continued the rail will eventually be in position ABF where BF is horizontal. Will a ball released from A now go on trying to raise to the height from which it started? If so, the ball should go on indefinitely at a constant speed. Of course in practice the ball stops because it is impossible to get rid of friction. But Galileo believed that if all frictional forces could be removed, the ball would go on for ever."

(Jardine, Nat Phil 3, p. 67-68)  
(Emphasis added)

The account presented suggests very strongly that the experiment described was used by Galileo "to investigate" motion. In reality, this "experiment" was presented in the "Dialogue" as part of an argument, and it was one of the "thought experiments" used by Galileo when presenting his ideas.

In the rest of the chapter, the effects of resistive forces of friction are illustrated, and examples of motion under reduced friction (air tracks; hovercraft, astronauts) are presented as examples of early uniform speed.

The concept of inertia is presented as:

"This property of matter which tends to keep it still or travelling in a straight line we call inertia. This does not explain it - it simply labels it. Galileo's answer to the ancient question 'What keeps a stone moving' was simply 'We do not know, but we can discover what makes it slow down on stop'."

(Jardine, Nat Phil 3, p. 69)

Probably, it would have been more accurate to say that Galileo's answer was that uniform motion was as a natural state for bodies as it was rest, and therefore no explanation was needed.
The problems presented at the end of the chapter do attempt to assess pupils' understanding of the Law of Inertia, from a qualitative and conceptual level, mainly in its relation with frictional forces. In the questions presented only retilinear motion is considered. This reflects the fact that, on the presentation of Chapter 7, no cases of motion other than retilinear were considered.

Chapter 8. Force, Mass and Motion (Nat Phil 3) is mainly concerned with the introduction of some qualitative ideas about Newton's Second Law. "Mass" is presented as the "quantity" of a substance and associated with the idea of inertia. From a description of experiments using trolleys and ticker-tapes it is concluded that the acceleration of a given mass is directly proportional to the force acting and inversely proportional to the mass.

The study of mechanics continues in Unit Four. Matter on the Move (2) - Mechanics and Heat (Nat Phil 4), in which certain topics presented in Nat Phil 3, are revisited, and the treatment is more sophisticated from a mathematical point of view. In Chapter 15, the first in the unit, vectors are introduced, and some simple ideas of vectorial kinematics presented, including the notion of relative movement and relative velocity. Chapter 16. Newton 2 - Force, Mass and Acceleration (Nat Phil 4) presents a more formal and qualitative treatment of the ideas introduced in Chapter 8. In particular, the \( F = ma \) version of Newton's Second Law is stated. The problems in the long series presented at the end of the chapter are mainly concerned with the application of the expression \( F = ma \) in a variety of circumstances involving
Chapter 17. Gravity and Projectiles (Nat Phil 4), deals with two-dimensional motion, and the motion of projectiles is explained by considering the independence between the vertical movement (fall under the action of gravity) and the horizontal movement (no forces acting). The idea of circular motion is illustrated by considering the motion of a satellite but is not explored. The impression given is that, at this stage, pupils are expected to see the relation between force and movement from an inertial point of view. In the text of Chapter 17 there is not a single diagram illustrating the direction of the force acting on a projectile or on a body moving in a circular path. In 4 of the 12 problems presented at the end of the chapter, however, the student will have to make use of the fact that the force acting on a projectile is not in the direction of motion. These sort of problems can help a perceptive teacher to assess the students' understanding of the relation between force and motion.

The rest of Unit Four deals with the Principle of Conservation of Momentum and Newton's Third Law (Chapter 18. Newton 3 - Interaction); with energy and work (Chapter 19. Kinetic and Potential Energy); and heat (Chapter 20. Internal Energy).

Nat Phil 5, the last book in the series is directed to the Scottish Higher Grade. Most of the topics presented in Nat Phil 3 and 4 are revisited and the level of the mathematical apparatus increased. Mechanics is treated in Unit One. Matter in Motion. Chapter 1. Motion (Nat Phil 5) presents
motion from the point of view of kinematics, and Chapter 2. *Principia* (Nat Phil 5) presents a summary of Newton's laws and applications. In this stage (H grade), students are certainly expected to have an inertial perspective of motion, and the text does not attempt to teach them this view.

10.4.4 Revised Nuffield Physics. The presentation in this curriculum differs from the others in some substantial ways. Being based on an "inquiry approach", the pupils' texts consist basically of descriptions of experiments to be performed and questions about them. Therefore the style is far less discursive than the normal textbooks. On the other hand, the material includes also teachers' guides. In these, pedagogical advice, in the line of the so-called "Nuffield spirit" is presented. On occasions some background reading for teachers is included, and some of these go beyond the scope of the material to be learnt by the pupils.

The curriculum is designed to suit, ideally, the five years of secondary school (at O-Level standard). The study of ideas related to force follows a "spiral approach" with the topic being introduced at an elementary level in the first year, and being revisited in later ones.

In the first two years pupils are expected to gain acquaintance with materials and their properties and behaviour. In Year 1, ideas about forces and presented from the intuitive sensorial point of view of "pushings" and "pulls". Words such as force, weight, balancing, pressure are used informally in connection with some experiments. The first chapter of Year 2 - Chapter 9. About Forces -
returns to the ideas of force which have implicit in the first year and the experiments and demonstrations are designed for pupils to:

"... see and feel the forces involving in deforming things (stretching, compressing, twisting, bending), to discuss briefly the 'turning effects of forces', and to experience the forces of attraction and repulsion between magnets."

(Revised Nuffield Physics, Teachers Guide Years 1 and 2, p. 97)

The study of forces and their effects is therefore basically, at this stage, a statical one. A more dynamic treatment of the subject is started in Chapter 12. More about forces (Revised Nuffield Physics, Year 2). Here "weight" is described as the "pull of the Earth" and "Newtons" presented as units for measuring forces and the difference between "weight" and "mass" (a "stodginess" of the stuff) stressed. The treatment is very informal and forces are strongly related to muscular "pushes" and "pulls".

An important aspect of Chapter 12 in relation to the study of force and movement in following years is that it introduces experiments and demonstrations designed to increase the pupils' awareness of the effects of frictional forces either between solid surfaces or between a solid moving in a fluid (liquid and air). Teachers are advised not to try to extract laws from the experiments or to ask pupils to verify laws presented to them. Instead:

"The effect of adjustable fluid friction in bringing a falling object to a terminal speed should be explored, in preparation for Newton's in later years. To children, as to adult Greeks, constant speed is the natural result of a steady force, and we need to face this before we can say that Newton's first law tells the same story."

(Revised Nuffield Physics, Teachers' Guide, Years 1 and 2, p. 131)
In this passage teachers are briefly reminded of a facet of "children's science", but the issue is not pursued further either in its pedagogical or historical aspects. The role to be played by the study of friction, however, is considered in more details in a later paragraph:

"Fluid friction is interesting and forms a valuable beginning for Newton's laws of motion. Instead of announcing Newton's laws as the right rules, as one might do in discussing things with a mature student, we shall be wiser to start looking at motion with friction, which is more common in the real world. Solid friction does not give such an interesting story as fluid friction, which has the important property of increasing its force with increasing speed. So a body whose motion is controlled by fluid friction will, if pulled by constant force, approach a constant speed (terminal velocity)."

(Revised Nuffield Physics, Teachers' Guide Years 1 and 2, p. 136)

In this case what was an implicit assumption in the other textbooks examined is in the last two quotations more clearly spelled out: by getting pupils aware of the effects of friction, the way to Newton's law can be eased. Although the examples presented in Revised Nuffield Physics are more sophisticated than those in the other texts, since they include an exploration of terminal velocity in fluids, the same comments made when analysing the other curricular materials are applicable. Basically the phenomenon can also be accommodated by an "impetus" type force theory at least from a qualitative point of view. It can be argued for instance that when the state of constant speed is reached, the resistive force of the fluid does not equal the gravity force, but just "cancels" part of it. What is left is enough to keep the body moving at the speed reached, but not to increase it.
The relation between force and movement from an inertial point of view is for the first time introduced during the third year in *Chapter 4. Motion and Force* (Revised Nuffield Physics, Year 3). The treatment is qualitative and intended to serve as a preparation for the more formal study of mechanics which constitute an extensive component of the fourth year. Chapter 4 also serves the purpose of introducing the pupils to the basic apparatus they will use in the experiments in mechanics such as trolleys, ticker-tape timers and friction compensated runways. In this chapter, as in the whole programme teachers are suggested to:

"... take FORCE as a basic well-understood quantity in dynamics. We describe FORCE as a push or a pull and expect pupils to accept the measurement of force by spring balances on stretched elastics threads. This differs from the professional convention that take MASS as basic and understood a priori, and defines force as MASS x ACCELERATION."

(Revised Nuffield Physics, Teachers' Guide, Year 3, p. 125)

What is referred to as a professional convention is one of the "scientists' science" interpretations of the relation between force, mass and acceleration (Section 10.2.4). Mass is, in its turn, considered a more unfamiliar concept:

"For O-Level pupils, we consider that force is something they can feel and we know that mass is an unfamiliar difficult concept. Indeed, we hope that by the end of the O-Level programme pupils will have gained a feeling for mass which will make it easier for them to understand space travel, atomic physics, nuclear energy, ..."

(Revised Nuffield Physics, Teachers' Guide, Year 3, p. 125)

On this particular issue, *Revised Nuffield Physics* departs from the other textbooks, which seem to assume
that mass is an easier concept, and that the only difficulty is to separate it from the idea of weight.

After an introductory part in which pupils are expected to observe the movement of bodies in inclined planes (by using trolleys and ticker-tapes) they are presented with a demonstration based on Galileo's "thought experiment" considering a ball rolling up- and-down between two inclined planes, and another demonstration based on a pendulum (Figure 10.2). Teachers are oriented to invite pupils guesses on the questions presented about the behaviour of the ball in the limiting cases of "no frictional forces" and "no slope at all". The conclusion reached by Galileo (that the ball will move on indefinitely) is then presented as a case of movement with no force. Again, the assumption in the presentation is that, once frictional forces are accounted for, Newton's first law, logically and immediately follows. This assumption is stressed in the teachers' guide. After remarking that in common sense physics, a body with no force acting on it tends to come to rest, it is pointed out that:

"That is just what an intelligent person would think if he watched things in ordinary life. Friction is all around us. No wonder the Greeks arrived at intelligent laws for motion controlled by friction."

(Revised Nuffield Physics, Teachers' Guide, Year 3 p. 138)

The Principle of Inertia is then demonstrated by situations in which bodies move under little effect of frictional forces such as a block of solid CO$_2$ or a brasspuck filled with CO$_2$.
Demonstration 63
Downhill-and-Uphill Motion

What would happen to a trolley which runs downhill and then runs along the level and then meets an uphill slope? See the demonstration sketched with a rolling ball instead of a trolley.

How would you explain this experiment's failure to give the simple result you might hope for?

Demonstration 64
Galileo's Pin-and-Pendulum Experiment

Three and a half centuries ago Galileo argued about that downhill-and-uphill experiment. He wanted to do it without any trouble from friction; and he succeeded. See Galileo's (almost) friction-less experiment.

Motion with No Force

A thought experiment. Feeling quite sure that the simple result is the true one, except for friction, Galileo carried out a 'thought experiment' in his head. You may call that just an argument; but in a way he was doing a proper scientific experiment because he was using information from other things he had seen.

He imagined the ball running down one hill and up another steep hill; then he made the second hill less steep; then still less steep until finally the second hill—in his imagination—did not slope at all. See the sketches. What do you think the ball would do in that last case, if it did not suffer any friction?
The concept of 'inertia' is introduced to account for the behaviour of bodies:

"Inertia: We say that every object possesses some 'INERTIA', some quality which makes it difficult to start or stop or accelerate. We believe that an object's inertia would be just the same on the Moon although gravity would pull it much less there."

(Revised Nuffield Physics, Pupils' Text, Year 3, p. 125)

And in the next paragraph inertia is equated with mass:

"A shorter name for inertia. We often say MASS instead of INERTIA. However, we still use the word 'inertia' because it reminds us of 'laziness' of matter, and MASS is the measured amount of inertia, measured in kilograms."

(Revised Nuffield Physics, Pupils' Text, Year 3, p. 126)

The rest of Chapter 4 deals informally with cases of movement under the action of a force such as the rectilinear motion of a trolley under a steady force, and the free fall of objects. At the end of the chapter, the idea of the independence between the horizontal and vertical motions of a projectile is introduced. Teachers are oriented to present these cases in an informal way regarding them as an induction for the more formal treatment of dynamics to be presented in the fourth year.

In the fourth year Section I. Mechanics, consists of five chapters, in which ideas introduced in the first three years are consolidated and extended in a formal and quantitative way. Newton's laws of motion are illustrated by experiments; the second law is considered in terms of momentum changes and the third law in terms of conservation of momentum. This knowledge is then extended in Section 2. Gases in which a mechanical model is applied to the kinetic
Chapter 1. Motion (Revised Nuffield Physics Year 4) deals basically with kinematical ideas such as motion, speed, acceleration and free fall. The experiments suggested make extensive use of measurements with the ticker-tape timer. In general the chapter can be considered as a revision of the material studied before. It was also designed to help pupils entering the scheme in the fourth year to catch up with the laboratory equipment (trolleys, timers, etc.) and procedures. In Chapter 2. Force, Mass, Acceleration (Revised Nuffield Physics, Year 4) the main aim is to introduce Newton's second law in the form $F = ma$. Pupils are expected to use (with the teacher's help) a mixture of hypothetico-deductive and inductive approaches to study (using trolleys and ticker-tape timers) the effects of mass and force on the acceleration of bodies. Concepts like mass, weight, gravitational field and acceleration of gravity are revisited. At the end of the chapter Newton's Second Law is applied to explain some paradoxes in fluidodynamics. Apart from the normal questions related to the experiments, a series of qualitative problems, involving the application of the expression $F = ma$ is also included. The treatment in Chapter 2, considers the Second Law only in relation to rectilinear motion.

Chapter 3. Newton's First Law (Revised Nuffield Physics, Year 4) is to a larger extent a repetition of the views and approach already presented in the third year. The First Law is stated and its anti-common-sense nature explained in terms of frictional forces acting in the real world. Galileo's thought experiment considering the ball and two inclined
planes is presented again and so are the demonstrations with the solid block of CO₂ and pucks. The need of treating the first as a separate topic is justified in the teachers' guide:

"Although we regard Newton's First Law as a special case of the Second Law, pupils do not recognize it as that - any more than did philosophers at the time of Galileo and Newton who found in it a change of view concerning the moon and the planets - a shattering denial of the current astronomical explanation. It seems wise to discuss the First Law with pupils as a separate topic."

(Revised Nuffield Physics, Teachers' Guide, Year 4, p.53)

The rest of the chapter deals with the concept of mass, its relation to inertia and its measurement. The section on mechanics in the fourth year ends with Chapter 4. Momentum; Conservation of Moment and Chapter 5. Kinetic Energy; Conservation of P.E. + K.E. The former presents the Second Law using the concept of momentum and links conservation of momentum with the Third Law; the latter deals with mechanical energy and its conservation.

The study of mechanics in Revised Nuffield Physics continues during the fifth year. Chapter 1. Motion in Orbit (Revised Nuffield Physics, Year 5) deals with circular motion and forces acting on a curved trajectory. Orbital motion of satellites is presented as an extreme case of projectile motion, following Newton's "thought experiment" of an orbiting cannon ball. The formulæ for centripetal acceleration and centripetal force in uniform circular motion are presented. This knowledge is used then in Chapter 2. Measuring Electrons (Revised Nuffield Physics, Year 5) for studying the movement of charged particles in electric fields perpendicular to the original trajectory. It is assumed that
at this stage, students would be able to dissociate the direction of movement from the direction of the force acting on the body. The study of non-retilinear cases of motion in Chapters 1 and 2, can be used by the teacher to check and reinforce this view.

Chapters 3, 4 and 5 are presented as home readings for students. They constitute an historical account of astronomical theories from the Greeks to the Newtonian synthesis, and were included in the specific purposes of showing an example of a physical theory (Newtonian Mechanics) being built and used. In the historical presentation the relation between the developments in mechanics and the changing views in astronomy is not fully explored. Although for instance the influence of the Galilean mechanics in Newton's work, mostly concerned with astronomical developments, is rightly acknowledged, the influence of Copernican astronomy in the shaping of Galilean mechanics is hardly mentioned.

10.5 Discussion

In this section I will discuss some aspects of the curricular treatment of force and movement in relation to "scientists' science" and "children's science". As in Section 8.5 the aim is twofold. First, the discussion is aimed at integrating and deepening some comments made in the analysis of the curricular materials; second, it intends to illustrate how a consideration of "scientists' science" and "children's science" can inform the analysis of "curricular science".
Although the presentation of the topic varied widely in the materials considered, there was one common logic underlying the introduction of the inertial view of motion, and that was related to the role played by frictional forces. This logic of presentation can be summarised in the following sequence:

a) A force is a "pull" or a "push". This builds on the intuitive association between force and muscular effort which is reinforced during the first years of secondary school.

b) A body at rest will continue at rest if there is not a resultant force acting upon it. A "common-sense" based proposition.

c) A body in movement will stop if there is not an apparent resultant force acting upon it. Another "common-sense" based proposition. In this case, however, the "common-sense" is deceived.

d) Bodies in movement are usually acted by non-apparent frictional forces. Therefore they tend to stop. This happens not because there are not any forces acting on the body, but because there are frictional forces opposing its movement. Therefore,

e) A body in motion will continue to move in the absence of acting forces, including friction.

f) Forces are used to change the speed or the direction of movement.
The implicit assumption in this logic of explanation is that, once aware of the effect of frictional forces, pupils will accept easily an inertial view of motion. However, as research on alternative conceptions (Section 10.3) and the analysis of the lesson extract to be presented in the chapter suggests, the assumption is doubtful.

A close look to the historical development of the scientific views about the relation between force and movement also indicates that the transition to an inertial view of force included for more than the recognition of the effect of frictional forces.

Early Aristotelians and more sophisticated "impetus" theorists were quite aware of the existence of friction. Aristotle, indeed, assumed that a "vacuum" could not exist and therefore friction was inherent in his theory of motion (Section 10.2.1). Nevertheless, Aristotelians and "impetus" theorists were quite able to accommodate, at least from a qualitative point of view, the existence of friction with the need of a force to keep a body in movement. A similar accommodation can occur in the case of pupils and some ways of doing it have been described in the last section (pp. 10-28 and 10-43).

More than the simple acknowledgement of the resistive effect of frictional forces, what the adoption of the inertial view of motion involved, was a change in the ontology of motion, that is uniform motion was given the same ontological level as rest: both were to be considered as states tending to be conserved, and therefore not needing to be explained.
In this new perspective only changes in movement need an explanation, hence the concept of force. Only one of the texts examined (Jardine's Nat Phil) mentions the change on what was to be considered "natural" and what not in relation to the transition to an inertial view of motion.

The main problem in the logic underlying the introduction of inertial view of motion, summarised above, is that it "puts the cart in front of the horse": an explanation of why moving bodies tend to come to rest based on friction, makes sense only in an inertial framework. For most children, intuitive "impetus" theorists, the problem of friction is actually not a problem, and the simple mention to it does not necessarily lead to a change of perspective as the analysis of the lesson extract to be presented in the next chapter illustrates. Although all the curricula examined do, actually, refer to the anti-intuitive nature of Newton's First Law, the reason for it is located in the wrong place. The inertial point of view does not simply offend common sense because people are not aware of friction, but because it situates uniform motion and rest at the same ontological level.

If curricular presentations were more historically orientated some of the pupils' difficulties in accepting the inertial view of motion would become more clear for them, and for the teachers. The a-historical character of the "curricular science" presentations have already been commented on when analysing the materials. The traditional texts (Abbot's and Nelkon's) convey the impression that the study
of motion, started with Galileo and Newton. But even Revised Nuffield Physics and Jardine's Nat Phil, although mentioning Aristotle's views do not refer to the "impetus" theory. From a constructivist point of view, this is critical, since "children's science" accounts for the relation between force and movement seem to be similar to the ones put forward by "impetus" theorists. Moreover, the connections between the development of the inertial view of motion, and parallel developments in astronomy are not properly considered in the curricular materials analysed. Nevertheless, Galileo's views on motion were a product to his commitment to a Copernican Universe, rather than induced by experimental results, as for instance it is suggested in Jardine's text.

10.6 Summary

In this chapter I have presented:

1) An historical overview of the development of conceptions concerning the relation between force and movement ("Scientists' Science").

2) A review of the literature on alternative conceptions about force and movement ("Children's Science").

3) An analysis of textbooks' presentation of this relation ("Curricular Science").

It is shown with the use of examples of these reviews and emphasis, that:

a) There are aspects in which it can be suggested that "children's science" parallels pre-Galilean conceptions of motion.
b) That although "curricular science" does acknowledge the anti-common sense nature of the inertial view of motion as expressed in Newton's First Law, the source of the problem is misplaced. This misplacement leads to a logic of presentation of the inertial view which was criticized.

c) The source of this misplacement can be related to unwarranted assumptions concerning the historical development of the scientific conceptions of the relation between force and movement.
CHAPTER ELEVEN

CASE STUDY II: FORCE AND MOVEMENT

(Analysis of a Lesson Extract)
11. CASE STUDY II: FORCE AND MOVEMENT (Analysis of a Lesson Extract)

11.1 Introduction

The lesson extract analysed in this section consists of a sequence of about 20 minutes long dealing with the relation about force and movement. The class and the teacher are the same described in Section 9.1. The lesson was the last one for that fourth-year group in the summer term 1981.

In the lesson immediately before the one analysed here the pupils were asked to answer the questionnaire used in Watts and Zylbersztajn (1981) survey of children's ideas about force (see Section 10.3). The teacher knew of the existence of the questionnaire, and asked me if she could apply it. She told me that she thought that it was more interesting to try to do this (with a diagnostic purpose) than to start a new topic. She also told me that the group was not taught the topic before, and that mechanics would be the first unit of the next year.

Although the lesson analysed is probably not typical (lessons at the end of term seldom are), its analysis is included because it highlights certain problems that teachers can face when teaching the topic under consideration.

In the extract presented, the discussion is concerned with a situation involving the movement of a cannon ball (Fig. 11.1). The analysis follows the same pattern of the one presented in Chapter 9, and described in Sections 7.4.
and 9.1. The analysis starts on Transaction 3 of the lesson (Exchange 032), which was the one in which the relation between force and movement started to be considered by the teacher. Until this point of the lesson the discussion was concerned with other items of the questionnaire and was related on the effects of gravity in bodies on the earth and on the moon.

![Diagram of the cannon ball question](image)

**Fig. 11.1 The cannon ball question.**
11.2 The Analysis

**TRANSACTION 3**

032 B Fo T). Now that's one thing.. there's another thing... some of you seem to think that you're very good at doing remote control forcing...
let's look at the cannon ball one please.. a cannon ball opening picture......

033 I O I will simply read what is written underneath... a cannon ball is fired from the common....
it's been fired from the cannon it's not in the time of what you're considering... in the cannon being exploded it's been fired.. from the cannon... now lots of you seem to think... that.... the power you know that several of you.. answered for the first diagram there... first question on that one... yeah lots...

034 Ch O put your hands up if you've answered A
A Ss). NV (majority put hands up)
F T). Yeah well that seems a fair consensus of opinion

035 I O if I tell you it's not then an awful lot of people is going to disagree with me...

036 P-E O B). Why is it not A then?

037 E O T). Well can you now give any arguments as to why it's not A... or rethink it
A B). (Robert) You said that
F T). Well because I said is not good enough Robert it won't do

038 P-I O B). (X) You see the ball is pushed out but it needs the force of gravity to pull it down the gravity
F T). You shut off the gravity for one thing

039 Ch O do you agree?
A B). (X) Yeah
F T). You shut off the gravity

040 I O gravity is acting... all the time... and it will be acting on the cannon ball... while it is in its flight... so remember gravity for one thing...
but you said things like... hum having answered A... the force as it passes through A is that put on it by the cannon firing it forward...
now I think perhaps it wasn't quite clear enough to you in the opening picture... that it had been fired from the cannon and fired on over..
so this is like to when you bowls and the ball has left... your hand and is in its flight...
now could you rething that situation .. you know imagine you're bowling and the ball has left your hand .. and is in flight .. that's the situation we want you to consider

P-I 0 B). (Roberts) I don't agree with you miss

T). Tell me Roberts?

P-E 0 B). What's going to be then?

A B). (Roberts) You're saying .. when you launched the stone then it's pulled by gravity ...

(2 boys talking at same time: not understandable)

T). What does gravity do to it?

A B). (Roberts) Bring it down

F T). Yeah

P-E 0 B). Why it goes straight down? Why?

A B) (Roberts). It forces

F T). I admit it's still going up

T). If it stops in midair/  

P-I 0 B). (Y) In that picture there .. it's still going up

P-I 0 B). (Roberts) Still going up .. and onwards

T). I admit it's still going up

P-I 0 B). (Y) And the forces are pushing it

F B). (Roberts). Yeah

B). (Y) I mean you've got it that it forces that way

F Ss). Yeah

(Various pupils talking about question)

P-I 0 B). (Roberts) Point B is going up and C is coming down

P-I 0 B). (Y) At point A it's still going up isn't it?

P-I 0 B). The force is going up is pushing it up miss
056 Oth O T). Right...
  ...such a minute ...... 147 m 148 oth

057 P-I O B). So according to you miss it wouldn't go any higher than A? 149 i

F T). No way no way no way 150 e

058 E O B). What does the explosion in the cannon or in your hands you know when you wave the ball...what does that do to the ball?...the explosion in the cannon let's say what does that do to the ball?...

A B). Forces it
B). Pushes it in an upward direction
B). Forces it to go in the direction of the cannon 153 rep 154 rep 155 rep

059 E O T). Gives kinetic energy? 156 e

A Ss). (Laughs) 157 oth

060 E O T). Hum......
  without that explosion...what had the cannon ball done? 158 m 159 e

A B). Nothing
B). Stop
B). Come down
B). Stay where it was

(Various pupils talking about question)

F T). Stay where it was right?
  it would have stayed in the cannon this is why we're trying (NOT AUDIBLE) you know nothing happens...the cannon ball would stay in the cannon...

164 e

061 E O T). Hum...
  moving? 166 m 167 e

A B). No...no power 168 rep

F T). Stationary... 169 e

062 E O T). speed? 170 e

A Ss). No 171 rep

F T). No..OK? 172 e

063 E O T). what does the explosion do to that cannon ball?...

A Ss). Pushes it out 175 rep
B). The force has been across 176 rep
064  I  O  T). Speed?.. gives it speed doesn't it? gets it moving .. gives it kinetic energy .. gets it moving .. hum gets the cannon ball moving gives it speed .. OK? . and it's a pretty blast force so .. if you're sitting on the cannon ball you'll be aware of the awkward joilt in the back wouldn't you? 177 i

065  E  O  . hum . what do physicists call that sort of jolt? .. or in a car you suddenly get .... 178 com 179 m

066  I  O  . acceleration is the word we use isn't it? when you build up speed when you get an increase in speed we use the word acceleration .. and the explosion on the cannon ball suddenly changes it from having no speed .. up to blasting out like hell so that it really .. gets a big acceleration .. during that explosion ... 180 el 181 i

067  Ch  O  . now . you .. feel that that goes on acting .. while it's moving upwards ...... 182 m 183 ch

A  B). It is isn't it? 184 rep

068  P-I  O  B). If it didn't it would come straight down 185 i

F  G). Yeah yeah straight down 186 e

069  P-I  O  B). It's still in it 187 i

070  P-I  O  B). (Roberts) You're wrong 188 i

Ss) (Laugh) 189 oth

F  T). You're all convinced it's there obviously 190 com 191 m

071  E  O  . hum .. . but the feeling is .. I mean it's a bit .. like .. if you've got your massive greater container truck accelerated and on move .. . what is quite difficult to do to that container truck? 192 s 193 el

A  B). To stop it
B). to stop 194 rep 195 rep

F  T). It is just as difficult to stop something as it is to get it going .. you know and you need a hectic force to stop a container truck .. you need a hectic force in a sense to stop a cannon ball 196 com

072  E  O  . and what have we got acting to stop our cannon ball? 197 el

A  B). The ground
B). gravity 198 rep 199 rep

F  T). OK . that's not all ..... 200 acc 201 com

073  Re-i  O  . I'm allowing other forces it's not all .. gravity 202 el

A  B). The wind 203 rep
The transaction starts with the teacher commenting on
the pupils' answer to the questionnaire (Ech 032). It is
clear from her comment that she was able to notice that the
majority of the pupils attributed a force in the direction
of the movement of the cannon ball, and that is a fairly
expectable result in the light of the amount of evidence
on the nature of "children's science". It is interesting to
notice that, when commenting on the answers given by the
pupils, the teacher uses a metaphor ("remote control forcing").
The metaphor is unfair and in one sense downgrades the
pupils' thinking, since they are not thinking that they can
control the force on the ball. What they are using is in
reality a sort of "impetus" theory explanation (see Section
10.2.2).

In Exch 035 she begins her transmission of "teachers'
science", by stating that the first diagram was not the
correct answer to Question 4 (see Figure 11.1). The way in which she states it indicates that she is aware that the pupils have a strong adherence to their alternative conceptions. The immediate elicitation from one of them (Exch 036) confirms it.

Instead of answering the question posed by the pupil she re-directs it to the class (act 111). It is important to notice the way in which she phrases the question. Instead of asking why the pupils think as they do, that is, why they think that the answer is A, she prefers to ask for arguments about why the answer is not A. One boy's (Roberts) answer (act 112) reflects the hidden curriculum behind transmission teaching. In this case the teacher cannot accept such an overt statement, and she presses on with the question (act 113).

The information does not, however, come from Roberts, but from another pupil (X), who advances the notion that the force of gravity must be acting as well. This answer pleases the teacher and she can start elaborating on the "right" ("curricular science") direction as Exchange 040 shows. It seems at that stage that she believes that one source of problems for the students is the fact that in Question 4 the ball is still very close to the cannon, giving the impression that it is still under the action of the blast. Therefore she presents the bowling analogy (act 122) and invites the group to think about this situation (act 124), in which the separation between the thrower and the projectiles is clear from the very beginning. The move is sound since it presents to the
pupils an equivalent situation that most of them experienced.

The pupils' problem, however, is not the one identified by the teacher. According to their alternative conception, a force must act in the direction of movement and that force was impressed to the body by the blast of the cannon, as the sequence of exchanges from 042 to 057 shows. Especially illustrative are the statements made by pupils on acts 137, 138, 140, 142, 144, 145, 146, 149. It is also important to notice the fact that the majority of exchanges in this sequence are pupil initiated. This flow of information from the class is blocked by the teacher's negative evaluation (act 150). This is an example of the teacher exerting control over the nature of classroom knowledge: the display of "children's science" (even in a diagnostic situation) does not seem to be acceptable by this teacher (at least in this particular case) as a relevant part of classroom discourse.

At this point the teacher changes her form of presentation, and the sequence of Exchanges 058 to 067 follows the teacher-elicits and teacher-informs pattern. She tries to introduce specialized language - "gives kinetic energy" (act 156), but the class reaction to this attempt of conducting the conversation in terms of "curricular science" concepts is negative (act 157). Nevertheless the term is used again by the teacher (act 177) and linked to the concept of acceleration (act 181). The sequence of Exchanges 067 to 070 shows that the attempt to conceptualize the problem in terms of "curricular science" concepts was not very successful. The teacher sees the action of the cannon as giving
kinetic energy to the ball or accelerating it and the pupils see the blast as giving a force to the ball; it is clear that they are sort of "cross-talking" with the teacher. She is thinking according to a classical mechanics framework and the pupils according to a pre-Galilean "impetus" theory framework. The comment by the teacher in Exchange 070 shows that she is aware that her message is not getting across.

Failing in her attempt to get her explanation in terms of kinetic energy and acceleration accepted, the teacher now tries a different trend, by analysing the cannon ball movement along its horizontal and vertical components. In Exchanges 071 to 076 she manages to elicit from the pupils that the effect of the force of gravity is to stop the ball rising.

**TRANSACTION 4**

<table>
<thead>
<tr>
<th>Exchange</th>
<th>Turn</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>076</td>
<td>B Fr</td>
<td>T) OK</td>
</tr>
<tr>
<td>077</td>
<td>E O</td>
<td>if gravity stops it rising .....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>what other sort of motion has it got other than sort of rising falling vertical sort of motion what we've used to consider as well? ...</td>
</tr>
<tr>
<td>078</td>
<td>I O</td>
<td>forward motion don't we</td>
</tr>
<tr>
<td>079</td>
<td>E O</td>
<td>what about forward motion? what stops it sort of orbiting the earth straight away?...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A B) The weight of it</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F T) We've got gravity pulling it down haven't we?</td>
</tr>
<tr>
<td>080</td>
<td>E O</td>
<td>but what hum .. what in a sense yeah what stops it going on forward?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A B) The air</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F T) The air .. OK? the resistance of the air because if you bring your arm over you're aware of that aren't you you can feel .. the resistance of the air the force of air .. acting on you so hum .. air resistance .... in a sense acts backwards on its forwards motion stops its forward motion</td>
</tr>
</tbody>
</table>

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11-10
what else will tend to stop its forward motion if you look at it... on bowling?

A) Something in the way

F) Yeah you know if you club something on the way yeah it could be... the bat you know the batsman over the cricket bat

or?

A) The three

F) Here the three

or?

A) The ground

F) Hits the ground or it hits something... it collides with something which stops... so air resistance will stop its forward motion... and also anything it hits on the way... so the forward motion is reduced by... air resistance... forward motion then is reduced by air resistance... or by... hitting something e.g. three cricket bat, ground... and his head...

actually I suppose it isn't just gravity that stops the groundward the downward motion is it?

what else stops the downward motion?......

). (NOT AUDIBLE)

B) (Laugh)

B) The ground

Yeah apart from gravity... hum no... gravity was stopping its upward motion wasn't it?

(NO AUDIBLE)

gravity was stopping its upward motion... hum... coming down... it's when it hits the deck... that it hum... stops it downward motion...

You need something to stop it....

Right... (lowering voice)
informative act (act 215) or mainly in the follow-up moves of the eliciting exchanges.

The discussion in terms of resistive forces makes sense in terms of the teacher's framework. She knows that there are no forces in the horizontal (forward motion) direction sustaining the movement, and that the stopping of the cannon ball must be related to the action of resistive forces. The idea, however, can also be interpreted in terms of the pupils' alternative conceptions, since the existence of the resistive forces is not incompatible with the notion that a force, impressed by the cannon ball on the ball, is acting in the direction of movement. For the teacher the horizontal component of the movement is completely explained in terms of the resistive forces; for the pupils the "impressed force" must be considered as well. The situation here parallels the one in "curricular science" in which resistive forces are considered in order to introduce the Principle of Inertia (see Section 10.4.5), and the same comments can be applied.

**TRANSACTION 5**

<table>
<thead>
<tr>
<th>B</th>
<th>F'T</th>
<th>T</th>
<th>248 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>087</td>
<td>Fr</td>
<td>T</td>
<td>Now ...</td>
</tr>
<tr>
<td>Fo</td>
<td>I realize that I haven't convinced you that thehum the cannon doesn't act once the blast is over ...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>088</th>
<th>O</th>
<th>249 com</th>
</tr>
</thead>
<tbody>
<tr>
<td>but if you think of bowling ... what I'm suggesting to you ...... is that .. you can only force the ball .. and accelerate the ball .. while you're in contact with it .... you can only be active on the ball while you're in contact with it while it's still in contact with your hand .. that's when you've got to do your work .... and I'm suggesting that once it leaves your hand you haven't got a remote control sort of .. hum ...</td>
<td>250 i</td>
<td></td>
</tr>
</tbody>
</table>
B). Psychic

T). Force on the situation on the ball you haven't any more.. once it leaves your hand.. the ball is at the mercy of these other forces that we've been talking about it's at the mercy of gravity... it's at the mercy of.. air resistance.. it's at the mercy of other things it hits

E O 

Roberts do you still feel that remote control.. you know your superforce are you you can act after you stopped touching the ball?...

A B). (Roberts) No.. but the force you put into the ball carries on going in that direction and that is what I want to say put it in that way gravity won't pull it straight down

F B). Yeah

P-I O B). It comes down gradually

T). I would like to do a swap.. in ideas there.. hum... in that your force acts while you're in contact with it while you can actually force it... what you do is to give the ball speed you accelerate it.. and then

Ch O 

would you agree?..

A B). Yes

T). They've both got mass.. they've both got substance and stuff they're the same ball but while sitting on the deck and it's stationary and not doing anybody much harm.. we say no speed.. and not momentum.. whereas one we're sending along with speed we say it's different in the sense that it has got.. this momentum... so that's the word we.. use and you know you'll get more used to.. for something with speed in motion we say it's got momentum

P-I O ). (NOT AUDIBLE)

T). That's right... OK?

I O 

and it's that momentum you've got to deal with in that content container truck coming towards you it's got massive mass and I I mean lots of mass and lots of speed.. so you're in great trouble eventually because you've got this big
mass at a big speed coming towards you. you've got to do something with that momentum...

I suggest you don't try I suggest you keep out of the way...

but something has to take its momentum away and stop it again and get it back to a momentum sort of...

100 P-I O B). (Roberts) But won't happen straightaway

F T). No takes time I agree takes time

101 P-I O B). (Roberts) And that's where you've got it wrong

102 P-E O T). Hum no the force of you on the ball can stop very quickly... when you had bowled it... it picked up momentum and it's got lots of momentum which it gradually loses... due to the sort of forces acting on it

103 P-E O B). What about the next?

104 P-E O B). Yeah the next one on the

105 Oth O B). (Roberts) No (NOT AUDIBLE)

(Various pupils talking at the same time)

The teacher shows awa mass that the pupils' concepts have not been very much shaken by her arguments (act 249). She returns to the cricket bowling analogy (act 250) which is awa to the pupils' experiences and can provide them with a kinesthetic feeling for the situation. She also uses again the "remote control" metaphor (Exch 091) in her attempt to convince one of the pupils (Roberts). The eliciting question (act 253) is phrased in a way which downgrades the boy's thinking ("remote control", "superforce"). Roberts' answer however shows that he is not impressed by this tactic, and he provides a sensible explanation from the point of view
of his alternative conception. He makes clear that he is not thinking in terms of "superforces" or "remote control" but that a physical force is transmitted by the thrower to the ball, which is a conception that was held for centuries by scientists working in the framework of the "impetus" theory. The explanation is supported by some of his peers (acts 255 and 256).

In Exchs 093, 095, 097 and 099 the teacher explicitly presents the curricular explanation. These four exchanges consist basically on relatively long pieces of information supplied by her, in which another attempt of conceptualizing the problem in terms of specialists' language - "momentum" - is carried out. It is easy to see, from the observer's privileged position, that the mere swap of words (to use the teacher's term, act 258), would not be very helpful in changing pupils' conceptions, as their statements (acts 269, 271 and 272) show.

### TRANSACTION 6

| 106 | B | Fr | T). Yeah ...
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fo</td>
<td>hum let's just clear the first one</td>
</tr>
<tr>
<td>107</td>
<td>P-E</td>
<td>O</td>
<td>B). So what should be?</td>
</tr>
<tr>
<td>A</td>
<td>B). No forces it should be ..</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 108 | I | O | T). Yeah
|     |   |   | . I might allow you ..... |
|     |   |   | . fourth years .. |
|     |   |   | . we haven't got a page reference page references would be nice won't it?... |
|     |   |   | . the first hum ... first one after the cannon ball right? first one there the A one .. |
|     |   |   | . yeah A one that's right so we have a reference .. |
|     |   |   | . looking at the A one .... the main force acting is gravity ... so that answer .. for the downward force acting on it .. that's the main force acting on this ball in .. mid air .. |
In this transaction the teacher summarizes the discussion by presenting the answer to the question presented in the questionnaire. According to her the fourth picture (only gravity acting) is the best answer, but she observes that if air resistance is considered the next picture would be a good representation of the situation (acts 298 and 300). It is illustrative to notice the words she uses when making this last point - "I would also allow..." - which shows an instance of explicit control of knowledge by the teacher in
the classroom.

The presentation of "teacher's science" to the class was completed. The general feeling, however, is that the pupils' conceptions were not very much changed as the statement from one boy (act 299) and the discussions among pupils which followed the presentation indicate.

11.3 Discussion

The aim of this section is to summarize and to extend some of the points disclosed in the analysis of the lesson extract. In the discussion, I will follow the same pattern of presentation of Section 9.3, considering initially aspects related to the form of the interaction and in a second stage aspects related to its content.

11.3.1 The Form of Interaction. The results of the socio-linguistic analysis of discourse, summarized in Table 11.1, shows the frequency of the different types of exchanges identified.

<table>
<thead>
<tr>
<th>Type of Exchange</th>
<th>B</th>
<th>E</th>
<th>Re-i</th>
<th>I</th>
<th>Ch</th>
<th>D</th>
<th>L</th>
<th>P-E</th>
<th>P-I</th>
<th>Oth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency %</td>
<td>06</td>
<td>24</td>
<td>01</td>
<td>18</td>
<td>06</td>
<td>02</td>
<td>02</td>
<td>10</td>
<td>28</td>
<td>03</td>
</tr>
</tbody>
</table>

Table 11.1 Frequency of Types of Exchange

Again, as in the extract analysed in Chapter 9, practically all the exchanges (97%) were identifiable according to
the categories proposed by Sinclair and Coulthard. The only three exchanges which were classified as others consisted of one in the teacher exerting disciplinary control (Exch 056) and in the other two the teacher was interrupted before completing his utterance in one case (Exch 048) and an inaudible utterance in the other (Exch 105). Again, it can be said that the high percentage of identified exchanges, moves and acts allows to conclude that the system was adequate for the task.

The relative frequencies of exchanges show a more even distribution between teacher initiated and pupil initiated exchanges. Although the number of teacher initiated exchanges is greater than the number of pupil initiated ones, the latter accounts for 38% of the total number of exchanges, which indicates that the interaction was not dominated so much by the teacher as in the extract analysed in Chapter 9.

One of the reasons that may have contributed towards this more even balance of power, is the fact that the lesson was based on a diagnostic questionnaire, previously answered by the pupils. Therefore they had the chance to think beforehand about the topics to be discussed, and were also aware of the possible directions in which the lesson could proceed. On the other hand it must also be considered that force and movement is a topic on which pupils tend to have quite solid alternative conceptions, which, given the chance, are likely to emerge explicitly during a lesson. More possible, still, is that the consideration of both factors, the answering of the questionnaire, and the well established alternative views,
can be seen as the reason for the relatively high number of pupil initiated exchanges.

11.3.2 The Content of the Interaction. In the lesson extract analysed, there is a clear resistance shown on the part of the pupils (at least by those voicing their point of view) towards the inertial explanation of motion presented by the teacher. The teacher deals with this open "defiance" to her control of knowledge using several strategies.

In two instances she gently downgrades the reasonable "impetus" type explanation advanced by the pupils in the questionnaire. This is the case of Exchanges 032, 088 and 091 in which she uses the "remote control" metaphor.

A second strategy is simply the use of negative evaluation in order to interrupt the flow of "children's science" (Exch 057).

A third strategy is to resort to the use of specialists' language in the presentation of "teachers' science" as when she introduces words like "kinetic energy", "acceleration" and "momentum".

It would be unfair and misleading to give the impression that the teacher is only trying to gain control over the knowledge being presented in the classroom and, in the process, making use of strategies based on her intellectual authority. It is noticeable that she also makes use of argumentative strategies, trying to defuse what she sees as the source of
the pupils' alternative explanations. In this case her efforts to make clear that, in the problem under consideration, the ball had already left the cannon and the resort to the cricket bowling analogy. It is also the case of her attempts to analyse the motion of the cannon ball in terms of its vertical and horizontal components. But this sort of analysis presupposes already an inertial view, i.e. that in the ideal situation, no force is needed to keep the ball moving in the horizontal direction.

From a constructivist perspective, I would argue that the teacher should have shown a more respectful attitude towards the "children's science" advanced. She could have even encouraged them to spell these views in a more articulate manner, and make clear to them that similar views represented respectable constructions during a long period of the history of mechanics. Considering that the lesson was the last one of the term, she could have hinted that these views, although reasonable, were transformed in the course of scientific development, leaving the introduction of the new view for the following term.

In the case observed, however, what was noticed was a head to head collision between "teachers' science" and "children's science", or more precisely between the inertial based interpretation of the teacher on one side, and the "impetus" type interpretation of the pupils on the other.
11.4 Summary

In this chapter an extract of a lesson dealing with an aspect of the relation between force and movement was analysed. Although the lesson was not typical (it was the last of the term and it was based on a diagnostic questionnaire) some features of it were illustrative of one pattern that the interaction between "teachers' science" and "children's science" can assume.

In the case presented the teacher was quite aware of the fact that the pupils' interpretations were divergent with hers. Nevertheless she tried strongly to impose her interpretation. The development of the lesson showed a collision between two views - one based on the "Principle of Inertia" held by the teacher and one similar to the "impetus" theory held by the pupils.
CHAPTER TWELVE

CASE STUDY III
12. **CASE STUDY III**

12.1 **Introduction**

This chapter consists of the presentation of a case study centered on a physics lesson observed in a third-year class of a comprehensive school. The central focus of analysis is on the interaction between "children's science" and "teachers' science", but consideration is also given to the relation between "curricular science" and "teachers' science" by discussing the transformation from the former to the latter in the specific context analyzed. The approach adopted follows the general lines of case study methodologies discussed in Chapter 7.

The sequence of presentation starts with a section in which the context and the methods for collection and analysis of data are discussed (Section 12.2). This is followed by a section in which the lesson observed is analyzed in terms of the interaction between "teachers' science" and "children's science" (section 12.3), and a discussion of some aspects derived from this analysis (Section 12.4). The presentation of the case study ends with a discussion of the transformation from "curricular science" to "teachers' science" (Section 12.5).

12.2 **Context and Methodology**

12.2.1 **The Context.** The group observed was a third form composed of 19 girls and 9 boys plus a young male teacher. The pupils were doing physics as a compulsory subject. The class was considered by the teacher as being well behaved
consisting mainly of academically oriented pupils, ranging from medium to high ability.

The teacher, after obtaining a degree in physics, had spent one term on a teacher training course, leaving it for economic reasons. He then started teaching and at the time of the observations was in his third term of teaching.

The physics department in the school had introduced the Revised Nuffield Physics schemes for O-Level, from the third year onwards recently (one year before the observations took place). The topic being presented to the group during the term in which the observations took place (autumn term/1980) was optics, following the sequence of Revised Nuffield Physics, Year 3 (Rogers and Wenham, 1976).

I started my observations in the third lesson of the term, and was present in a total of eight lessons. The one analyzed in this case study was the fifth of the term. It was selected for presentation because it is a quite typical one in the context of secondary school physics at CSE and O-Level - a double period including a demonstration, practical work based on a worksheet, and sequences of formal lecturing. Secondly, the group observed and tape-recorded during the lesson, was actively involved in the task and apparently talking freely in spite of the presence of the tape-recorder and the observer. Thirdly, the quality of the recording was so reasonable to allow for a transcription of most of the interactions. It should be remembered that the last two conditions are not always met in real classroom situations, particularly when practical
work is being conducted.

In order to put the lesson analysed in context a summary of the previous lessons follows:

**Lessons 1 and 2:** The concept of wave was introduced in the first lesson and in the second the pupils did some practical work using the ripple tank. I was not present in those lessons.

**Lesson 3:** The pupils experimented with a [pinhole camera](https://en.wikipedia.org/wiki/Pinhole_camera), a device which they were acquainted with from the second year. They were asked to answer a list of questions presented by the teacher on the blackboard. They did not finish the task and were asked to complete it at home.

**Lesson 4:** The teacher started the lesson by commenting on the homework, after which he started a demonstration using the "smoke-box" apparatus (Demonstration 8, Revised Nuffield Physics, year 3). After trying for 20 minutes to make the apparatus function, he gave up and explained what should have happened to the light rays in the box on the blackboard. He then presented a second demonstration showing the change of the image position when an object is moved backwards in relation to a convex lens.

After the demonstration the teacher displayed some old cameras on his desk and asked the pupils to examine them. As homework they were asked to compare the camera and the eye, concentrating on similarities and differences between them. The teacher advised the pupils to go back to their second-year notes for information about the eye.
This lesson and the previous one were not tape-recorded because it was agreed with the teacher that it was better to get the class used to my presence before introducing the tape-recorder.

12.2.2 Methodology. In the lesson observed two tape-recorders were used. One was placed on the teacher's desk in order to register the interaction between him and the class as a whole. The second was placed on the desk of a group in order to register their verbal comments during the practical and their interaction with the teacher. I stayed nearby taking notes. The tapes were then transcribed and the transcripts complemented with the notes taken (e.g. on handling of the apparatus).

The transcript, which can be regarded as a reconstruction of the lesson from the observer's point of view, constituted the basic material for the analysis, although in the discussion some material from two interviews with the teacher is also included.

Three types of interaction were observed in the lesson:

a) group interaction - the pupils working by themselves during the practical.

b) teacher-group interaction - the teacher interacting with the group

c) teacher-class interaction - the teacher interacting with the class as a whole.

In case c) the analysis followed the same lines of the ones presented in Chapters 9 and 11 (discussed in Chapter 7). In cases a) and b) the transcript was divided
in Episodes according to the type of interaction involved. For instance, Episode 1 consists of a discussion between the members of the group (group-interaction). At the moment that the teacher joins the group (teacher-group interaction) a new episode was considered to start. The concept of "Transaction" was only employed when considering teacher-class interaction since Sinclair and Coulthard's scheme for analysis of discourse was designed specifically for this type of interaction. Both episodes and transactions are followed here by comments.

The quality of the recording was, in general, very good when the teacher was talking. During teacher-class interactions, however, the pupils' utterances were not always audible. The tape-recorders were not sensitive enough to a combination of long distance and low voice.

The major difficulty was to transcribe the recording of group-interaction. The two main problems being the background noise which normally occurs during practical work and the difficulty in identifying the authors of utterances in a group. When, during a discussion, it was possible to recognize the voice of a pupil in separate moments, this was signalled in the transcript by using arrows. Particular utterances, which are referred to in the comments after each episode are preceded by an identification number.
12.3 **Analysis of Lesson 5**

During the first 15 minutes of the lesson the teacher repeated the "Smoke-Box" demonstration that failed in the previous lesson, being more successful this time. During the demonstration the teacher switched off, accidently, the power supply of the tape-recorder that was on his bench. Therefore this part of the lesson is not analysed.

After the demonstration the pupils were asked to collect the apparatus for the practical work and were also given a mimeographed worksheet (Fig. 12.1) with instructions and questions. I placed a small tape-recorder on the desk occupied by a group of four girls who were starting to do the practical, and stayed nearby observing them and making notes about details of their work.

**Episode 1**

(With the equipment being arranged, two of the girls start reading item a) of the worksheet)

- Set up the apparatus as shown above. Where would the screen of the camera have to be to get a well focussed image of the light light source?
  - And the camera? Where is the camera? This is the camera?

(1.1)

(The girl switches on the light source and starts moving it)

- Watch there's the light if it goes forward (NOT AUDIBLE) if it goes back it is quite sharp.
  - Yes
  - Far away it is pretty sharp isn't it?

(20 seconds later another girl starts reading item b) and is joined by other members of the group)

- Move the light source closer and further from the lens. What happens to the focus in each case?
  - Further the focus point gets sharper and near
A Model of the Camera.

(Important: Run the lamps off a 12 volt supply - no more!)

Light Source.

Imagine that you have a pinhole camera with a large number of holes in the front. These holes are represented by the gaps in the metal comb.

(a) Set up the apparatus as shown above. Where would the screen of the camera have to be to get a well focused image of the light source?

(b) Move the light source closer and further from the lens. What happens to the focus point in each case? How does a camera focus on close objects? (How does the lens have to be moved?). What happens in the human eye to focus on close objects?

(c) How good is the focusing in our model of the camera? Block out the rays of light that go through the edges of the lens (this is like reducing the aperture of a camera). Does this improve the focusing?

Can you explain why cheap cameras have such small character lenses?

(d) What advantages might there be in having a camera with a large aperture? (Expensive cameras have lenses that are good enough to give good focusing even with a large aperture.)

Fig. 12.1 The Worksheet.
(One girl puts the metal comb behind the lens and supported by it, while another moves the light source)

- When the .. when we move the camera away from the lens
- When the camera is focussed
- Is near the lens
- Near the lens
- When you move the camera near the lens your focus point is further away
- Yeah
- When the camera is moved away from the lens .... hum ...
  this point gets near

(The girls start to write down what they have observed and two of them speak while writing)

(1.2) - When the camera is moved away from the lens .... the ...
     focus point .. near the lens .. lens
(1.3)' - When you move the camera away from the lens the focus point is near the lens and when you move the camera away ...
     near the lens .. lens .. the focus point
- Is further away
- Is further away from .. the .. lens.

In this episode the group was trying to follow simply the instructions on the worksheet. Nevertheless some discrepancies between these instructions and the performance by the group were noticeable. The diagram on the worksheet shows the metal comb placed between the light source and the lens, a set up designed to create ray streaks of light. The girls placed the comb behind the lens, however, therefore missing its function in the experiment.

The group also moved from item a) to item b) without discussing the question presented in the first item. This was due to the action of one girl who started to move the source of light and to comment about her observation (1.1), while the other members of the group were still reading item a). Her action shifted the attention of the group to item b). By concentrating on item b) the group managed to observe correctly (and quickly) the qualitative relationship
between the displacement of the object and the position of the image.

On the other hand, the premature focussing on item b) led the group to not consider the analogy with the camera, which was the central point of the experiment. The details of the analogy were, at this stage of the practical work, completely missed by the group. That is clearly shown by the way in which the girls started their discussions (1.2 and 1.3), when they refer to the light source itself as being the camera.

**Episode 2**

(Just after the events described in Episode 1 the teacher is passing near the group and is asked by one of the girls to help the group with the second part of item b))

(2.1) T) Right ... a close object isn't it? Right.... suppose we move that ... here we are

(The teacher corrects the position of the metal comb)

T) Right .. that's what we must have to start off ... OK?
   - Yeah

(2.2) T) Say you put the screen there
   - Yeah

(2.3) T) Now suppose you're bringing very close .. what happens?
   - Further away.
   - The focus point goes further away.

(2.4) T) Right .. so how might ... we focus that?
   - Move the
   - Move the lens further away
T) I've got I've got to bring this back here, haven't I?
   That .. I've got to bring this point back to that.
   - Move the ... lens back to a point.

(2.5) T) That's right .. if I bring the lens back I move this point back .. that's what a camera does .. you see .. when you've got a lens and you try to focus on the near close the lens move out.

(2.6) - My dad turns the thing where he's got the lens.
T) That's right .. moves the lens out ... and then if you're photographing a far away object
   - Yeah
   T) Like that
   - Yeah
T) You have to move the lens back
How does the lens have to be moved? In and out? (2.8) T) That's right .. backwards and forwards because you can't move the screen and you've got to move one of them .. you've got to try to keep that cross point there .. that focus point ... on the screen.

So how does the camera focus on close objects? (2.9) - By moving the lens.

By moving the lens backwards and forwards ... in fact by moving the lens forwards ... that's how we focus on .. on closer objects

---

The help of the teacher was asked for when the requirements of the task changed from an answer based on direct observation to one involving application of a relationship to the real situation modelled by the apparatus (the camera). It is relevant to notice that the girl called the teacher before the group had discussed the question.

The teacher started his intervention by correcting the position of the metal comb (2.1) without, however, making any comment about it. The implication is that for the teacher the comb is a minor detail in the experiment.

The teacher mentioned, very briefly, the position of the "screen" (2.2), a point not actually discussed by the group. He was, probably, taking for granted that the details of relation between the model and the real camera were understood by the pupils.

The interaction between the teacher and the group was characterized by large periods of teacher's talk alternated with short interventions by the pupils. In the first part of the interaction the teacher followed a questioning approach (2.3;2.4). Satisfied that the girls had observed what they were expected to, he started
an explanatory sequence (2.5). Towards the end of the dialogue an inversion of roles was observed with the girls asking the questions they were supposed to answer (2.7;2.9), and the teacher phrasing the answers for them (2.8;2.10). The questions asked by the girls were not new, original ones, but the same appearing on the sheet.

The only genuine contribution of a member of the group during the dialogue was the comment of one of the girls (2.6) relating the situation to real life.

Overall, however, the dialogue was dominated by the teacher, and can be seen as an instance of presentation of "teacher's science".

Episode 3

(Just after Episode 2 the girls start to discuss the last question of item b))

(3.1)  
\[\text{The iris gets bigger and smaller, isn't it?} \]
\[\text{The pupil isn't it ... until it lets the light in ...} \]
\[\text{I'll show that .......... I'll show you ... there is not light in my eye} \]
\[\text{I get bigger ... it gets bigger} \]
\[\text{The pupil gets smaller} \]
\[\text{So when the light focusses the oh God .. how do you spell .... say the pupil is the lens pupil is the lens} \]
\[\text{pupil is the lens} \]
\[\text{It's not ... the retina is the lens} \]
\[\text{I know I know it} \]

(3.2)  
\[\text{If there is the light .. the pupil is smaller and} \]
\[\text{if it's dark the pupil gets larger so you can see.} \]

(3.3)  
\[\text{So ...... what you write.} \]

(3.4)  
\[\text{How do you focus on closer objects?} \]
\[\text{Moving the lens forwards it focusses on closer objects .. that's what he said to me.} \]

(3.5)  
\[\text{Focus how? If it gets forward it's far away isn't it?} \]

(3.6)  
\[\text{It's what he said.} \]
\[\text{It should be back.} \]

(3.7)  
\[\text{No it should be forwards .. yeah ...............} \]
\[\text{Because look .. he put the lens forward that is the there and the closer object} \]
(One girl starts to write down the answer while talking aloud)

(3.8) - You focus on closer objects......by moving the lens forwards ... moving the lens forwards

(3.9) - How how does the lens have to be moved?
- I I supposed that's the one about the eye
- If if you've got a lot of light rays your eye becomes smaller because it can't take so much light in but if it's dark your iris and your pupil become much bigger don't they?
- So you can see
- That's right
- To focus on closer objects it gets .... smaller
- When it's light the pupil becomes smaller and when it's dark .. the pupil becomes larger this is how the they

(3.10) - When it's light .. the pupil doesn't need there's much light in so .. smaller

(3.11) - I don't understand ... hum

In the first part of the episode (3.1 to 3.3) three of the girls were involved in a discussion based on their previous knowledge about the functioning of the eye. Although elicited by the question on item b), the discussion is clearly centered on a different problem. The conclusion stated by one of the girls (3.2), therefore, does not explain what was required.

In the second part of the episode (3.4 to 3.8) two of the girls return to the question discussed in Episode 2. The conclusion is clearly anti-intuitive for one of the girls at least (3.5). It is difficult for her to make sense of the fact that to focus on closer objects the lens has to be moved forwards. According to her view the lens should be moved forward if the object is further away (a reasonable "children's science" explanation). Another member of the group tries to convince her, firstly
by using the "authority" of the teacher (3.6) and secondly, by showing the phenomenon (3.7).

In the third part of the episode (3.9 to 3.11) the group returns to the discussion of how the eye focusses, and the statements are not more than a repetition of what has been said at the beginning of the episode. The girls involved in the discussion about the eye, did not apparently realize that they changed the task. With the exception of one girl, who made public her lack of understanding (3.11), the group seems to be satisfied with their answer. Even the members of the group, who gave a correct answer in the case of the lens of a camera, did not manage to apply the same reasoning to the case of the eye. In the case of the camera the discussion was in terms of focussing distances; in the case of the eye the discussion shifted towards the amount of light entering the iris, a topic closer to their previous knowledge. The analogy between both situations was missed by the group.

Episode 4

(At the end of Episode 3, the teacher comes to the group and is asked to explain the question about the eye)

T) That's the eye again .. that will be my retina
   - Yeah
T) Yeah?
   - Yeah
T) That's the retina .. that's the lens there .. OK?
   Now if I bring an object close ... I get a blurred image on the back of my retina ... OK? and to make that sharper I've got to bring these rays back in again .... OK? Now I can't move my lens I can't move my lens ..... as you ....
   - You can't move it?
T) You can't move it I mean your eyes wouldn't pop out would they?
   - No
Your eyes wouldn't go like that... OK? So what what can
- The pupil gets smaller
T) No it's not
- Move the object
T) No they can't move the object as they're looking at it
- Do something to the pupil
T) Is ... is something to do with the lens ..... how could I
- You you change the amount of light that comes from the lens isn't it?
T) No I change the shape of the lens
- Thinner
T) I make it
- (NOT AUDIBLE) the iris in fact that makes the lens shape fatter and thinner
T) No the muscles up in ... either sides of the lens .. yeah .. if I if I put a fatter lens in there it will make it be a more powerful lens .. so it brings the points together quickly
- Oh that makes .. listen when one is focussing on a closer object the retina becomes larger
T) No not the retina no I can't move the retina .. what I can do is to make the lens more powerful ... if I had a more powerful lens then this would if I had a more powerful lens there
- Yeah
T) These would come to a point there instead of there
T) What does the retina do?
- The retina?
- Yeah
T) That's the screen
- What happens in the human eye to focus on close objects?
T) Yes well something is going to change ... and in fact is the shape of the lens that changes
- (NOT AUDIBLE)
T) It's going to be it's going to become fatter to be more powerful .. If I put a fatter lens in there that focus point would come down there ............. the muscles no even .. you can squeeze the lens in the eyes
- It will look like a bull's eye
- It's a human eye
- Special kind of human eye
T) That's the lens in your eye .. OK?
- Yeah

T) That's the retina the muscles will pull that or let it relax .. so when they pull it they make it thinner ... when they relax they make that that eye fat that lens fat
- Where does the water come? When you cries? cries?
T) The tear drops? It's got nothing to do inside
- OK yes I know I haven't thought that
- (NOT AUDIBLE)
- Sir? What do they call the ... hum the lens in the eye?
T) The lens
- Lens

(The teacher leaves the group and the girls start to write down the answers)
The first part of the dialogue was characterized by the girls advancing their answer to the teacher (4.1 to 4.3). This answer receives a negative evaluation on the part of the teacher without being explored. The teacher's answer is immediately presented (4.4,4.5).

The same inversion of roles observed in Episode 2 occurs again in Episode 4, when one of the girls directs the question presented on the worksheet to the teacher (4.9). As in the former case the teacher presents the answer for the group, and the episode can also be considered as an instance of "teachers' science" being presented.

**Episode 5**

(One of the girls starts to read item c))

- How how good is the focussing in our model of the camera?
- Ohh
- Is bad really isn't it?
  (Laugh)
- You can't move the lens
- It's pretty bad
  - You can move it in that
  - Yeah but you can't do that in a camera can you?
  - We can .. because we put the lens in
  - Yeah

(Another girl reads again the same item)

- How good is the focussing in our model of the camera?
  .... quite good isn't it?
  - (Laugh) She is putting her finger in the way
  - In fact is quite good
  - Yes pretty good yeah

(One girl continues to read item c))

- Block out the rays of light that go through the edges of the lens
  (5.1)
  - That's what I'm trying to think the past half one our .. and you do that ... and that ...

(The girl puts one sheet of paper in each side of the lens, but externally to it (as in Fig. 1.2.2) - This arrangement does not actually reduce the aperture of the lens)
Right that's what we do
- Does it improve the focussing? Yes
- It does

Fig. 12.2 Setting up of apparatus by the girl

(The girls write down the answers, one of them speaking aloud)

- ... side of the camera .. does im .. prove ... the focus
  (NOT AUDIBLE) yes reducing the rays of light on either
  side of the camera does improve the focus.

(One girl reads the end of item c) from the worksheet)

- Can you explain why cheap cameras have such small
  - Diameter lenses .. no.
    (Laugh)
  - They are cheap .. cheap don't focusses cheap
  - If they have cheap lenses

(5.2)
(5.3)
- There's nothing to do with money Sarah
  - (NOT AUDIBLE)
  - Block out the rays of light that go through
  - (NOT AUDIBLE)

(One girl calls the teacher)

This episode shows a case of misinterpretation of an
instruction (5.1). Although carrying out the instruction
in a "wrong" way the answer given was the "correct" one (in
terms of the requirements of the exercise). The sensation
of "improvement" of the focussing, may in that case be due
to the darkening caused by the shadows of the sheets of
paper.

The main point of the exercise (the effect of reducing
the aperture) was therefore missed by the group, making it
impossible for them to relate their observation to the question about cheap cameras. The suggestion of one girl (5.2) is dismissed by another member of the group (5.3) who found an answer in terms of price non-acceptable. Finding themselves unable to answer satisfactorily the girls asked for the teacher.

**Episode 6**

(The teacher comes to the group and one of the girls reads the question)

(6.1) - Can you explain why cheap cameras have such small diameter lenses?
  T) Have you done ... the first part of c?
  - Yeah
  - Yeah
  T) What did you reckon?
  - The way it focusses
  - It focusses better

(6.2) T) Yeah. OK if you make this a smaller diameter by blocking of ... those you see? Smaller aperture if you like OK? then you've got a small hole in the camera .. then you get a sharp image.
  - Yeah

(6.3) T) Unless you've got a super duper lens
  - Super duper

(6.4) T) Unless you've got a super duper lens you see? You get your you get faults in it like this
  - Yeah

(6.5) T) So expensive cameras have very good lenses they make nice focussed pictures.
  - Oh I thought of that

(6.6) T) Cheap ones have cheap lenses and you only use a small part of the lens otherwise the picture will become blurred.
  - Mr. DELETED if you have only a small part of the lens
T) Well?.. then .. where?
  - (NOT AUDIBLE) Can you explain why cheap cameras have such small diameter lenses?
  T) That's that's because they've got cheap lenses
  - Oh that's that's
  - Oh Sarah got it.
  T) They've got cheap lenses like this one
  - (Laughs)
  T) Got cheap lenses like this one OK? They haven't a very good focus ... unless they've got a small diameter
  - Hum hum
  T) So that's why they have such a small diameter
  - So cheap when .. because they've got cheap lenses
  T) Yes it is
(6.7)  - (Laugh)  
T) Doesn't sound as if you have understood it  
- (NOT AUDIBLE)  
T) That's right that's focussing ... they have different lenses ... doesn't have to move the lens in and out  
- (NOT AUDIBLE)  
T) Oh no no no you can't the lens is fixed and it's only a tiny one  

(The teacher leaves the group)  

(6.8)  - (Laugh) Because they've got cheap lenses (Laugh) they are cheap cameras because  

In this episode one of the girls re-directs to the teacher, at the beginning of the dialogue, the question presented on the worksheet. Instead of answering the question immediately (as in Episodes 2 and 4), in this instance the teacher first checked if the group had completed the first part of item c). Satisfied with the "correct" answer to the first part of item c), he then answered himself the second part. When statements (6.2 to 6.6) are read in sequence the lecturing character of the teacher's intervention becomes clear. Again, a case of "teachers' science" being presented.

The teacher did not perceive, however, that the pupils misinterpreted the instructions of the worksheet (see Episode 5), and therefore were not really able to appreciate his arguments (6.2) relating the diameter size and the quality of focussing of a lens. Being unable to relate the size of the lens with the quality of focussing, the rest of the discussion is perceived by some members of the group as an explanation involving just prices of cameras and lenses ("cheap cameras have cheap lenses"). One of the girls expressed with irony her dissatisfaction with what she perceived as being the explanation (6.7;6.8).
TRANSACTION 1

001 B Fr T). Can you look this way .... 001 s
Fo . Can I just go through a and b please ...
. ssh .. OK come on ...
002 I O . on a) we decided that the screen should be where
these rays of light cross .. OK? 003 ms
003 E O . on b) you find when you move the lens close ...
. what happened to that point? that focus point? 004 oth
A Ss). Further away 004 i
F T). It went further away from the lens 005 s
004 E O . now 006 s
. in a camera .. when you focus on something that
is very close ..
. can you move the screen back/
005 E Ss). No 006 cl
004 F T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 007 rep
A Ss). No 008 e
005 E O T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 009 m
005 E O T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 010 s
A Ss). No 011 cl
005 E O T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 012 rep
005 E O T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 013 cl
005 E O T). To accommodate it like that? ... when I'm holding
a camera can I move the screen back so that the
screen gets on that focus point again? 014 rep
006 E O T). What do I do instead? 015 el
. yes?
A B). (NOT AUDIBLE) to let more light in 016 n
007 Re-i O . though it's something to do with the lens
. yes?
A . You move the lens closer to the film 017 rep
F T). That's right .. you move ..
. closer to the film?
. yes you .. in fact you focus
. ssh 018 e
008 I O . you can experiment with this again in a minute
. when you're focussing on a very close object
you'll find that .. to get the .. to get the
focus point back on to the screen again where
it was .. not behind (NOT AUDIBLE) then you have
to push the lens forwards .. closer to the object...
007 Re-i O . though it's something to do with the lens
. yes?
A . You move the lens closer to the film 019 com
F T). That's right .. you move ..
. closer to the film?
. yes you .. in fact you focus
. ssh 016 n
008 I O . you can experiment with this again in a minute
. when you're focussing on a very close object
you'll find that .. to get the .. to get the
focus point back on to the screen again where
it was .. not behind (NOT AUDIBLE) then you have
to push the lens forwards .. closer to the object...
008 I O . you can experiment with this again in a minute
. when you're focussing on a very close object
you'll find that .. to get the .. to get the
focus point back on to the screen again where
it was .. not behind (NOT AUDIBLE) then you have
to push the lens forwards .. closer to the object...
027 ms
009 E O . how does the eye focuss on something that is very
. close?...
. because it can't move it it can't move the lens
. can it? Your eyes don't pop out like that when
you ...
028 i
009 E O . how does the eye focuss on something that is very
. close?...
. because it can't move it it can't move the lens
. can it? Your eyes don't pop out like that when
you ...
029 e1
009 E O . how does the eye focuss on something that is very
. close?...
. because it can't move it it can't move the lens
. can it? Your eyes don't pop out like that when
you ...
030 cl
G). The lens gets fatter or thinner with the muscles

T). Yes, so the lens gets fatter or thinner.

What does the fat lens do?

A). (NOT AUDIBLE)

T). Yes...

The fat lens is the more powerful lens... OK?

And when you have something that's close, you need a more powerful lens to bring that focus point back to where it was before...

So do you use the fat lens to focus on a close-up object or a thin one?

Fat

T). Fat.

What about a far-away object?

Thin

T). Thin OK?

If you...

Ssh...

That's one quick experiment that everyone can do...

When you stop talking over there...

In fact... Your muscles relax as much as they can, then your eye lens literally can't get any further than it is when your finger is about there... any further if your fingers become any closer to your eye, your eye lens just can't just accommodate it at all... OK?

Can someone suggest why?

Yeah?

B). (NOT AUDIBLE)

T). That's right yes.

Your muscles relax as much as they can then your eye lens literally can't get any further than it is when your finger is about there... any further if your fingers become any closer to your eye, your eye lens just can't just accommodate it at all... OK?

Any suggestions if you have a finger there... in front of your eyes... any suggestions how you can get it on focus?

Shut one eye

Going cross eyes

No you don't cross eyes
A Ss). Shut one eye  
B). Cross eyes

017 E 0 T). An experiment we will try next time  
if you've got if you want to make your lens more  
powerful what might you do?  
059 rep 060 rep 061 ms  
A G). Open it  
B). Squeeze your eyes  
). ( NOT AUDIBLE)  
062 e1  
A G). Open it  
B). Squeeze your eyes  
). ( NOT AUDIBLE)  
063 rep 064 rep 065 rep  
F T). Yes you might put another lens in front of it  
so that you have two lenses ...  
ssh  
two lenses make it more powerful than one lens  
066 e 067 com 068 oth 069 com  
018 I 0 O . if you've got a magnifying glass at home you can  
try this ...  
ssh .... shush ....  
those lenses that you've got there probably won't  
work well because they are not ...  
070 i 071 oth 072 i  
019 P-I 0 G). It gives a blurred image  
073 p-i  
020 E 0 T). Does it work?  
074 e1  
A G). No (Laughs)  
075 rep

(The teacher asks the class to continue with the  
practical)  
(Teacher asks how many did not understand item c))

The transaction above follows the classic sequence of  
eliciting exchanges interrupted by informative ones. The  
sequence can be seen as a form of presentation of "teachers'  
science", with all the initiative and control resting in the  
teacher's hands and with a high teacher's talk/pupils' talk  
ratio.  

The questioning, although frequent, does not reflect  
a real concern with the pupils' views. Only "correct"  
answers - those fitting in the teacher's discourse - were  
considered; "wrong" ones, in their turn, were not explored.  
Even an answer which was "correct", according to the infor-
information presented by the teacher shortly before (act 064), was not discussed because it did not fit in the teacher's line of presentation.

Practically all the discussion was concerned with the questions presented in item b) and item a) was only briefly mentioned (act 004). Again, as in Episode 2, the teacher either does not see the analogy with a camera as important or it can be assumed that analogy to be understood without problems by the pupils.

When explaining the function of the muscles attached to the eye lens (acts 049 and 054) the teacher's account of their operation did not match with the accepted explanation, even a simplified one. In reality, in order to increase the power of the eye lens the ciliary muscles do contract, bulging the eye lens; when the muscle is relaxed the eye lens is thinner and focussed on infinity. The teacher presented a similar account when interacting with the group in Episode 4.

**Episode 7**

(The girls are concerned with item d))

- Well come on kiddies grow up
- you'll be able to focus on .. hum .. further away objects
(8.1) - We've done it
- You'll be able to focus on further objects
- well, right, you'll be able to focus on further away objects

A "wrong" answer (8.1) is accepted without discussion by the group. The reason for this can be that the answer
represents a logical explanation in terms of "children's science", that is, cameras with larger apertures will be able to photograph objects placed further away.

After Episode 7 I asked some questions to the group. They also spent some time looking around other groups and talking particularly to each other. The talking was not audible on the tape.

**Episode 8**

(The girls are still discussing item d))

- Large .. having a large aperture
- Aperture? What's that
- What's an aperture? do you know?
- Hole
- Hole
- Hole
- Expensive cameras have large apertures but you've got a large hole then the focus is sharper than will be for the picture
- What's aperture again?
- Hole
- The advantage of having a large aperture
- Is .. that .. you can

(The teacher says that he will give five minutes more for the class to finish the practical)

- Have we finished?
- Yeah
- Yeah

The meaning of the word aperture is raised by two of the girls. The same word passed unnoticed when the group was discussing item c). The group managed to link the meaning of the word presented in specialists' language (aperture), with everyday language (hole).

Since the group reckoned that they had finished the
practical I spent some time talking to them about the experiment.

(Near the end of the lesson the teacher again asks for the attention of the group)

**TRANSACTION 2**

<table>
<thead>
<tr>
<th>Time</th>
<th>Role</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>021 B</td>
<td>T). Can I just go through c) and d) very briefly .....</td>
<td>076 ms</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>those are very cheap lenses as I've said to quite a lot of people (NOT AUDIBLE) more expensive ones OK? when you've blocked out the edges of the lens what happened to the focus?</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>G). Gets nearer</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). It was much better OK?</td>
</tr>
<tr>
<td>022 I</td>
<td>O</td>
<td>now if you've got a cheap camera with a cheap lens you find that you can only use a very small part of that lens because if you use a very wide diameter lens OK? you get just the same effect that you get with these two lenses that you've been using there you get a very fuzzy sort of picture OK? so you can only use a small part of it yeah? block out the sides of it if you like if you look to a very cheap camera like those ones you saw the apertures last week when you looked to the cameras they are very tiny OK? with a more expensive camera with a more expensive lens the lens doesn't have so many defects you can use a wider diameter and still get a sharp focus OK? that means that you can use a much bigger aperture much bigger hole in the front of the lens</td>
</tr>
<tr>
<td>023 E</td>
<td>O</td>
<td>so what advantage does having a large aperture give us? yeah?</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). Sharp picture</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). No no just the fact that we've got a bigger aperture does not give us a sharp picture it's the lens that gives us a sharp picture not the aperture</td>
</tr>
<tr>
<td>024 Re-i</td>
<td>O</td>
<td>yeah?</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). Brighter pictures</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). Gives a wider picture?</td>
</tr>
<tr>
<td>025 Re-i</td>
<td>A</td>
<td>B). Brighter</td>
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<td></td>
<td>F</td>
<td>T). Brighter?</td>
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</tbody>
</table>
026  Re-i A G). Let in more light
     F  T). Let in more light OK?
027  E O . so why will that be an advantage?
     A B). Faster shutter speed
     F  T). Faster shutter speed OK?
     . so that the shut the shutter that goes in front
     of the hole can be opened and closed much quicker
     with the large aperture because more light comes
     in more quickly
028  E O . why is that an advantage?
     . yeah?
     A G). Fast shutter speed
     F  T). Fast shutter speed all right
029  Re-i O . why is the fast shutter speed an an advantage?
     A B). Because you can now take pictures of fast moving
     (NOT AUDIBLE)
     F  T). Yeah
     . if you've got something that is moving very quickly
     you want to shoot at speed otherwise it looks as
     though it is blurred
030  Re-i O . yeah?
     A G). You can take pictures of things further away
     F  T). Further away?
031  P-I O G). Yes because with a cheap camera when you've got
     a small lens on it you can only take things near
     F  T). Hum ...
     . it all depends .. we're talking about the amount
     of light coming into it
     . no I don't
032  P-I O ). (NOT AUDIBLE)
     F  T). Yeah you can take better pictures in dark places
     with the larger aperture in churches and things
     like that ... as someone suggested
     . you've got a large dark place .. and you need
     you want a large aperture to let in a lot of light
     .. OK? just like your iris .. opens up your pupil
     when it's very dark OK?
033  Ch O . are there any questions on that?
034  B Fr . right

(T. asks for someone to collect materials and books)
The pattern of presentation in this transaction is similar to the one observed in Transaction 1. The elicitation format is the dominant one; large (teacher's talk/pupils talk) ratio; "right" answers are included in the teacher's presentation and "wrong" answers not explored.

In Exch 030, one of the girls of the group observed presented the answer the group gave to idem d): a camera with a larger aperture can take pictures from objects further away. Although "wrong" in the context of the teacher's presentation this explanation can be a sensible one in terms of the children's perspective. Nevertheless it was dismissed without exploration.

On the other hand, a technical term - "faster shutter speed" - introduced by a boy (act 097) was readily accepted by the teacher because it fitted in his pattern of presentation. On another occasion the meaning of an answer (act 079) was changed (act 080) in order to serve the purpose of the presentation of "teachers' science".

12.4 Discussion

The analysis presented in the previous section shows basically three types of interactive situation occurring during the lesson. The first type is the group working through the worksheet (Group Interaction), occurring in Episodes 1, 3, 5, 7, 8. The second type was the teacher interacting with the group (Teacher-Group Interaction); this was the case in Episodes 2, 4 and 6. Finally, the third type of interaction was the case of the teacher
lecturing to the class as a whole (Teacher-Class Interaction) as illustrated in Transactions 1 and 2.

In the rest of this section I discuss each of these situations separately.

12.4.1 Group Working Through the Worksheet. The worksheet handed to the pupils consisted of a series of instructions and questions. This presentation structures a situation, which, ideally, should lead the pupils to observe the phenomena and "discover" the principles that the teacher expects them to observe and discover.

In order for this to happen some conditions must be fulfilled. The instructions must be interpreted and followed in the planned way, the "right" phenomena observed and the "correct" answers given. The analysis of the episodes involving the group working through the worksheet showed discrepancies between what the group was ideally expected to do and what was really done. Even on the basic level of following instructions the interpretation was occasionally different from the planned one.

Item a), for instance, deserved practically no attention from the group. The apparatus was not set up in the planned way and the question included in the item was not discussed at all. Consequently the details of the analogy between a camera and the apparatus were missed by the group (Episode 1). Nevertheless, that was one of the main aims of the exercise as its title suggests.
Another case of an instruction being interpreted in a different way than the one intended by the teacher occurred in Episode 5. In this particular case the instruction was carried out in a way in which the size of the lens was not reduced at all, making it therefore difficult for the group to relate their observation to the question they were expected to answer.

When the answers to the key questions are considered the situation was also far removed from the ideal case. The question about the camera on item b) was only partially answered and the details of the analogy between the apparatus and a real camera missed by the group (Episode 1). In the case of the eye in the same item, the group agreed on an explanation that, although sound in itself, was not the answer to the question proposed. In the case of item c) the instruction was interpreted by the group in such a way that made it difficult to establish a relation between the observation and the question proposed. In the case of item d) a "wrong" answer was accepted by the group without discussion.

At this point some speculations can be made about the reasons for the instructions not being followed as expected and for the failure of the pupils to present the "correct" answers. From the perspective of the constructivist position adopted in this thesis, I would suggest that pupils are likely to approach a given task with some pre-conceived ideas, tending therefore to interpret the instructions and to answer the questions in the light of these ideas.
In this particular case the group observed started the practical work with a more or less defined idea of what they were expected to do with the apparatus even before reading the instructions. This sort of "mental set" was suggested by the demonstration performed by the teacher in the beginning of the lesson, and in the previous one, the purpose of which was to show the variation of the focal point with the movement of the source. This "mental set" led them to a superficial reading of the worksheet and to concentrate on points that tuned with their perception of the task (moving the light source and observing the focus) as stated in item b). It also led them to miss the points in item a) and the introduction before it, which stressed the analogy with a camera (Episode 1). Moreover, it must also be considered that the teacher did not offer any opportunity for the class as a whole to discuss the "experiment" before the group started to work.

In the case of item c) the instruction "block out the rays of light that go through the edges of the lens" was ambiguous and certainly open to the sort of interpretation given by the pupils (Episode 5). Had they paid more attention to the statement in brackets, they might have realized that their procedure was not the one expected by the teacher. But at that stage the word "aperture" was not noted by them, and its meaning was only discussed later in connection with item d) (Episodes 7 and 8).

Other instances of the effects of pre-existing conceptions on the work of the group are found in Episodes 3 and 7.
In the first part of the former the group changed the focus of discussion to a problem more related to their previous knowledge. In the later an answer offered by one girl was readily accepted, probably because it did offer a sensible explanation in terms of "children's science".

12.4.2. Teacher Interacting With the Group. All the three episodes (Episodes 2, 4, 6) involving the interaction between the group and the teacher can be characterized as being mainly instances of presentation of "teacher's science" rather than a discussion about the work actually performed by the group.

In the three cases the teacher was concerned with presenting to the group the "right" answers to the questions of the worksheet. Nowhere were details about the task discussed, even when the teacher perceived that an instruction was not properly followed, as in the case of the position of the metal comb in Episode 2. In one other instance, however (Episode 6), the fact that an instruction was "mis-interpreted" passed apparently unnoticed by the teacher, because the group ended with the "right" answer to the question relative to that instruction.

The way in which the girls approached the teacher during the interaction conveyed the impression that they were aware of his predisposition to present the "correct" answers. For instance, in the three episodes they simply directed to the teacher almost "verbatim" the questions they were supposed to answer. Teacher's science, however, was not always "correct" (in relation to "curricular science"),
as for instance when he inverted the functions of muscles linked to the eye lens.

12.4.3 Teacher Interacting With the Class. The two instances in which the teacher interacted with the class as a whole (Transactions 1 and 2) were similar in their features. The main purpose was not the discussion of the experiment and the analysis of the results obtained by the groups, but the explicit presentation of "teacher's science".

This presentation was characterized by all the initiative and control being in the hands of the teacher and a very high (teacher's talk/pupils' talk) ratio. This ratio can be roughly estimated by counting the lines in the transcript, giving a value of 5 to 1. Furthermore, the teacher was always the centre of communication, with the questions being presented by him, and the answers being directed to him.

The discourse followed the pattern—Opening by the teacher; Response from a pupil; Follow-up by the teacher. The questions themselves were always convergent ones and the treatment given by the teacher to the pupils' answers indicates that the questioning was not directed to identify and explore the pupils' perceptions of a situation, but had rather a rhetorical purpose. "Correct" answers were incorporated in the teacher's discourse, and the "wrong" ones not considered for discussion.

Although the transactions were based on practical work performed by the pupils, the situation was not one in which both parties (teacher and pupils) could interchange and negotiate their perspectives.
12.4.4 A Pattern of Presentation. When the situations described before are considered together a pattern of presentation of "teachers' science" emerges.

The teacher presented the group with a practical task by means of a worksheet. The knowledge to be acquired by the pupils was present in it in an implicit and potential form and, in an ideal case, would be "discovered" by the pupils. The pupils, however, approached the task with their own interpretation about what they were expected to do and about the phenomenon being studied. As a consequence, the instructions were not followed as planned and the implicit knowledge not uncovered by the pupils.

The teacher was himself aware that the pupils, in general, would not be able to uncover the knowledge by themselves. In an interview some weeks later, I raised with him the issue of experiments, and an extract of the interview is presented below:

I) Hum and ... would you say that in general when analysing their answers they understand
T) Yes yes
I) Quite quite well what the experiment is
T) Yes yes ... well as if, hmmm ... very often the teacher will almost state the conclusion and they will just copy it out ... hum yes I I think we can see through their answers whether or not they understand what's been going on.

(Emphasis added)

So, by interacting with the pupils, either in small groups or as a class, the teacher presented to them the knowledge they were expected to learn. This presentation was,
in its turn, characterized by not considering the pupils' own approach to the work. The objective of the interaction was to present "teachers' science" explicitly, and not to discuss what the pupils did or were doing.

The pattern of presentation sketched above can be seen as an example of a "Transmission approach" (Section 5.2), in spite of the fact that, during the lesson, the pupils were, for a large part of the time, doing practical work in small groups. Moreover, the other lessons in which the same teacher was observed suggest that this approach was quite typical. In the "Transmission-Interpretation" continuum proposed by Barnes (Section 5.2) I would situate the teacher near the "Transmission" end. Although the observations alone would be enough to justify their classification it is illustrative to examine the teacher's own view of his role. When asked in an interview about what he thought should be the place of physics in the curriculum and the importance of it to the children he answered:

T) To be .. honest I haven't enough time to think about it .. I've been thinking more in terms of how to present the real physics the actual physics ... so that one of the slightly disappointing things for me has been the fact that .. before I started teaching I you know I thought ah .. I'll be able to get there and there change a lot of ideas about the curriculum I thought of this quite long (NOT AUDIBLE) as I did as I saw it in school. I thought I'll be able to change it but I've been so .. much work just actually being in the classroom teaching marking books and preparing lessons hum marking tests and things like that .. that I really haven't got round to .. thinking about it .. in relation to the .. to the rest of the school .... but .. physics .. physics is just an important qualification that the kids have to .. have .. hum well the bright ones anyway and the ones who want to continue .. with science really .. need to have to have some knowledge of that side of science .. to really be able to continue effectively ...

(Emphasis added)
So, in spite of willingness of doing something new (hindered, according to his perception by routine teaching activities) this teacher assumes, quite consciously, a "transmission" role: there is a "real" and "actual" physics to be presented to the pupils; a "qualification" to be acquired by the "bright ones".

When asked more explicitly what his main concerns were when preparing a lesson, he stated:

T) Well the first well .. optimally they've got to be able to understand the physics understand what is going on .. hum I try to present it in a way that is mixed in other words I use a variety of different .. methods and then also I try to present it in a way that is enjoyable interesting and relevant ... the first consideration is that they should understand what is actually ... actually being taught the understanding is hum comes absolutely first rather than just enjoying and playing with things.

The teacher could only express his concerns by vaguely stating that his first preoccupation was to promote understanding of the physics being taught. This understanding is something to be obtained by the teacher using a variety of methods. From the lessons observed it can be inferred that the "variety of methods" referred to by the teacher means the use of demonstrations, practical work in groups and lecturing in order to transmit "teacher's science". In no instance in the interview, or in conversation, was any concern with the existence of "children's science" stated: knowledge was seen as something to be transmitted.

In the case of this particular teacher that perspective was certainly influenced by the "ethos" of his department, which was strongly examination oriented, as the teacher him-
self described it:

T) .. hum the point is that the third year is essentially part of the .. O-level and CSE courses those who actually do O-Level and CSE unlike the other departments the biology and chemistry departments that put on courses which hum really sort of try to sell the subject try to present something that is .. enjoyable and of general interest rather than something that is leading to an exam we really have to try to get to work this .. oriented in the end towards the exams.

12.5 From Curricular Science to Teacher's Science

Since, in the situation described in the present case-study, the teacher was formally following the Revised Nuffield Physics materials, a comparison can be drawn between the curriculum itself and the way in which a particular activity was implemented. In the case analysed differences between the curriculum and its implementation were noticeable at two levels.

At a first level there is the clear contradiction between the transmission style adopted by the teacher, and the so-called "Nuffield spirit" assumed by the developers of the curriculum. The use of class experiments is justified in the Revised Nuffield Physics course on the grounds that pupils used the personal experience of science, and as professional scientists they can devise their own experiments, meeting difficulties as well successes, and observing with an open mind the results of their efforts. But,

"For that they used plenty of time and encouragement, but not many detailed instructions; because they need to feel that it is their own experiment and to learn by their mistakes as well as their successes. Of course we should provide guidance - something like 'sailing orders' for the captain of a ship, but not much more."

(Rogers and Wenham, 1977a, p.5)
The role to be assumed by the teacher is clearly suggested in a further passage:

"And we trust teachers will avoid giving away the answer that is being looked for. Far from that they may use to praise an unexpected answer, which though not wholly true, is the result of a serious work."

(Rogers and Wenham, 1977a, p.41)

The contradiction between the approach adopted by the teacher, and the "spirit" of the curriculum, seems to parallel a similar one, with regard to the physics department of the school, which was examination oriented in the traditional sense (see quotation on page 12-35).

At a more tangible and immediate level, differences can be noticed in the way the task is proposed in the Nuffield text and in the worksheet prepared by the teacher. Although the worksheet was based on Experiment 10 (Revised Nuffield Physics - Pupils' Text Year 3), it was not a copy of it.

The first difference between the Nuffield experiment and the teacher's version of it occurs in the title, changed from "Model of Rays and a Camera (A first experiment with ray streaks')" to "A Model of the Camera", and the missing of some words in the teacher's title can be more significant than would be suspected at a first glance. The notion of ideal rays of light is commonly used in physics teaching and the ray streaks created by the comb represent an experimental approximation to this notion. In the teacher's version of the experiment, however, the function of the comb is seen in a different way, namely to represent the holes on a pinhole camera. As the idea of a multi-holed pinhole camera is not
related to the rest of the work, the metal comb becomes a superfluous detail in the setting of the apparatus. This fact is, actually, illustrated by the action taken by the teacher in Episode 2, when, although noticing that the girls misplaced the comb, he did not discuss the point with them.

The analogy with the camera is more explicitly treated in the Nuffield text than in the teacher's one. In the former the pupils are asked to draw an outline of a camera box on the paper, marking a place for the film at the back, and also presented with a diagram showing what their drawings should be like. In the adapted version it is assumed that the pupils will be able to work out the analogy by themselves when answering item a). An assumption that proved to be wrong, at least in the case of the group observed.

The question about the focussing of close objects by a camera and by the human eye, included by the teacher in item b) does not appear in the Nuffield version. Actually, the functioning of the human eye is not discussed at this stage in the Nuffield scheme.

When items c) and d) of the worksheet are compared with their equivalent in the original text the differences in presentation are clear. The worksheet consists of instructions to be followed and questions to be answered. The original text includes an explanation comparing cheap and expensive cameras.

In an interview after the lesson I raised the issue of the textbook with the teacher:
I) And, hum ... do you find it difficult that they haven't got the book, as far as I understand they haven't got

T) No

I) The book and

T) I don't know because the book is very detailed .. and if we are only going to have them ... in ... one double period a week .. it's it's fantastic the amount of detail in those students' books .. hum and unless you're prepared to put a lot of time into it that's more than a double period a week you can get bogged, isn't it?

I) I see

T) Hum ... so usually I'd rather write instructions on the board .. as I did, I think the previous two times on I give them a of sheet so they've got sort of a work-sheet, they've got some written instructions there.

According to these comments advanced by the teacher the worksheet is supposed to be a less detailed, condensed and therefore easier to follow, version of the textbook. It can be argued, however, that by missing the details and explanations included in the original text, more intellectual demands are placed upon the pupils.- intellectual demands that the observed group was not able to cope with satisfactorily.

12.6 Summary

In this chapter a case-study based on the analysis of one lesson was presented. The central focus was on the interaction between "children's science" and "teacher's science". It was suggested that although during most of the lesson pupils were involved in practical work, the pattern observed was of a transmission of "teacher's science" and not a negotiation of knowledge. By disregarding opportunities of actually getting to know the pupils' perception
of the activities they were involved in, in favour of
the presentation of his knowledge, the teacher failed to
notice instances in which pupils' interpretations of the
task were not the ones assumed by him. This unnoticed gap
led the pupils in the group observed to miss important
aspects of the practical task.

The interaction between "teacher's science" and
"curricular science" was also discussed. It was argued
that the teacher's approach departed from the curriculum
adopted (Nuffield O-Level) both in the pedagogical "spirit"
and in the most tangible level of task presentation.
This was linked to examination oriented ethos of the
department.
CHAPTER THIRTEEN

CASE STUDY IV
13. CASE STUDY IV

13.1 Introduction

The case study presented in this chapter is based on a sequence of lessons in which the topic "Refraction of Light" was introduced to a third-year class in a comprehensive school. This particular sequence was part of a larger one I observed from February to May 1980.

This was the first series of observations I conducted as part of my work as a research student in the IED, and it took place in the very beginning of my activities. In this very early stage the central focus of the observations was already the interaction between "teachers' science" and "children's science". On the other hand there was also a strong concern with exploration. My preoccupation was to aclimatize myself with secondary classrooms in this country. Instead of tape recording the lessons a decision was taken of just to observe and make notes, and to complement those with a tape-recorded interview with the teacher.

As a consequence the data collected during the lessons lack the detail in terms of verbal exchanges that characterizes other instances of classroom interaction presented in this study. Nevertheless, since they can be used to illustrate some aspects of the interaction between "teachers' science" and "children's science", I opted for presenting an analysis of the observations as a case study.

In the rest of this chapter I present initially an account of the context and methodology used (Section 13.2).
This is followed by a reconstruction of the sequence of lessons in which the concept of refraction was treated (Section 13.3) and a discussion of some aspects of this sequence (Section 13.4). Finally in Section 13.5 the teacher's perception, identified in an interview is discussed.

13.2 **Context and Methodology**

13.2.1 **The Context.** The group observed consisted of a male physics teacher and 32 pupils of a third-year form. The pupils were considered to be an upper stream group and physics in the third year was taken as a compulsory subject. The teacher was the head of the department and can be considered an experienced one, having been in the profession for more than seven years. He acquired a B.Sc. in Electronical Engineering, and started a Ph.D., giving up after 6 months. He then spent 15 months in industry before starting teaching. He did not have any formal teaching training.

Eight double period lessons (held weekly) were observed and the general topic was optics. When the observations started the group was finishing the study of lenses and starting the study of refraction, which was covered in five lessons. The group was not following any particular text, and most of the information presented by the teacher on the blackboard or by dictation was recorded by the pupils in their notebooks.
13.2.2 **Methodology.** During the lessons observed I was seated in the back of the classroom. Interaction with the teacher and the pupils was kept at a minimum level. I used no special schedule for the observations, and just took notes of what, at the moment, appeared to be relevant events. My attention was, of course, selective, and a relevant event was considered one which was perceived as being related to the interaction between "teachers' science" and "children's science". In this case the note-taking was greatly facilitated by the fact the teacher made extensive use of the blackboard. I tried to record in my notes everything that was written or pictured on the board, since the information displayed can be interpreted as being important from the teacher's point of view.

The events taken during the lesson were the basic material for the reconstruction of the lessons. This reconstruction reflects obviously the selective character of the observations.

In the next section the reconstruction of the sequence of lessons dealing with the concept of refraction is presented. In the presentation the recorded events are coded on the left hand side of the page in order to facilitate later reference. Notes taken from the blackboard are indicated by the use of vertical frames.
13.3 The Sequence of Lessons

Lesson 1

(1.1) The teacher asks the class what is refraction. A few pupils try to answer. The teacher does not analyse any specific answers and writes on the blackboard:

Caused by the fact that light travels slower in glass than in air. Means that light changes direction.

(1.2) The teacher presents an analogy between refraction of light when passing from air to glass and a group of soldiers marching on two different soils. He draws a diagram on the board:
We will now perform an experiment to find out if there is any relationship between the angle of incidence $i$ and the angle of refraction $r$.

The teacher asks the pupils to come to the front of the classroom and explains the method to be used, which is the classical one using a rectangular block of glass, pins and a protractor. He says that the result will be a broken line as shown on the board.

He also explains how he wants the experiment written up.
The pupils are instructed to leave three blank columns in the table, but the reason for doing this is not explained.

The pupils collect equipment and start doing the practical work in groups of three. In general they are not very careful in the measurements. For instance, they allow for pins to be inclined. Some of the pupils are recording not the angle of refraction but its complement. After observing the groups working for a while the teacher asks the attention of the class and explains again what the angle of refraction is.

At the end of the lesson the teacher asks for the pupils to stop. Since they have not finished the experiment he says that they will continue next week.

Lesson 2

The teacher reviews the experimental method that the pupils were following in the last lesson. The pupils collect the apparatus and complete the measurements.
(2.2) The pupils are instructed to put heads in columns 3, 4 and 5 of the table of results (\(\sin i, \sin r, \sin i/\sin r\)). The teacher says that he knows that they never met the word sine before, but that they will learn about it in due course. He explains then how to find the sine of a given angle in a table of trigonometric functions and asks the pupils to complete the table of results with the values of \(\sin i\) and \(\sin r\), but to leave the calculations of \(\sin i/\sin r\) for homework.

(2.3) The teacher instructs the pupils to leave 10 lines for the conclusion.

(2.4) The teacher writes on the blackboard and asks the pupils to copy:

```
Examples of Refraction

1) Bent stick in water
```

```
When drawing the picture above the teacher asks the class about the direction of the bending rays coming out of the water, by using an auxiliary picture:
```
One of the pupils answers that the direction will be that of ray 2. The teacher replies: "WRONG" (emphatically). He then completes the diagram and the explanation of the "bent stick in water", and adds that better diagrams can be obtained by "cheating a bit". By this he means tracing the rays from the eye to the stick.

(2.5) The teacher demonstrates the phenomenon by using a recipient with water and a stick. He explains that the same explanation can be applied for the apparent depth of a swimming pool. He draws a diagram on the board:
The teacher says that the picture is a bit exaggerated but that is the sort of thing that really happens.

(2.6) The teacher explains the homework, which is to complete the table of results with the values of \( \sin i / \sin r \).

Lesson 3

(3.1) The teacher asks the pupils about the results of their calculations. One pupil says that his values varied between 1.46 and 1.64. The teacher replies that the differences are due to experimental errors (but he does not discuss the sources of experimental errors), and that "the values must be 1.50". He then writes on the board and asks the pupils to copy, and to fill the blank space with their average value.

```
Conclusion: Looking at the results in the last column we can see that in each case \( \sin i / \sin r \) is a constant figure (allowing for experimental errors). The constant figure is called the Refractive Index of Glass, \( n_g \). In my case, average value of refractive index of glass: _____
```

(3.2) The teacher asks the question: "What is the refractive index of air?" One pupil answers: "It is zero"; another one says: "It can be anything". These wrong answers are not explored by the teacher who states that the value is 1, since the rays do not change direction in the air. He then draws on the board:
The teacher says that the pupils must know by heart the values of the refractive index for air (1), glass (1.5) and water (1.33).

(3.3) The teacher explains what total internal reflection and critical angle are. He draws diagrams on the board:
The teacher writes on the board:

Experiment to find the critical angle for glass

Apparatus: Leave 1/3 page
Method: Leave 8 lines
Results: For angles of incidence up to the light emerged from the glass block.
For angles of incidence greater than the light is totally internally reflected.
The critical angle for glass lies behind _____ and _____.

The teacher explains the experimental method for the pupils, which consists of a variation of the last experiment using a semi-circular block of glass and pins.

The pupils collect the apparatus and start the experiment.

The teacher collects the apparatus, though most of the pupils have not finished. He then explains the homework which is to write the method of the experiment and to draw a diagram of the apparatus.

Lesson 4

The teacher draws on the board and asks the pupils to take notes (see next page).
Experiment on real and apparent depth of a rectangular glass block.

**Apparatus**

- Clamp stand
- Pin
- Block of glass
- Pencil line drawn on paper beneath block

**Method:** Leave 8 lines

**Results:**

- Real depth of block = cm.
- Apparent depth of block = cm.

\[
\begin{align*}
\text{Real depth} & = \text{Apparent depth} \\
\therefore \text{Real depth} & = \text{Apparent depth}
\end{align*}
\]

(4.2) The teacher asks the pupils to come to the front and explains the experimental procedure, which consists, basically, in moving the pin until no parallax is observed between the pin and the drawn line.

(4.3) Pupils collect the apparatus and start the practical, working in groups of 2 or 3.

(4.4) Almost all groups finished.

(4.5) The teacher draws on the board:
Experiment on real and apparent depth of water

Method: Leave 6 lines

Results: Apparent depth of water = \_\_\_\_\_ cm
Real depth of water = \_\_\_\_\_ cm

\[ \text{Real depth} \div \text{Apparent depth} = \_\_\_\_\_ \]

(4.6) The teacher sets up the homework which is to write up the method for the experiment with the block of glass and to work out the results.

Lesson 5

(5.1) The teacher recalls the method used in the experiments of the previous week. He then performs a demonstration by doing the experiment of the apparent depth of water. He presents the conclusions on the board:

\[
\begin{align*}
\text{Real depth} &= 15.7 \text{ cm} \\
\text{Apparent depth} &= 11.1 \text{ cm} \\
\text{Real depth} \div \text{Apparent depth} &= 1.41
\end{align*}
\]

(5.2) The teacher asks for the results of the experiments with the block of glass and writes them on the board:
1.5  1.5  1.5
1.4  1.6  1.7  Average = 1.5
1.6  1.5  1.5
1.7  1.6  1.6

(5.3) The teacher states that the result is equal to the refractive index of glass (1.5). He says that the result of his demonstration with water should have been 1.33, and that the value 1.41 was due to experimental errors. He writes the conclusion on the board.

Conclusion: Taking the result for the entire class we find that the average value of
\[
\frac{\text{real depth}}{\text{apparent depth}} = 1.5
\]

Conclusion to both experiments:
For glass refractive index = 1.5 and we found that
\[
\frac{\text{real depth}}{\text{apparent depth}} = 1.5
\]

For water refractive index = 1.33 and we found
\[
\frac{\text{real depth}}{\text{apparent depth}} = 1.41
\]

Allowing for experimental errors we seem to have found another formula for refractive index.

\[
\text{refractive index} = \frac{\sin i}{\sin r} \quad \text{or} \quad \text{refractive index} = \frac{\text{real depth}}{\text{apparent depth}}
\]

(5.4) The teacher starts the section on colours of light.

13.4 The Presentation of Teacher's Science

The sequence of lessons reconstructed in the previous section shows a situation in which "teacher's science" assumed a dominant role. This role was asserted by different means.
The importance of "teachers' science" was signalled constantly to the pupils by asking them to copy from the board the definitions, methods and examples presented by the teacher. On the other hand, at no time were the pupils' conceptions explored. Although, for instance, the pupils were very likely to be familiar with sticks being "bent" when immersed in water or even with apparent depths of swimming pools, those cases were only introduced as examples of refraction in the second lesson. In the first lesson a formal definition and explanation was presented.

It should be noticed, however, that when introducing the new idea of refraction, an attempt was made by the teacher (Event 1.2) to relate the new idea with a more familiar one, through the presentation of an analogy. One problem with the presentation was that it was not made clear that the analogy is only valid as far as a wave model of light propagation is considered. Since no reference was made to a wave model the risk exists that the pupils can associate the soldiers with moving particles.

Since the lessons were not tape-recorded a formal analysis of discourse by using Sinclair and Coulthard scheme could not be conducted. Nevertheless the general feeling was that this particular teacher made more use of purely informative exchanges than of eliciting exchanges. On the few occasions when a question was posed to the class they were not intended to actually explore "children's science". Events (2.4) and (3.2) are cases in
which this form of knowledge was neglected by classifying the answers as "wrong" without further discussion.

Even the practical work was presented following an approach in which little room was offered for the pupils to express their own ideas. The experiments were decided by the teacher, the methods presented by him, who also phrased the conclusions (Events 3.1 and 5.3). No real discussions pre and post the practical work were observed. To the pupils it was left the role of performing measurements and carrying on the calculations. In the instance of the experiment to find the law of refraction even the meaning of the figures they were getting was unknown to them, since they had not come across the concept of "sine" before.

The practical work can be viewed as an attempt on the part of the teacher to legitimatize the knowledge being presented by demonstrating it practically. Since the practical results did not match perfectly with the theory, the notion of "experimental error" was included in the conclusions (Events 3.1 and 5.3), but the sources of those were not discussed. This can be interpreted as a compromise between the pure transmission and the legitimatizing of "teachers' science" by experimental evidence.

The way in which practical work was introduced is compatible with an empirical-inductivist view of science. This is particularly clear in the case of the experiment leading to the law of refraction, but also in the one relating the refractive index and the relation between real
and apparent depth. Inductive discovery was simulated in both cases. The empirical-inductivist view can also be noticed in the way the pupils were instructed to write down the experiments, i.e. following the neat sequence of apparatus → method → results → conclusion. This sort of sequence of presentation imitates the classical presentation of scientific papers. Medawar (1963) referred to it as being a fraud in the sense that it helps to convey the impression of an empirical-inductivist approach not actually followed in the majority of the cases.

In summary, the approach adopted by the teacher can be characterized as an effort of presenting to the pupils a topic of formal knowledge — "curricular science" mediated by "teacher's science"— which was not only a target towards what the pupils' knowledge was expected to move, but also the starting point and central focus of the instructional strategy. "Teacher's science" was privileged throughout the sequence of lessons and "children's science" consequently devaluated. The use of language was mainly for transmission purposes and a monopoly of the teacher. Communication was practically unidirectional with the pupils involved in activities of a rather passive nature, such as listening, copying from the blackboard or performing measurements in a recipe style of practical work.
13.5 The Teacher's Perception: An Interview

The teacher's approach was characterized in the last section as being one which fits the "Transmission" style (see Section 5.2). That characterization was done from the point of view of an observer supporting a view of knowledge which is antithetical to the one displayed by the teacher. In an interview, of about 35 minutes long, conducted at the end of the period of observations, I tried to identify the teacher's own views about his approach.

In the interview it became clear that the "cultural-transmission" perspective was one consciously adopted by the teacher. In the interview I asked him why he preferred to introduce the idea of refraction by a definition instead of referring first to a situation closer to the children's experiences as the bent-stick in the water. His reply was quite an elaborate one:

T) Hum that question is a very deep one actually isn't it? You know you've you've given a very good example there of probably something I do in all my teaching and really it is it goes very deep that question doesn't it? in that it is it's a question of teaching philosophy ... how do you get kids to learn .. and there are two methods as I see it .. one is you ask them to bring the ideas out for themselves and to learn really for themselves they do it themselves .. you just guide them and the other one the way I see it that I do it I I tell them what to do to begin with and then I try to relate what they've done to the things that they have experienced and I tell them more or less what lines to think along and I actually you know more or less spoon-feed them .. I suppose now I think that way is better because .. yeah .. but you know this is something I suppose this I thought I I gained of the years .. I think that way is better .. to actually .. tell them what them what to do and to actually tell them what results to look for .. because for the vast majority of them I don't think they are
actually capable of fitting together the facts for themselves hum possibly something like ten percent might be able to but I I would think ninety percent of them wouldn't get anything from it and that is why I question you see .. this idea of finding up by themselves was a great idea of the seventies and the sixties as well really I suppose .. Nuffield Physics in a way they just do a lot of experiments and they find out things for themselves .. now I don't agree with that I don't I don't think it really works .. it might work for a few of them but on the all I don't think it does work so I prefer to do it in the way I do it in the moment, but I I agree it's it's a very good question and it's a very deep one .. and I'm sure that it's just my view against somebody else's.

In this statement the teacher locates what he calls his "teaching philosophy" clearly at the transmission pole of a "Transmission-Discovery" dicotomy. In his perspective knowledge is something that is either discovered (but only a few pupils can do it even in a higher ability stream) or transmitted by the teacher (for the benefit of the vast majority). The constructivist idea that knowledge can be construed in an interactive negotiation does not seem to fit in the teacher's polarised dicotomy.

In another part of the interview I asked the teacher about his main concerns when preparing a lesson:

T) Doing? How do I do it? How do I plan it you mean?

I) Yes

T) I don't .. that is a very difficult question because you don't I don't think one does plan it as such .. what I think one does is to teach from experience in that you find that some things work and some things don't and so in the next year you tend to leave out or or amend the things that didn't work very well and start trying to change things and by .. you know say the seventh year of teaching which is where I am doing .. I don't think you do necessarily plan lessons as such I think what you tend to do is remember the things you're going to do and the things you're not going to do ...
Teaching, therefore, is regarded by this teacher as an empirical activity. The new ideas and modifications tried each year are however piecemeal innovations, not affecting the overall "Transmission" view, which underpins his approach:

T) ... there are only two things I try to remember .. one is the fact that there is a certain course pattern a certain syllabus that I am trying to teach them certain ideas I'm trying to get across in as interesting a way as possible to try to get them to enjoy it .. so you know in planning those are the true things really .. just to get something across and also to to make it as interesting as possible ...

From the lessons observed and the concerns voiced by the teacher, it is evident that the notion of the existence of children's prior knowledge is not part of his way of conceiving teaching. The knowledge to be put across is in its turn seen in connection to examination needs:

T) Well .. what we are trying to do in this school is to prepare them for an O-Level .. now hopefully in an ideal situation every child who comes to this school would take an O-Level in physics and will pass .. now that doesn't work because some of them don't enjoy physics in which case they drop it at the end of their third year hum also some of them are not intelligent enough to take O-Level physics and some of them although they like physics and although they take physics in the fourth and fifth years they are not intelligent enough to take O-Level and they what they do is to take CSE in physics ...

And the concern with examinations starts at an early stage:

T) .. but .. all we can do in the second and third year is to say to ourselves now .. what will be useful .. to .. not only to the kids but also to us should they decide to carry on with their physics in the fourth
and fifth years and the things that would be useful would be certain parts of that O-Level syllabus ...

In the interview I also asked the teacher what his views were on the importance and the place of physics in the curriculum:

T) Well I think it's a very important subject hum ... for various reasons ... I think the fact really is it has a great deal of relevance to everyday situations in that .. hum the sort of things the kids are going to experience in their everyday lives either when they are in school or even after they leave school so I think it's it's very important for this reason .. alone it is also important because .. it involves .. two parts of the curriculum which themselves are very important that is there is a fair amount of maths involved in physics and there is also a fair amount of English .. involved in physics there is the two things there is the fact that they've got to be numerous they've got to be able to .. work out any calculations that may come in their way and there is also the fact that they've got to be able to express themselves either .. well on paper and in and verbally they've got to be able to express themselves either in exams or just in class when they are doing accounts of experiments and so on ..

Of the three aspects valued by the teacher of physics as a subject, only one was effectively displayed in the lessons observed. His concern with the mathematical side of physics led him, for instance, to introduce the law of refraction even knowing that the class did not know what sine means. On the other hand the formalised way in which the topic of refraction was presented contrasts with his statements of the importance of physics to everyday life situations.

Another contradiction between the statement above and the teaching observed was the expressed concern with enhancing
the abilities of expression and the displayed teaching style which did not actually enable the pupils to use their language: for instance the conclusion of the experiments being written by the teacher. In this case the contradiction was dissolved by the teacher when asked to elaborate more on this point. It then became clear that what he had in mind when referring to linguistic expression was either the normative grammatical side of it (punctuation, spelling) or stylistic rules (writing concisely, writing complete short sentences). A concern that is consistent with the transmission style adopted by the teacher.

13.6 Summary

In this chapter a sequence of lessons during which the topic refraction of light was introduced to a third-year class was reconstructed from notes taken during the lessons. The approach adopted by the teacher was characterized as an effort in presenting "teachers' science" without considering the conceptions held by the children. Practical work, which was an activity that occupied a large part of the lessons, was carried on in a recipe-style and conveyed an empirical-inductivist view of science.

An interview conducted with the teacher at the end of the observations showed that a "Transmission" style approach was consciously adopted by the teacher who construed learning as a "discovery-transmission" dichotomy, but thought the first pole to be inadequate for the majority of the pupils. The knowledge to be transmitted was, in its turn, strongly related to examination needs (O-Level and CSE).
CHAPTER FOURTEEN

TOWARDS CONSTRUCTIVIST SCIENCE EDUCATION
14. TOWARDS CONSTRUCTIVIST SCIENCE EDUCATION

14.1 Introduction

In the first chapter of this thesis a conceptual framework considering different forms of knowledge (scientists', curricular, children's, teachers' and students' science) and their transformations and interactions was introduced. I pointed out then that the framework provided a distinct way by means of which science education could be conceptualized. I also proposed that the framework stressed the role played by pupils' conceptions which pre-exist formal teaching—"children's science"—in the process of conceptual change. The framework was therefore seen as being compatible with a constructivist view of human knowledge and with results derived from recent research in science education.

The forms of knowledge considered in the framework were discussed in detail in Part A (Chapters 2 to 6) of this study. When considering "scientists' science" in Chapter 2, I emphasized the change of perspective that occurred in philosophy of science since the late 50's. Among the representatives of the new view, which superseded the former empiricist tradition, particular attention was paid to the work of T.S. Kuhn.

Part B (Chapters 7 to 13) consisted of the presentation of four case studies in which aspects of physics education at secondary school level were investigated. The aim of Part B was twofold: first, the case studies were presented in order to illustrate the components of the conceptual framework by applying it to everyday practice; and second, this everyday practice was explored from the perspective offered by the
framework.

In Case Studies I and II the conceptual framework was applied comprehensively. Their presentation illustrated how a consideration of "scientists' science" and "children's science" can be used to inform the analysis of "curricular science" and of the interaction between "children's science" and "teachers' science". In Case Studies III and IV the focus was on the investigation of the classroom interaction component of the framework.

The analysis of the curricular materials in Case Studies I and II, the results of which are extensively described in Chapters 8 and 10, is presented in the form of a critique of curricular treatments of "Light and Colour" and "Force and Movement". As far as the classroom interaction component of the case studies is concerned the investigation illustrated some aspects of traditional teaching concerning the use of language and practical work. In contrast to most studies of classroom interaction, which focus on formal aspects only, the case studies presented here are also concentrated on the content of the interaction, particularly on the treatment of "children's science" by the teachers.

The form of presentation of the classroom interaction instances consisted of a critical analysis of both their form and content. The critical approach followed served the purpose of highlighting and stressing the contrasting points between the practices observed and the assumptions underlying this thesis with regard to the nature of knowledge in general and scientific knowledge in particular. In the
following sections of this chapter, dealing with implications of these assumptions for classroom practice and for "curricular science", these contrasts will be restated.

The case studies presented here can serve the pedagogical purpose of inducing teachers and student teachers to reflect on their own practice and the textbooks they use from the perspective of the assumptions of this study. To better serve this purpose, the case studies will have to be specially edited in order to conform to the more usual format of papers and materials for discussion in teacher training courses. One example of that is Zylbersztajn and Gilbert, 1981, a paper based on Case Study III.

In this chapter, I intend to go a step further from the level of criticism and to address some implications for science education from the point of view of a constructivist position. Some of these implications are already implicit in the critical analysis presented in the case studies, and an aim of this final chapter is to discuss them in a more explicit and comprehensive way.

In Section 14.2 I discuss the problem of conceptual change from a constructivist point of view. Sections 14.3 and 14.4 deal with implications for classroom interaction and "curricular science" respectively. Section 14.5 considers some areas for further research and development.
14.2 Conceptual Change

14.2.1 Children's Science and Conceptual Change. The constructivist position which underlies this study implies a view of knowledge that considers it as being constructed by the knower (interacting with the physical and social world), rather than a commodity being transferred. In the process of constructing, existing knowledge appears to play a substantial role in the incorporation of new knowledge to a cognitive apparatus. It is clear that such a view contrasts strongly with a traditional approach to teaching in which the teacher is privileged as a transmitter of information.

On the other hand, it also highlights a point which was not given due to consideration by the proponents of the curriculum reform movement of the sixties (Chapter 4). If on the one hand these developments tended to shift the centre of classroom activities from the teacher to the pupils (a positive feature in itself), then on the other hand they also tended to conceptualize that activity in terms of an inductive process of discovery. It is an irony that what became to be considered a radical new approach to science teaching, was, to a large extent, based on a philosophy of science in crisis and due to be soon superseded. Thus the former inherited a weakness of the latter.

Similar to the way in which the empiricist tradition tended to overlook the role played by theories and worldviews in the interpretation of empirical data, discovery learning approaches tended to overlook the fact that learners do approach their tasks with preconceived ideas which influence
the interpretation of their observations and even their perception of the task. In the case study presented in Chapter 12, this point is illustrated by the performance of a group of pupils doing a practical activity with lenses. Driver (1983) also presents a number of examples in which shortcomings of inductive discovery are pointed out.

These shortcomings can be seen as one of the reasons by which discovery learning approaches (guided or not) failed to exert a greater impact in teaching. Some teachers, for example the one interviewed in Case Study IV (Chapter 13), reject the approach in a straightforward manner as being ineffective for the great majority of pupils. Others, such as the one interviewed in Case Study III (Chapter 12), although using a curriculum (Revised Nuffield Physics) which stimulates the pupils' own activities and observations, will organize the group work in such a way as to present them with the right answers.

Driver (1975) and Wellington (1981) commented on the fact that pupils very quickly become aware that "right" answers are the ones actually valued by the teachers and start acting accordingly. In Case Study III this behaviour was illustrated in the instances where members of the group being observed re-directed the questions of the worksheet, which they were supposed to answer, to the teacher. In the same case study it was also shown how the teacher's preoccupation with the right answer led him to fail to notice cases in which the pupils' performance diverged from the intended one.

In overlooking the role played by "children's science"
in the process of learning, both the traditional and heuristic approaches seem to conceive the process of conceptual change as a movement from a **state of ignorance** to a **state of knowing**. In the one approach this movement is to be achieved by the teacher transmitting the knowledge, and in the other through the pupils' active involvement in an (often guided) discovery task.

The *dichotomy* "Transmission-Discovery" offers what seems to be a common way, for teachers and some research workers in science education to conceptualize the problem. The teacher in Case Study IV could not have been more explicit both in expressing the dichotomy and his adherence to a transmission view. Novak (1978), following Ausubel's ideas, uses a similar construct (albeit in a far more sophisticated way) when discussing a "Reception-Discovery" continuum of learning.

The framework proposed in this thesis offers an alternative formulation for the problem of conceptual change, by conceptualizing it as a movement from "children's science" to "students' science". This movement is usually mediated by the action of the teacher, and therefore frequently involves the interaction between "children's science" and "teachers' science".

As it was indicated in Chapter 6, "students' science" can present various forms of outcome among a group of pupils. Science teachers in general, quite naturally, have as their aim the maximizing of achievement of what was described as the "unified scientific outcome". That is the outcome in which pupils will have mastered the conceptions
they are supposed to learn, aligning their views with a particular instance of "curricular science".

The aim stated above is, in principle, a reasonable one, since it considers a move towards forms of understanding which, as part of our culture, proved to be highly successful in dealing with the physical world. Nevertheless, from a constructivist point of view, it would also be reasonable for teachers to accept sympathetically the fact that, for a number of pupils, this aim will not be achieved.

There appears to be a tendency for science teachers to consider those pupils who do not succeed in achieving examination standards as being in some ways intellectually less capable. The teacher of Case Study III, for instance, referred to physics as "... an important qualification that the kids have to . . . have . . . hum the bright ones anyway . . ." (Section 14.4.4). The teacher in Case Study IV pointed out that "... some of them are not intelligent enough to take O-Level physics and some of them, although they like physics, and although they take physics in the fourth and fifth years, they are not intelligent enough to take O-Level and what they do is to take CSE in physics . . . ." (Emphasis added).

The sort of view advanced by the teachers seems to be a strong component of the ideology of science teaching. It can be argued, however, that it fails to recognize two important points. Firstly, examination achievement does not necessarily mean sound science understanding. After all, even some U.K. university students in science show recurrences of "children's science", as research quoted in Chapter 3
demonstrates. Secondly, and more importantly, the fact that some pupils fail to align their views with those of "curricular science" does not necessarily mean that they are less intelligent than the ones who do. It can 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. After all, the great majority of people (including very intelligent academics who are not physicists) can survive quite well with pre-Galilean ideas concerning force and movement. And even physicists would prefer in some circumstances to think about "the flow of heat", or the "rising sun".

With the qualification above, I would like to come back to the problem of conceptual change. If it is accepted as a reasonable, though not absolute, aim, the next question which requires consideration is how it can be facilitated. Although most of the practical action in the field of alternative conceptions has been concentrated on their identification rather than on their transformation, some aspects related to the latter have been considered by researchers.

14.2.2 Revolution or Evolution? In a review of the work of several researchers present at a recent international conference, West (1982) suggested the existence of two main emphases in terms of their perspectives in relation to conceptual change. According to one, which he calls the "revolutionary" perspective, conceptual change involves the radical abandonment of an existing conception and its substitution by a new one. The other, which he calls the "evolutionary" perspective, stresses
continuity in the process of conceptual change, and the development of concepts through their integration and differentiation. The "revolutionary" perspective is represented in the work of Driver (1979), Erickson (1979), Nussbaum and Novick (1981), whilst the evolutionary perspective is more evident in the work of Sutton (1982a) and West (1982).

The two perspectives are not, however, mutually exclusive, and it would be more fruitful to regard them as complementary. In some cases it appears that the change to be achieved consists of a deep restructuring of the learners' knowledge; in others, the change would involve an extension in the richness and precision of the meaning that a pupil holds for a term. Strike and Posner (1982) distinguish the two situations by talking about "large-scale" conceptual change, which they labelled accommodation, and "small-scale" conceptual scale, labelled assimilation.

The first situation, i.e. a deep reconstructuring of the learners' knowledge, would, in general involve the learning of some central conceptions of a discipline which are not in consonance with the learners' preconceptions, such as for instance the composite nature of light (discussed in Chapter 8) or the inertial conception of motion (discussed in Chapter 10). Nussbaum and Novick (1981) suggest also as examples the learning of the particulate nature of matter, the energy view of heat, and heliocentric cosmology. Since the existing conceptions are usually inadequate for subsuming subsequent learning, the situation can be best conceived as involving, analogically speaking, a paradigmatic change of revolutionary
nature.

On the other hand, there are cases, probably more frequent, in which an extension on the meaning of a concept rather than its radical transformation seems to be needed. For instance the notion of force can be extended from the intuitive idea of pushes and pulls caused by "contact" to the idea of action at distance of electromagnetic or gravitational origins; the meaning of the word "work" can be extended to encompass its scientific denotation; the concept of energy can be differentiated in its forms and integrated with other ideas such as light, heat, sound, etc. Rather than a paradigmatic transformation I would like to suggest, as an analogy for these cases, the articulation of paradigms during periods of normal science. In the same way that scientific development can be conceptualized as a succession of periods of normal science and revolutions, science teaching can be thought of as involving a succession of both revolutionary and evolutionary approaches.

14.2.3 Stumbling or Building Blocks? In the review mentioned at the beginning of Section 14.2.2, West (1982) also points out that although researchers in the two perspectives tend to agree on the assumption that existing conceptions do play a vital role in the process of conceptual change, they differ on what this role is. He suggests that researchers with a revolutionary perspective "would see children's present knowledge as a potential barrier to subsequent learning" (stumbling blocks). On the other hand, researchers with an evolutionary perspective "would see prior knowledge as the
interpretative framework for subsuming subsequent learning" (building blocks).

It is clear that, in situations in which the "evolutionary" perspective is more appropriate, it will be more convenient to treat "children's science" as frames of understanding to be developed. The "status" of "children's science", in cases in which a "revolutionary" perspective seems to be more adequate, however, requires some clarification. West (1982) is certainly right in stating that researchers with the latter perspective see existing knowledge as a "potential barrier to subsequent learning"; but I would suggest that the key word in this statement is not "barrier" but "potential". In this case the message in the statement is not that pre-existing knowledge is necessarily a barrier, but it tends to become one if not properly considered by teachers and pupils.

If the pupils' existing perspectives are simply ignored or treated as irrelevant they are likely to act as stumbling blocks as far as conceptual change is concerned. If, on the other hand, pupils are given the chance to become more aware of the nature of their own conceptions, of the range of their applicability and of their limitations, it can be expected that their appreciation and acceptance (the former being a necessary but not sufficient condition for the latter) of the new perspective would be enhanced. When viewed from this angle, "children's science", rather than being a barrier can be used as a contrasting background that can actually facilitate the understanding of "curricular science".

It is relevant to notice that researchers assuming an
evolutionary perspective do, similarly, stress the importance of increasing the pupils' awareness of their own conceptions as a starting point for the extension and refining of their meanings.

14.2.4 Strategies for Conceptual Change. It seems therefore that either in situations which require a "revolutionary" perspective, or in the ones which are best dealt with from an "evolutionary" one, an increase in pupils' conceptual awareness is an important initial stage in any teaching strategy. But obviously, this is not enough for accomplishing conceptual change.

Researchers working from a "revolutionary" perspective argue in general for a "conceptual conflict" strategy. According to it pupils are expected to restructure their conceptions in order to accommodate results that present discrepancies when compared to predictions and/or explanations derived from their own ideas. These approaches are best summarized in the guidelines for the designing and sequencing of learning activities proposed by Nussbaum and Novick (1981):

1. Create a situation which requires pupils to invoke their conceptions in order to interpret it.
2. Encourage the pupils to describe verbally and pictorially their ideas.
3. Assist them to state their ideas clearly and concisely.
4. Encourage the debate of the pros and cons of different interpretations of pupils.
5. Create a "cognitive dissonance" between the conceptions presented and some phenomenon which cannot be explained by them.
6. Support the search for a solution and encourage signs
of forthcoming accommodation. Encourage the elaboration of the new conception when it is proposed.

Nussbaum and Novick applied their guidelines to the teaching of a "particulate" model of gaseous matter to young Israeli and American adolescents holding a "continuous" model. They claim that some pupils were able to propose by themselves that a "particulate" model could better explain the phenomenon introduced to create cognitive conflict, and that during the discussion on Phase 6 of their approach this view gained increasing support from the rest of the class.

It would be extremely optimistic however to expect that in general the pupils will be able to reach, by themselves, the accepted curricular conceptions. Most likely, these conceptions will have to be introduced by teachers didactically. Their role in this case would be comparable to a scientist trying to convert others to a new paradigm. They will have to introduce the new conceptions to the group, and to function as the "translators" Kuhn talks about (Section 2.3.5) when describing inter-paradigmatic debates. They will have to suggest to their pupils that their old experiences and conceptions, although sensible and useful from a personal point of view, can be more fruitfully substituted by the new ones. An understanding of the pupils' conceptions on the part of the teacher seems essential in this case.

The fact that the new conceptions will have to be introduced by the teachers does not invalidate the approach proposed by Nussbaum and Novick, since the preparation done in Phases 1 to 5 is, as argued before, an essential component
in the process of conceptual change. Furthermore, the approach can be regarded as a good exercise to foster creativity and debate in the classroom. Provided that the ideas advanced by the pupils are treated respectfully by teachers (for instance by stressing whenever possible parallels between these ideas and former scientific views) the approach can also induce pupils to be more confident in their use of language and in their power of constructing knowledge.

Researchers working with an "evolutionary" perspective would probably agree with the general features of Phases 1 to 4 from the guidelines proposed by Nussbaum and Novick. They would, however, in the next stage, emphasize the linkages between the new and the previous knowledge and "make pedagogical applications that place stress on relationships, integration and differentiation" of concepts (West, 1982). Particularly important, in this context, is the notion of meaningful learning (Ausubel, 1968), in which new knowledge is incorporated in more general structures. Sutton (1981b) points out that an important job for the teacher is to identify points at which these new ideas can be attached, and to build "cognitive bridges" between the new ideas being presented and children's earlier experiences. It has been suggested (e.g. Sutton, 1978; Pope and Gilbert, 1983) that a more deliberate use of metaphors and analogies as a pedagogical tool can help the building up of these cognitive bridges.
14.3 Implications for Classroom Interaction

14.3.1 Language in the Classroom. From what has been said it should become clear that approaches, such as the ones discussed above, would have implications for the way in which language is used by teachers and pupils in the classroom. A constructivist approach, either from a "revolutionary" or from an "evolutionary" perspective, would require plenty of opportunities for pupils to use language for sorting out and restructuring their conceptions. It seems, however, that science classrooms do not, in general, offer enough opportunities of this kind.

In Chapter 5 it was pointed out that in science lessons language is, for most of the time, under the control of the teacher. This dominant role played by the teachers in the use of language was illustrated in the case studies presented in Part B of this thesis. It was shown, for instance, how formal classroom discourse following the pattern—Opening by the teacher, Reply by a pupil, Follow-up by the teacher—can be detrimental for the emergence and consideration of pupils' ideas. In this pattern of discourse questions presented by the teacher are not aimed at the exploration of pupils' ideas, with their participation in the discourse being restricted to the voicing of short phrases, which are only valued if they fit the teacher's line of presentation. In such a case formal classroom discourse can be likened to a verbal game, the rules of which are implicitly accepted by teacher and pupils (Sinclair and Coulthard, 1975; Stubbs, 1976; Edwards and Furlong, 1978).

But is is not only in formal classroom discourse
situations that opportunities for pupils to actively use their language are restricted. In Case Study III (Chapter 12), it was illustrated how the interaction between the teacher and a group of pupils performing practical work was used by the teacher for the transmission of his knowledge rather than for exploring the knowledge of the group. In Case Study IV (Chapter 13), the writing up of practical work was so tightly constrained by the teacher that even the conclusions were phrased by him. The only task left to the pupils was to fill blank spaces with the data from their measurements. In one case (Snell's law experiment) they did not know the meaning of the numbers they were filling in (sine of an angle).

In connection with the use of language it may be helpful to consider the distinction between "Transmission" and "Interpretation" teachers (Barnes, 1976), already described in Chapter 5. Barnes assumes a relation between the teachers' view of knowledge and their use of language in the classroom. "Transmission teachers" tend to regard language primarily as a means of communicating ideas (generally from them to the pupils). They will tend therefore to see classroom discourse as a way of transmitting their views to the pupils, not realizing that sometimes they may be trying to impose a structure over another structure which already exists. They will also tend to value normative rather than creative uses of language. This tendency is illustrated, for instance, by the views on language of the teacher of Case Study IV, which were mostly concerned with its normative, grammatical and stylistic features (Section 13.5).
"Interpretation teachers", in their turn tend to see language not only as an instrument by means of which meaning is received from others, but also as a tool to think with, by means of which meaning is constructed and interpreted by the knower, and knowledge reshaped. It is clear that a constructivist view of knowledge implies an interpretation view of language. The adoption of such a view will require a shift from language controlled almost totally by teachers to a wider use of opportunities for pupils to use language by talking, writing and reading.

One way in which the use of written and spoken language by pupils can be fostered is through approaches similar to the one proposed by Nussbaum and Novick (1981), in which pupils have a chance not only of becoming more aware of, and to systematize, their own views, but also to discuss other people's ideas.

Sutton (1981b) proposes the use of what he calls "burr diagrams" as a way of helping both teachers and pupils to get insights into the pupils' patterns of connotations in relation to a particular concept. A key word related to the topic under consideration is written in the centre of a page or on the blackboard and pupils are encouraged to talk about it. Words arising during the talk are linked to the central thematic word, with the key connections (those leading to the curricular denotation of the word) being stressed by the teacher. Some of the curricular meanings of the word will have to be introduced didactically by the teacher, since some of the ideas of science are too remote from everyday life experience and talk. The usefulness of the exercise resides
in preparing the pupils (by having to sort out their own meanings for the word) to explore other people's thoughts. Sutton argues that care must be taken in the process not to dismiss the idiosyncratic connotations made by pupils as peripherical and dispensable, since they very often give reality to the new idea being taught, by making it more tangible and visual. The aim of the approach is therefore to offer the chance for pupils to enrich and reappraise the personal connotative meanings of a concept with a more consensual denotative one.

Diagnostic questionnaires, such as for instance the one used by the teacher in Case Study II (Chapter 11) constitute another technique which allows teachers to assess the general patterns of conceptions in a class in a relatively short period of time. At the same time, by answering the questionnaire the pupils can become more conscious of their own conceptions. As argued before, this consciousness is regarded as the most important pre-condition for conceptual change.

A comparison of the lessons analysed in Case Studies I and II shows a higher degree of pupils' initiative and participation in the classroom discourse in the second case. One difference between the lessons was that the first was based on a demonstration and the second on a diagnostic questionnaire, and that could be one of the factors influencing pupils' behaviour. The act of answering the questionnaire prepared them for the interaction with the teacher by making them more aware of their own conceptions and by signalling the possible development of the lesson.
But Case Study II (Chapter 11) also illustrated the difficulties faced by the teacher (in spite of her experience) in dealing constructively with the instances of "children's science" advanced by the pupils in the questionnaires and during the lesson. Instead of exploring them from a respectful point of view, she dismissed them (through negative evaluation and unfair analogies) and from the very beginning pressed with the presentation of "teachers' science" (Section 11.3).

14.3.2 Group Discussion. In the case study commented above the diagnostic questionnaires were answered individually by the pupils. The task however can also be done in small groups. The use of small group discourse has been advocated by Barnes (1976) on the grounds that it induces pupils (by having to communicate their ideas to their peers) to use language as a thinking tool as well. The approach is not, however, without risks for its success depends on careful choice of materials and planning from the part of the teacher.

Hornsey and Horsfield's (1982) study of group work, involving first to third-year science pupils, suggests "that if pupils are allowed to develop as groups, which have been carefully mixed and prepared, then the language and social interactions are educationally worthwhile". They noticed a relatively high number of speculative questioning and answering by the pupils, more reasoning than recall, and longer utterances (when compared to the ones in formal classroom discourse). On the other hand, the linking of existing knowledge with the materials presented for discussion
was infrequent, and that may indicate "... the need for further investigation into the nature of materials selected, or perhaps, closer examination of social pressures generated amongst pupils who had little experience of teacher-less groups".

In spite of its potential, the use of groups in science teaching currently appears to be restricted to practical work, and even so, mostly to serve organizational purposes (e.g. quantity of equipment not enough for providing each pupil with a set) rather than as a teaching strategy (Sands, 1981).

14.3.3 Practical Work. Practical work is one sort of activity which could, in principle, induce groups of pupils to talk and write about their ideas. It has also a well established tradition in British science teaching, and more often than not pupils spend most of their time in science lessons involved with it. Beatty and Woolnough (1982) point out that in a large sample of teachers in England and Wales, 83% of them reckoned to spend between 40 and 80% of their time on practical work. That research was directed to the 11-13 year band, and my own observations in the 13-16 band, although less representative, conveyed the impression that a large share of science teaching time was dedicated to some form of practical work.

It seems, however, that the full potential of this activity is rarely explored. Sands (1981) investigated groups of first to third year children doing practical work in six comprehensive schools involving 13 teachers. He observed very
little imaginative talk, with the pupils for most of the
time working mechanically through their worksheets. He
suggests that this behaviour can result from the way in
which the tasks were set by the teacher. Rarely was there
a constructive discussion involving the sharing of experiences
between groups before and after the manipulation of the
apparatus. When follow-ups were observed they consisted
of writing the results of each group on the board, with a
brief summary and instructions for the writing-up of the
experiment.

The two case studies involving practical work presented
in this thesis shows aspects which illustrate these points.
In Case Study III (Chapter 12) the group observed started
the work by following mechanically (although not correctly)
the instructions of the worksheet. Perhaps some of their
problems could be avoided if a class-and/or group discussion
about the aims and procedures were organized beforehand.
The follow-up by the teacher did not include a discussion of
the conclusions and problems faced by each group; it consisted
of the teacher summing-up some of the points he considered
relevant.

Case Study IV (Chapter IV) illustrated an extreme instance
of pupils being guided through a sequence of measurements and
calculations, the full meaning of which they were not aware of.
The approach followed by the teacher seemed to value more a
neat presentation of the writing up (Apparatus, Method,
Results, Conclusion), than any discussion about the practical.
Even the phrasing of the conclusions was presented by him.
Practical work can be an instrument for promoting awareness of one's own ideas and of other persons' ideas. It can also help conceptual change and conceptual consolidation. For this to happen, however, the "hands on apparatus" approach is not enough. More important than this would be to encourage discussion before and after the "experiment" in which predictions and conclusions are talked about; to encourage the reading not of recipe-style worksheets, but of less directive materials that would require inter-group discussion; and to encourage and value original writing up of the activity.

14.4 Implications for Curricular Science

In Chapter 4 of this thesis it was pointed out that "curricular science" tends to be based on (often implicit) and to reflect assumptions concerning the nature of human knowledge in general and scientific knowledge in particular.

It can be argued for instance that the style of presentation of traditional textbooks (represented in this study by Abbot's O-Level Physics, Nelkon's CSE Physics and Jardine's Nat Phil) can be seen as, both a product of, and an instrument for, the reproduction of a Transmission view of knowledge. On the other extreme, materials developed during the curriculum reform movement of the sixties (represented in this study by Revised Nuffield Physics) followed in general a discovery learning approach. In Section 14.2.1, I stressed the fact that both approaches fail to consider properly the implications of a constructivist view of knowledge for science education.
In the previous section I discussed some implications for the classroom, derived from the constructivist perspective assumed in this study. Science curricula assuming such a perspective will have to incorporate in their design ways of actualizing such implications. In particular a consideration of "children's science" in the design of instructional sequences will be required, including materials with potential for inducing the use of writing, speech and reading and an "Interpretation", in the sense proposed by Barnes (1976), use of language. Being a new development, including a view of knowledge different from the ones governing existing curricula, the design of teachers' guides would seem to be as important as material designed for pupils' activities.

With regard to the nature of scientific knowledge, it was pointed out in Chapter 4 that "curricular science" tends to convey an empiricist view of science. According to this view scientific knowledge is conceived as being derived purely from neutral observations of nature. The fact that such a view was superseded by developments in the philosophy of science which took place in the last quarter of a century, was discussed in Chapter 2.

There seems therefore to be a need for "curricular science" to introduce in a more explicit way updated views concerning the nature of science as a human enterprise. The idea that science education should aim as well at the exploration of science as a cultured activity, taking into account its history, philosophy, was voiced by several authors (e.g. Elkana, 1970; Brush, 1974b; Ebison, 1974; Russell, 1981).
This idea was also advanced in ASE (1979) and incorporated in "Education through Science", the most recent policy document of the Association for Science Education (ASE, 1981).

In this study, I singled out Kuhn as a representative of the modern "Weltanschauungen" perspectives which superseded the empiricist tradition of philosophy of science (Chapter 2). His views, considering the role of paradigms influencing the development of scientific theories, are compatible with a constructivist perspective of human knowledge. But I do not want to imply that his views are unique in this respect. Popper (1968), Lakatos (1970), Toulmin (1972) and Feyerabend (1975), for instance, fall in the same category.

I am not advocating that science curricula are to be transformed in courses on philosophy or history of science. I would argue, however, that the use of suitable historical examples could be instrumental in conveying ideas about the nature of scientific knowledge. The prevalence of the Newtonian paradigm in Optics, in spite of some of its obvious inadequacies, and the resulting hostility towards Young's ideas in England (Sections 8.2.3 and 8.2.4a) can be used as an illustration of the conservative role played by paradigms in science. Similarly Kepler's mystical ideals in relation to the Sun (Kuhn, 1977b) can serve as an illustration of the influence of broader worldviews in the development of scientific theories. It should be not surprising that such examples are not usually part of "curricular science" based on an empiricist tradition.
A more careful consideration of the history of science can also serve the purpose of helping the teaching of some concepts, mainly when parallels can be drawn between "children's science" and past scientific ideas. As it was shown in Chapter 10, for instance, the usual presentation of the inertial view on motion is based on assumptions which are not warranted by the history of science. On the other hand, no mention is made to the "impetus" theory of motion developed during the Middle Ages, to which a common pattern of "children's science" is similar. By stressing such similarities, "curricular science" can induce teachers to consider with more respect their pupils' alternative conceptions. It can also help pupils to see the value of their constructions, and at the same time by showing how similar ones changed in the course of history, it can help them to reconstrue their views.

Modifications in science curricula such as the ones suggested above will require an appraisal of the content of the already overloaded syllabuses at CSE and O-Level. If more time for pupils' use of language is to be given, and if a more serious treatment of history and philosophy of science is to be included, part of the existing content will have to be left out. I can only agree with the comment of Driver (1983) that "perhaps curtailing the syllabus is not too great a price to pay if as a result pupils gain greater confidence in their understanding of the ideas covered". But it must also be realized that curtailing the syllabus is not a trivial decision for a teacher, or department to take in an examination-oriented system. Collective coordinated
action leading to negotiations with the examining boards will have to be considered.

14.5 Further Research and Development

In the previous sections of this chapter I consider some general implications of a constructivist view of knowledge for classroom interaction and for science curricula. In this final section I will suggest some areas which the writing of this study indicated as needing further research and development.

14.5.1 Children's Science. The number of studies concerning children's ideas about specific concepts in science have increased considerably in recent years. Physics however has been a privileged discipline when compared to biology and chemistry. But even in physics, some areas have been far more investigated than others, as for instance mechanics. Other areas like electricity and heat received less, but still considerable attention. On the other hand, optics was very little explored (Chapter 8), and sound apparently not investigated at all. Since information concerning children's conceptions can be helpful for teachers and curriculum planners, it is desirable to extend the investigation of children's conceptions to those areas which so far have been almost completely ignored.

Apart from the exploration of children's ideas about specific concepts, there is also scope for research on more general characteristics of "children's science". In Section 3.4.2 some general patterns of understanding in "children's
science", suggested by Gilbert, Watts and Osborne (1982) were presented. Those patterns were identified in relation to concepts in mechanics and further studies concerning their generality (over populations of pupils and over different concepts) are recommendable. Other general characteristics which deserve further exploration are notions such as physical laws and regularities (Rodrigues, 1980) and conceptions of science and scientific method (Swift, 1981). In relation to the latter, it would be interesting to investigate the effect exerted by the media (TV, cinema, comics) in the development of children's ideas.

14.5.2 Students' Science. In Chapter 6 some general outcomes of science teaching, based on a categorization suggested by Gilbert, Osborne and Fensham (1982) were presented. A further category not described by these authors was identified, and that seems to indicate the need of further explorations concerning the comprehensiveness and generality of these categories. As in the case of the patterns of understanding in "children's science" these categories can serve useful descriptive purposes, but they need to be vindicated by further research.

In their research Gilbert, Osborne and Fensham (1982) did not investigate how the suggested outcomes of science teaching are related to the context in which they were developed, since their aim was to use the categories for descriptive purposes only. It seems desirable to extend the scope of the research and to explore, for instance,
whether (and how) the outcomes described can be linked to the pupils' initial conceptions and to their learning experiences. The investigation of such connections can throw some light on the process of conceptual change.

14.5.3 Conceptual Change. Research on strategies for conceptual change from a constructivist point of view have been until now conducted on a limited scale with researchers being more concerned with the identification of children's ideas than with their transformation. Studies such as the one conducted by Nussbaum and Novick (1981), involving the development of a strategy and its implementation for the teaching of a specific concept have been the exception rather than the rule.

General ideas and strategies have been proposed in research papers, and books specially directed to an audience of teachers were recently published (Sutton, 1981c; Driver, 1983). Such efforts are commendable, since they can rouse the teachers' awareness for the new view and even induce some of them to try and develop the recommendations by themselves. But if science education based on a constructivist perspective is to bridge the gap between science education journals and science classrooms, researchers in the field will have to meet the challenge of testing their approaches in real situations and well defined contexts. What sort of material can, for instance, be used to induce a group discussion directed to help pupils to become more aware of their views about a specific concept? What experiment can be used to challenge another specific concept? What analogy, metaphor
or historical example can be employed by a teacher to facilitate the understanding of a new interpretation? If an innovation is to succeed, it is their proponents task to show it in action.

The implications for the classroom described in Section 14.3 offer a basis for developments but their actualization in teaching methodologies, however, will require their testing in real classrooms. Probably the best arrangements for such developments will consist of a cooperative enterprise between research workers and school teachers, that could lead to the breaking of barriers between teaching and research.

14.5.4 Curricular Science. Developments towards a technology for constructivist science teaching will have to be, if such a perspective is to become wider disseminated, incorporated in the design of new science curricula. This is a task that will demand a high degree of articulation between teachers and researchers and political negotiations with the examining boards, since modification in the content and in the forms of assessment of existing syllabuses will be required. In the development of new curricula a considerable amount of material resources is also needed, and in the present climate these do not seem to be available.

The considerations above seem to indicate that the design, testing and implementation of new comprehensive curricula is not a development to be accomplished in the near future. Meanwhile, there is still scope for more piecemeal sort of research and development, that can pave the way for developments on a larger scale.
In Chapters 8 and 10, a sample of curricular materials was investigated in relation to the topics "Light and Colour" and "Force and Movement". The result was a critical analysis of such materials, informed by a study of "scientists' science" and "children's science". This sort of analysis can be helpful to teachers, curricula developers and textbook writers, by pointing at problems with the existing presentations. The exploration presented in this study was restricted to two topics and a sample of four textbooks. I would suggest the desirability of conducting studies of the same sort in other central topics of school science, and to extend the sample of textbooks, including for instance A-Level materials.

A sort of development which could be helpful for teachers wishing to redirect their practices towards a more constructivist perspective is the production of materials designed to be used in conjunction with existing textbooks and syllabuses. Watts and Gilbert (1983) are producing a series of booklets centered on specific physics concepts (force, gravity, energy, light and heat). These booklets consist of a diagnostic questionnaire, an exploration of the curricular treatment of the concepts, a description of patterns of children's conceptions identified in interviews and questionnaires and recommendations for their use.

14.5.5 **Teacher Education.** One area in which urgent research and development seems to be needed is teacher education. Here I am using the term education in the broadest possible sense, including not only pre and in-service training of science teachers, but education as a process aiming at the
arousal of one's consciousness.

In the same way that pupils develop their own conceptions about science concepts, teachers do develop their own views about the nature of knowledge and education. Most of practising teachers and teacher trainees have been educated in a system based on a non-constructivist approach to knowledge and on an empiricist view of the nature of scientific knowledge. As such they tend to conceptualize their educational problems inside this framework, and researchers must be aware that the problems as identified by teachers and teacher trainees are likely to be different than the ones identified by them (Olson, 1981a).

But the adoption of a constructivist view of science education will require the acceptance of such a view by teachers, and for most of them this will imply a conceptual change. The development of new curricular materials, the publication of books and of research papers supporting the new view can be helpful in inducing some teachers to reflect upon their practice from a different perspective, and possibly to change it. But this sort of incidental education will not be enough.

The creation of opportunities and the development of materials and strategies for teacher education (pre and in-service) would seem to be essential. It would seem important, however, for such education to follow a constructivist approach, starting with a critical reflection on the part of the teachers of the existing practices and materials, and of the usually "taken for granted" assumptions underlining them. It is in this context that the discussion of case studies such as the
ones presented in this thesis can serve the pedagogical purpose of offering to teachers and trainees the chance of reflecting on existing practices and provisions, as a starting point for the acceptance of new ones.

The creation of opportunities for teacher education, however, seems to be restricted to formal courses. One encouraging new avenue for the introduction of changes in science education is the recently established Secondary Science Curriculum Review Project (West, 1982). It is the aim of that project to promote the development of new approaches to science teaching through the interaction between science teachers and researchers. It would be advisable for those researchers advocating a constructivist approach to involve themselves in such, or similar, collaborative efforts.

In this sort of common undertaking, researchers can help teachers to become more aware of recent developments, and on the other hand be helped by teachers to become themselves more aware of the practical problems related to the introduction of educational innovations. Through this process of mutual education, maybe, the right combination between research and practice can be approached.
REFERENCES


OSBORNE, R.J. and GILBERT, J.K. (1979): An approach to student understanding of basic concepts in science. I.E.T. University of Surrey.


RAMAN, V.V. (1975): The energy conservation principle. The *Physics Teacher*, 13(2), 80-86.


APPENDIX

A Summary of Sinclair and Coulthard's Scheme for Analysis of Classroom Discourse

(based on Sinclair and Coulthard, 1975 and Open University, 1979)

A.1 Introduction

According to Sinclair and Coulthard, lessons in which the teacher is in front of the class, interacting with it as a whole, can be decomposed in five ranks: Lesson (L), Transaction (T), Exchange (Exch), Move (M), Act (A). These ranks are hierarchically organized, that is, the major units are composed of a number of the less inclusive ones: a lesson is composed of a number of Transactions, which are composed of Exchanges, and so on (Fig. A.1).

Fig. A.1 The structure of lessons
A.2 Description of the Ranks

A.2.1 Acts. These are the units at the lowest rank of discourse. Sinclair and Coulthard propose twenty-two acts, which are defined in terms of their discourse function (Table A.1). Although they claim that these Acts are sufficient to describe all classroom discourse, in a few occasions I find it impossible to classify some Acts according to the categories suggested. In such occasions I classified the Acts as Others (Oth).

<table>
<thead>
<tr>
<th>Table A.1 Definition of Acts (Coding Categories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(According to Open University, 1979)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LABEL</th>
<th>SYMBOL</th>
<th>REALIZATION AND DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>marker</td>
<td>m</td>
<td>Realized by a small class of items - 'well', 'OK', 'now', 'good', 'right', 'alright'. When a marker is the main item in a framing move, it has a falling intonation, and is followed by a short pause. Its function is to mark boundaries in the discourse.</td>
</tr>
<tr>
<td>starter</td>
<td>s</td>
<td>Its function is to provide information about, or direct attention to, or thought toward, an area in order to make a correct response to the initiation more likely.</td>
</tr>
<tr>
<td>elicitation</td>
<td>el</td>
<td>Its function is to request a linguistic response.</td>
</tr>
<tr>
<td>check</td>
<td>ch</td>
<td>Realized by a small class of polar questions concerned with being 'finished' or 'ready', having 'problems' or 'difficulties', being able to 'see' or 'hear'. They are 'real' questions, in that, for once, the teacher doesn't know the answer. (If he does know the answer to, for example, 'are you listening', it is a directive, not a check.) The function of checks is to enable the teacher to ascertain whether there are any problems preventing the successful progress of the lesson.</td>
</tr>
<tr>
<td>directive</td>
<td>d</td>
<td>Its function is to request a non-linguistic response: to get the pupils to do something.</td>
</tr>
<tr>
<td>informative</td>
<td>i</td>
<td>Its sole function is to provide information. The only response is an acknowledgement of attention and understanding.</td>
</tr>
</tbody>
</table>
prompt p Realized by a small class of items - 'go on', 'come on', 'hurry up', 'quickly', 'have a guess'. Its function is to reinforce a directive or elicitation by suggesting that the teacher is no longer requesting a response but expecting or even demanding one.

cue cl It is subordinate to the main item in an initiation and functions by providing additional information which helps the pupil to answer the elicitation or comply with the directive.

cue cu Realized by a small class of utterances, examples of which are 'hands up', 'don't call out', 'is John the only one'. Its sole function is to evoke an (appropriate) bid.

bid b Realized by a small class of verbal and non-verbal items - 'Sir', 'Miss', teacher's name, raised hand, heavy breathing, finger clicking. Its function is to signal a desire to contribute to the discourse.

nomination n Realized by a small class consisting of the names of all the pupils, 'you' with contrastive stress, 'anybody', 'yes', and one or two idiosyncratic items such as 'who hasn't said anything yet'. The function is to call on or give permission to a pupil to contribute to the discourse.

acknowledge ack Realized by 'yes', 'OK', 'cor', 'mm', 'wow', and certain non-verbal gestures and expressions. Its function is simply to show that the initiation has been understood.

reply rep Its function is to provide a linguistic response which is appropriate to the elicitation.

react rea Realized by a non-linguistic action. Its function is to provide the appropriate non-linguistic response defined by the preceding directive.

comment com Realized by statement and tag question. It is subordinate to the main item in the move and its function is to exemplify, expand, justify, provide additional information. On the written page, it is difficult to distinguish from informative because the outsider's ideas of relevance are not always the same. However, teachers signal paralinguistically, by a pause, when they are beginning a new initiation with an informative as its main unit; otherwise they see themselves as commenting.

accept acc Realized by a small class of items - 'yes', 'no', 'good', 'fine' and repetition of pupil's reply, all with neutral low fall intonation. Its function is to indicate that the teacher has heard or seen and that the informative, reply or react was appropriate.

evaluate e Realized by statements and tag questions including words and phrases such as 'good', 'interesting', 'team point', commenting on the quality of the reply, react or initiation, also by 'yes', 'no', 'good', 'fine', with a high fall intonation and repetition of the pupil's reply with either high
fall intonation and repetition of the pupil's reply with either high fall (positive) or a rise of any kind (negative evaluation).

**silent stress**  
Realized by a pause of the duration of one or more beats, following a marker. If functions to highlight the marker when it is serving as the main item in a boundary exchange indicating a transaction boundary.

**metastatement**  
Realized by a statement which refers to some future time when what is described will occur. Its function is to help the pupils to see the structure of the lesson, to help them understand the purpose of the subsequent exchange, and see where they are going.

**conclusion**  
Realized by an anaphoric statement, sometimes marked by slowing of speech rate and usually the lexical items 'so' or 'then'. In a way it is the converse of metastatement. Its function is again to help the pupils understand the structure of the lesson but this time by summarizing what the preceding chunk of discourse was about.

**loop**  
Realised by a small class of items - 'pardon', 'you what', 'eh', 'again', with rising intonation and a few suggestions like 'what did you say', 'what do you mean'. Its function is to return the discourse to the stage it was at before the pupil spoke, from where it can proceed normally.

**aside**  
Usually marked by lowering the tone of voice, and not really addressed to the class. It is really instances of the teacher talking to himself, 'it's freezing in here', 'where did I put my chalk'.

In the following illustrative sequence the Acts are identified. Some of the conventions used in this study are also shown. For instance, the numbers in front of the symbols for the Acts represent the order in which they appeared in the lesson they were extracted from.
The sequence starts with a metastatement (act 016) in which the teacher describes in general terms what the lesson will be about. This is followed by a short informative act (017), a marker (018), and a starter (019). In act 020 the teacher tries to elicitate an answer from the pupils, and in act 021 she offers a clue. Act 022 is a prompt used to reinforce the elicitation. In act 023 a boy answers the question and his answer is evaluated in act 024.

A.2.2 Moves and Exchanges. These are constituted by a number of acts. There are five classes of moves and these realize
two classes of Exchanges: **Boundary** and **Teaching Exchanges**.

a) **Boundary Exchanges** (B). Their function is to signal the beginning or the end of the major units in a lesson (Transactions). Boundary Exchanges are realized by two classes of moves.

**Framing** (Fr): Indicates a boundary between large units in the discourse (Transactions).

**Focussing** (Fo): Indicate the direction in which the lesson is going to proceed or are used to summarize a discussion.

In the following sequence a Boundary Exchange (Exch 001) composed of a Framing and a Focussing Move is illustrated.

<table>
<thead>
<tr>
<th>Number of the Exchange</th>
<th>Type of Exchange</th>
<th>Class of Move</th>
<th>Move</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>B</td>
<td>Fr</td>
<td></td>
<td>T). OK .....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fo</td>
<td></td>
<td>. we want to look at the combination of colours</td>
</tr>
<tr>
<td>002</td>
<td>E</td>
<td></td>
<td>0</td>
<td>if I ask you what the primary colours are?.....</td>
</tr>
<tr>
<td>003</td>
<td>Re-1</td>
<td></td>
<td>0</td>
<td>. what sort of answers?..</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>. I can get two different sort of answers always</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>B). Blue red and yellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B). Blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B). Yellow yellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ss). Red blue and yellow</td>
</tr>
</tbody>
</table>

Lines indicating the starting of a Exchange
b) Teaching Exchanges. These are defined as the individual steps by which the lesson progresses (Sinclair and Coulthard, 1975) or a minimal interactive unit of conversation, for example a question followed by its answer (Open University, 1979). Three classes of Moves appear in Teaching Exchanges.

Opening (O): Often performed by the teacher but sometimes by pupils. Its function is usually passing on an information, directing an action or eliciting an answer.

Answering (A): A verbal reply to an elicitation, or a non-verbal reaction to a directive, usually performed by the pupils.

Follow-up (F): Usually serves the function of providing a feed-back to the pupils in relation to an answer, or to a piece of information advanced without elicitation. This sort of Move is seldom performed by pupils. In the structure of classroom discourse Follow-up Moves are used to close Teaching Exchanges.

Sinclair and Coulthard consider the following categories of Teaching Exchanges.

Teacher Inform (I): This exchange is used when the teacher is passing on facts, opinions, ideas, new information to the pupils. The pupils may, but usually do not make a verbal response to the teacher's initiation. Often it consists only of an Opening Move. In the following sequence, Exch 076 constitutes an example of a Teacher Inform Exchange.
Dearest dear me, yeah... do go on.

A B). Ah.. red orange yellow green

F T). Oh well done red orange yellow green blue indigo violet

yellow comes sort of between red and green so perhaps our well it's really our brain responds to the average of red and green and sees it as the yellow. That's how we respond to the sort of combination or average of the red and green.

Teacher Direct (D): This category covers all exchanges designed to get the pupils to do but not to say something. Realized by an Opening Move followed by a non-verbal Answer Move. Sometimes a Follow-up move is also included. In the sequence below Exch 036 is an example of a Teacher Direct Exchange.
Teacher Elicit (E): This category includes all exchanges designed to obtain verbal contributions from pupils. Very often it is used by the teacher to move the class step by step to a conclusion. In most of the cases it is realized by a sequence of Opening, Answer and Follow-up Moves. It is considered the most common type of Exchange in classroom discourse. Represented by Exch 038 in the following example.

<table>
<thead>
<tr>
<th>Exch</th>
<th>Type</th>
<th>Move</th>
<th>Text</th>
<th>Rep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>038</td>
<td>E</td>
<td>O</td>
<td>T). What colours have we got there? ..</td>
<td>100 el</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B). Red blue and green</td>
<td>101 rep</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>T). Red blue and green</td>
<td>103 e</td>
</tr>
<tr>
<td>039</td>
<td>I</td>
<td>O</td>
<td>. and we've now added .. what we could describe as a pinky red yeah? and a bluey green ...</td>
<td>103 i</td>
</tr>
</tbody>
</table>

Pupil Elicit (P-E): Characterized by an Opening Move in the form of a question, performed by a pupil. Represented by Exch 046 below.

<table>
<thead>
<tr>
<th>Exch</th>
<th>Type</th>
<th>Move</th>
<th>Text</th>
<th>Rep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>045</td>
<td>E</td>
<td>O</td>
<td>T). What does gravity do to it?</td>
<td>129 el</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B). (Roberts) Bring it down</td>
<td>130 rep</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>T). Yeah</td>
<td>131 e</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B) (Roberts). It forces</td>
<td>133 rep</td>
</tr>
<tr>
<td>047</td>
<td>E</td>
<td>O</td>
<td>T). What's the what's the result of that downwards force of gravity on the ball?</td>
<td>134 el</td>
</tr>
</tbody>
</table>
Pupil Inform (P-I): Information advanced by a pupil without request on the part of the teacher. Represented by Exchs 092 and 094 in the following sequence.

091 E 0 Roberts do you still feel that remote control you know your superforce are you you can act after you stopped touching the ball?..
A B) (Roberts) No .. but the force you put into the ball carries on going in that direction and that is what I want to say put it in that way gravity won't pull it straight down
F B) Yeah

092 P-I 0 B) It comes down gradually

093 I 0 T) I would like to do a swap .. in ideas there .. hum ... in that your force acts while you're in contact with it while you can actually force it ... what you do is to give the ball speed you accelerate it .. and then

094 P-I 0 B) You've directed it

Check (Ch): The teacher uses a Check Act to assess if the lesson is being followed, as in Exch 096 below.

095 I 0 T) We use another word for what you've given the ball .... we call it its momentum .. and that's a strange word that you haven't come across again but there's a difference between a ball sitting on the ground and one heartening towards you

096 Ch 0 would you agree?.. A B) Yes
Re-initiation (Re-i): Used by a teacher when he gets no response to a question or a wrong answer. Usually, prompts, clues and nominations are attached to the original elicitation. Represented by Exch 072 to 075 below.

<table>
<thead>
<tr>
<th>Exch</th>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>071</td>
<td>237m</td>
<td>E 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>. hum ..</code></td>
</tr>
<tr>
<td></td>
<td>238s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>239e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>except if you think through the spectrum ... think through the spectrum ....</code></td>
</tr>
<tr>
<td></td>
<td>240c1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>241c1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>what is the sort of average of red and green? .....</code></td>
</tr>
<tr>
<td>072</td>
<td>242c1</td>
<td>Re-i 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>. yeah you've got what? red ....</code></td>
</tr>
<tr>
<td>073</td>
<td>243rep</td>
<td>Re-i 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>. going through the spectrum ....</code></td>
</tr>
<tr>
<td></td>
<td>244rep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>245rep</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>. rainbow</code></td>
</tr>
<tr>
<td>074</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>246z</td>
<td>B). Orange</td>
</tr>
<tr>
<td></td>
<td>247p(n)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B). Red orange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B). Red orange ..</td>
</tr>
<tr>
<td>075</td>
<td>248rep</td>
<td>Re-i 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T). Dear me</td>
</tr>
<tr>
<td></td>
<td>249e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><code>. yeah .. do go on</code></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B). Ah .. red orange yellow green</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T). Oh well done red orange yellow green blue indigo violet</td>
</tr>
</tbody>
</table>

Listing (L): The teacher continues with the initial question until two or three answers to the question are offered by different pupils. In the following sequence Listing Exchanges are represented by Exchs 082 and 083.
<table>
<thead>
<tr>
<th>Page</th>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>O</td>
<td>. what else will tend to stop its forward motion if you look at it on bowling?</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). Something in the way</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). Yeah you know if you club something on the way yeah it could be the bat you know the batsman over the cricket bat</td>
</tr>
<tr>
<td>82</td>
<td>L</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). The three</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). Here the three</td>
</tr>
<tr>
<td>83</td>
<td>L</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). The ground</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>T). Hits the ground</td>
</tr>
</tbody>
</table>

**Reinforce (R):** A very occasional Exchange bounded to a Teacher Direct Exchange. They occur when the teacher has told the class to do something and one child is slow or reluctant or has not fully understood. Not observed in the instances of classroom interaction which are part of this study.

<table>
<thead>
<tr>
<th>Page</th>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). NV</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B). NV</td>
</tr>
</tbody>
</table>
Repeat (Rep): The teacher asks for an utterance to be repeated. Does not mean that the teacher did not actually hear what was said. The repeat may have been asked for other reasons.

<table>
<thead>
<tr>
<th>E</th>
<th>O T). What are you laughing at Rebecca?</th>
<th>e1(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>G). (Rebecca) Nothing</td>
<td>rep</td>
</tr>
</tbody>
</table>

Rep O T). Pardon
A G). (Rebecca) Nothing

F T). You're laughing at nothing.

A small number of Exchanges observed in this study did not fit to any of the categories suggested by Sinclair and Couthard. In these cases I classified them as Others (Oth).

A.2.3 Transactions. These are the larger units in which classroom discourse is divided. They usually consist of a series of Teaching Exchanges limited by Boundary Exchanges.