CHILDREN'S LEARNING IN SCIENCE PROJECT

ASPECTS OF SECONDARY STUDENTS' IDEAS ABOUT LIGHT

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SECTION 1

INTRODUCTION

1.1 Overview

The experience of light is universal. Through it we receive some of our earliest impressions of the world. While the study of vision is a vast and well developed subject, little is known of how children develop ideas about light and sight in the school years. The aim of this study is to describe aspects of secondary school students' ideas about light and to set these in the context of results from other studies in the area and of the history of ideas about light and sight.

A number of research studies into the ways children explain phenomena relating to light have been reported (Andersson and Karrqvist, 1981; Jung, 1981; Stead and Osborne, 1980; Guesne, 1985; Watts, 1983). This study incorporates some aspects addressed by other studies but it also includes further material. One additional aspect is the inclusion of information relating to the possibly diffuse matrix of ideas and feelings in which children's explanatory frameworks are embedded. Because information about "affective" as well as "cognitive" features of children's ideas may be important and useful, this research study incorporates student tasks designed to probe such aspects.

A further novel aspect of this study is an exploration of children's schematic representations of light phenomena. This is considered important because much of optics teaching in the secondary school involves ray diagrams. Teacher/textbook diagrams represent in symbolic form a few selected aspects of particular light-vision phenomena and the related symbolism is governed by accepted conventions. However, this study enquires into children's diagrams depicting light-vision phenomena, exploring not only those aspects they spontaneously select, but also the kinds of 'symbols' and 'conventions' they use to depict phenomena.

Besides being of interest in itself, this enquiry is relevant to optics teaching from at least two points of view. First, there is the widespread classroom use of diagrammatic representation in this subject area. Second, since drawing is a mode of expression of ideas, it is to be expected that a study of children's diagrams may provide further insight into how their understanding of light may be developed.

The report sets the discussion of children's ideas and representations about light in the context of an account of the historical development of scientists' theories about light and vision, which may provide insights into the development of children's thinking in this area.

1.2 Sources of data used in the study

This work was partly motivated by an earlier study conducted by the first author in some Bombay secondary schools. That study concerned the preconceptions of 13-14 year old students about light and their use of schematic representations in the context of light (Ramadas, 1981 & 1982). Where appropriate, account was taken of that work together with other published reports about children's ideas about light. The main sources of data for this study were of two kinds:

a) Responses to a nationally administered written task on light and sight. This task was part of the 1981 'Assessment of Performance Unit' survey of 15 year old students. A stratified random sample of 456 British students of all abilities and following a range of science curricula responded to an open-ended question on light as part of a one-hour written test package. The question is given in Appendix 1.

b) A local study in two schools.
This study was conducted with students, aged 13-14 years (third form secondary) in two schools. One school was an inner city school in Leeds, the other was a school in a small town near Bradford. One hundred students from four classes, two from each school, were involved in the study.

These students were given two different kinds of tasks. The first task, shown in Appendix 2, consisted of a number of open-ended questions about light. The questions were meant to explore in what contexts they thought about light and what life-experiences (both in and out of school) they associated with light.

The second type of task, shown in Appendix 3, consisted of four questions to do with light propagation and vision. In these questions students had to represent a situation by a diagram, and then use it to predict, describe and explain what happened. The questions were designed to elicit students' ideas relating to the geometry of propagation of light, including ideas about vision, line of sight and regular reflection. The task was administered in three versions to three different groups of students in each class. Students, judged by their teacher to be of 'high', 'medium' or 'low' ability, were present in equal proportions in the three groups. The three versions of the task were:

a) the 'verbal' version in which the problem situations were presented via purely verbal descriptions;

b) the 'diagram' version in which the same situations were presented with corresponding schematic diagrams that students were required to complete; and

c) the 'actual apparatus' version, where again presentation was assisted by schematic diagrams, but the students had an opportunity to set up apparatus, showing the geometry of the situation, before making their prediction. Then, they saw the apparatus working, before giving an explanation of the phenomenon.

Tests and follow-up interviews, with a sample of students, were administered before and after the students underwent a six week course in geometric optics. (The content of the courses in the two schools is summarised in Appendix 5.)

Nine students were interviewed after doing the tasks. Most of the students interviewed were selected from those who had done the 'verbal' version of the task, so that they would not be influenced by previous exposure to diagrams or models. Five children were interviewed both before and after teaching and the other four only after teaching. During interviews students' conceptions were explored in detail by encouraging them to talk about their responses. The interviews were taped, transcribed and then analysed. (Information about the sample interviewed is included in Appendix 4.)

1.3 The Structure and Purpose of the Report

The results of the local study on students' feelings and general orientations to phenomena and contexts involving light are described in the next section. Prior to analysing students' ideas about light and sight we found it useful to review the ways that scientific theories about light and vision had developed historically. This review, given in Section 3, is followed, in Section 4, with a review of the literature on children's understandings about light. The responses to the nationally administered written task on light and sight are analysed and discussed in Section 5. A number of distinct ideas used by secondary school students are identified. The frequency of occurrence of these ideas is compared with that for a comparable sample of Swedish students. Comparisons are also made of the types of response given by male and female students.

More detailed analysis of students' thinking about light was possible from the 100 students involved in the local study. Details of the tasks used are given in Section 6, together with an analysis of ideas concerning aspects of students' thinking about light travelling in space and the process of vision. Section 7 provides an analysis of students' understanding of the reflection of light in a plane mirror and Section 8 gives an account of the place of schematic representations in students' thinking about light.

The main purpose of the analysis of the local study is to identify in some detail the ways that school students think about simple optical phenomena and how this is affected by teaching. It is hoped that the study provides the kind of documentation on students' thinking about curricular tasks which will inform teachers and lead to curricula which are better adapted to the thinking and learning of students in classrooms.

SECTION 2

STUDENTS' ORIENTATIONS TO LIGHT PHENOMENA

2.1 Contexts in which students think about light

2.1.1 Everyday contexts

Whereas a science course about 'light' for 13-14 year olds draws their attention to pinhole cameras, ray boxes, glass blocks, mirrors, lenses, and optical instruments, it is of interest to know the daily life contexts in which they think about 'light'. The first question, designed to explore this, in the open-ended task (Appendix 2), given to 13-14 year old students prior to the teaching of optics, was as follows:

"What are the things you think of when the word 'light' is mentioned?"

The responses are listed in Table 2.1.

The wide variety in these responses indicates that there is no single, homogeneous context for children's thinking about 'light'. However, two generalisations may be made. First, most associations refer either to very bright sources of light or to diffuse illumination. Second, two contexts namely, sunlight and electric lighting, predominate over others.

The ways in which students conceive of 'light' in these contexts is a matter for speculation. It would appear that some regard light as an agent for change (as in 'life and growth'), or as an agent for illumination (as in 'showing up clearly'). Others associate light with objects under human control (as in 'light bulb' and 'candle'). Yet others refer to light as a circumstance or state (as in 'daytime' and 'brightness'). The connection between broad context classifications and students' specific conceptions about light is discussed later in Sections 5 and 6.

2.1.2 Vivid memories

Among children's several experiences with light some make a special impact. Question 2 in the open-ended task asked for these:

"Are there any things that have happened to you, to do with light, which you remember vividly?"

TABLE 2.1: PERCENTAGE OF STUDENTS ASSOCIATING PARTICULAR THINGS WITH 'LIGHT'

Things associated with light	% students[1] (n = 93)
A. Electric lighting	
Light bulbs/street lights/strip lights (Diffuse lighting)	53
Floodlight/car light/torch/lighthouse (Directed beam)	12
Lasers, a beam	3
Electricity	13
B. Natural phenomena	
Sun/sunlight	49
Sky/daytime	22
Moon/stars	11
Lightning	2
C. Other responses	
Brightness/bright things	22
Seeing/showing up clearly	18
Fire/candles/explosions/fireworks	18
Heat/energy	10
Prisms/rainbows/spectra	4
Colours	6
Life/growth	2
D. Responses each given by 1% (one child) only	
Kaleidoscope, mirrors, discos, TV, hologram, glow worms, shop windows, Blackpool, detergent, a bright idea, not heavy	1 each
E. No reply	1

[1] Since each student generally gave more than one response, percentages do not total 100.

Students had trouble understanding the word 'vividly'. Many thought it meant 'vaguely', but when that was explained, they gave the responses shown in Table 2.2.

TABLE 2.2: PERCENTAGE OF STUDENTS HAVING 'VIVID MEMORIES' TO DO WITH 'LIGHT'

'Vivid memories'	% students[1] (n = 93)
Light bulb blowing up	14
Electric shock whilst fixing light bulb	9
Burnt hand on touching light bulb	2
Light bulb fell off	2
Power cut	6
Magnesium ribbon/fireworks	7
Eyes strained by bright light	6
Sudden bright light (e.g. coming out after end of movie, reflected from mirror)	4
Lightning	8
Eclipse	4
Other unique responses: Dentist's light, lasers in Blackpool, electricity experiments in school, burnt hand on flame, smell of fire, blue flash in sky	6
No such memories	26
No reply	8

[1] Percentages do not add up to 100 due to rounding error.

Table 2.2 shows that a considerable number of the 'memories' refer to light bulbs. Many refer to the experiences of intense brightness, total darkness, a loud sound, or other spectacular effects. Some 'memories' appear to include an element of danger, mild fear, or pain.

It is interesting that the experience of lightning was mentioned only by students in the small-town school where there was open countryside, and not by students in the inner-city school. This suggests that the vividness of these experiences depends on the school environment. This may be a factor when considering implications for teaching.

2.1.3 Implications for teaching

Although conclusive implications cannot be drawn from the limited data above, this method of eliciting students' ideas could be adapted to the classroom. For example, a listing of responses like those in Tables 2.1 and 2.2 is a useful starting point for a classroom discussion on light.

The responses could be used to raise questions such as: Is there a difference between 'natural' and 'artificial' light? Light is often a diffuse illumination but sometimes occurs as a directed beam, how does this happen? Is there a difference between the two types of light? How far does light go out from a source? Can you have light at a place though it may not be seen? What are the ways of detecting light? Is the eye a kind of detector? Can light be hot and cold? Discussion of such questions might help relate 'light' in the students' experience with the 'light' they are going to study in the classroom.

2.2 Feelings about light

2.2.1 Are feelings important?

Educational objectives have traditionally had an 'affective' component. In science teaching this component is usually restrictively interpreted to mean aspects of the 'scientific attitude'. Feelings and emotions are thought to be outside the domain of rational science. This point was reflected in the responses of students to the question:

"What kinds of feelings does 'light' bring to your mind?"

2.2.2 The responses

The responses to the above question were found to have enough variation in points of similarity to support a multi-level system of classification. The system used here is the technique of systemic networks, adapted from linguistics for educational research by Bliss, Monk and Ogborn (1983). Full details of the notation used are explained in Appendix 6. The vertical straight lines, or bars, indicate subclassifications into mutually exclusive categories. The categories become progressively more specific from left to right so that the extreme right hand side of the network comes close to the actual responses.

The network on 'feelings' is shown in Figure 2.1. The percentage of students giving each type of response both before and after teaching is shown in the two columns on the right of the network. Since some students gave more than one type of response, these percentages do not total 100.

Progressing from the left, the first level classifies students as those who expressed some feelings and those who did not.[1] The second level divides the feelings into 'physiological' or 'psychological'. The first of these categories includes responses where feelings are not explicitly stated by children, but where they have listed experiences in which a clear affective component can be identified. For example:

> ".... without light, you could not see anything."

In comparison, responses in the 'psychological' category were like the following:

> "To me light is company and I am not afraid of light."
>
> "Not romantic. Happy."

For some experiences like 'warmth' and 'brightness' the physiological experiences provide metaphors for describing feelings. The network shows that these experiences can be included in both physiological and psychological categories. Examples are:

> "Light brings feeling of beaches and sunny seaside resorts and warmth."
>
> "It brings to mind warmth and glowing heat."

---

1 A point to note here is that this is the only subclassification in the network where the group of responses also corresponds to a division of <u>students</u>. In the succeeding classifications, it is only the response <u>categories</u> that are mutually exclusive.

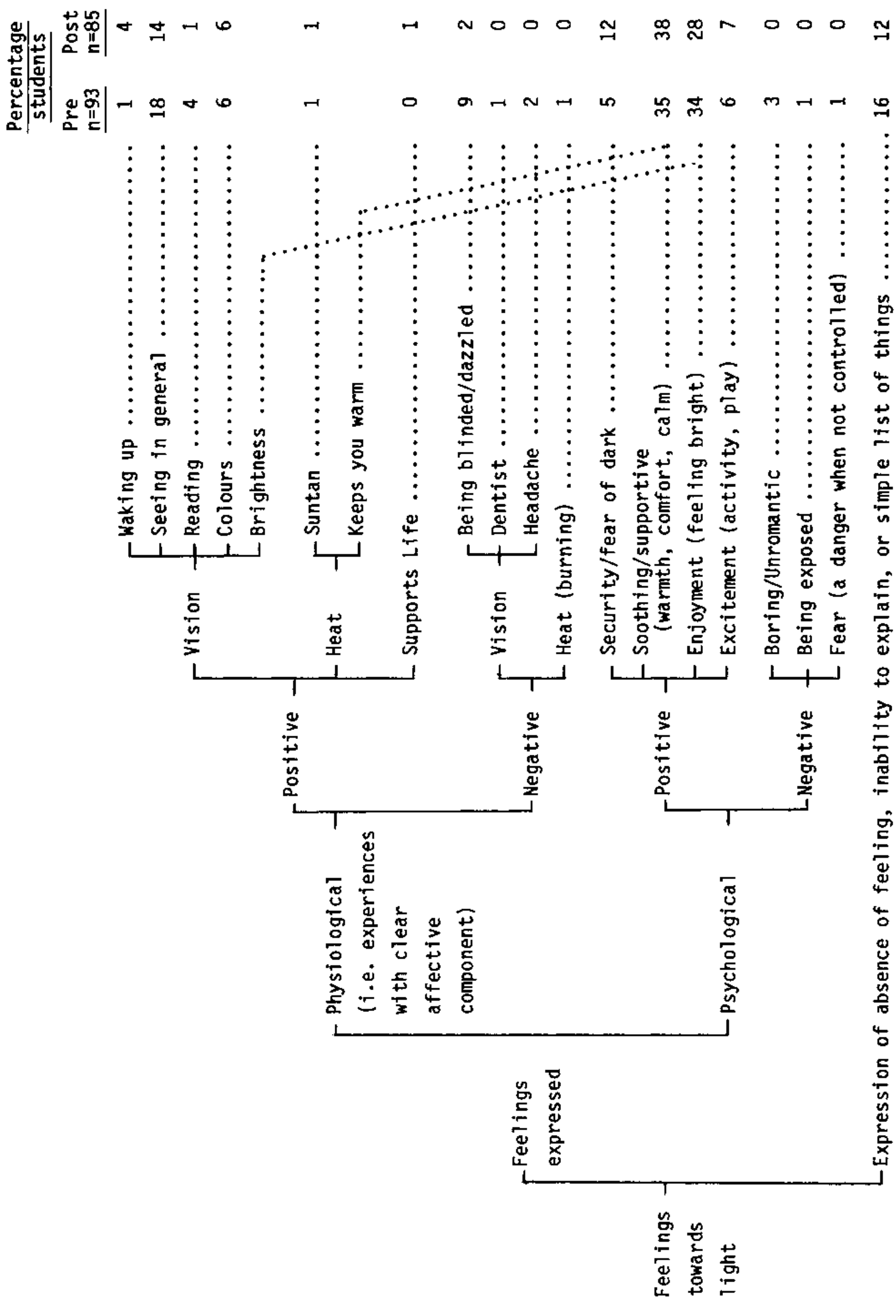


Figure 2.1: Network on feelings about light

2.2.3 Positive and negative feelings

The next level classifies feelings as 'positive' or 'negative'. The percentages of responses show a much larger number in the 'positive' category. The actual numbers of responses are shown in Table 2.3.

TABLE 2.3: NUMBERS OF POSITIVE AND NEGATIVE RESPONSES TO 'FEELINGS' TASK

Task occasion	No. of students	No. of responses	Positive responses	Negative responses
Pre	93	137	120	17
Post	85	107	105	2

X^2=9.13 for numbers of positive and negative responses in the before and after teaching. This is significant at the 1% level.

Although the proportion of positive responses prior to teaching was high (88%), the proportion after teaching was greater (98%).

A large number of the positive responses were in the 'warmth' and 'brightness/happiness' categories. This is not surprising in the North of England where sunshine and warmth are rare and holidays are taken in the sun. In a tropical country like India, on the other hand, the bright heat of summer can become unbearable and the monsoons are eagerly awaited.

A similar observation can be made about language. Terms like 'glowing heat' do not have the same positive connotation as their equivalent among Indian languages. In the Marathi language, the word 'thanda' meaning 'cool' is used as a metaphor for a peaceful/restful feeling. Of course, the point must not be over stretched. A commonality in cross-cultural 'feelings' related to light may also be considerable. Such a possibility requires further study.

For this task, more than for any other, students had queries such as, "What does this question mean?" and "What are we supposed to write here?". It seemed that they were not used to being asked about their feelings in the context of science lessons. A case could be made for conveying to students that their feelings are valued in school even in the science classroom.

SECTION 3

THE HISTORY OF IDEAS ABOUT LIGHT AND VISION

3.1 Rationale

Implicit in the literature description of children's spontaneous conceptions as 'common-sense notions' is the assumption that these conceptions are in some sense shared. The roots of this commonality are epistemological in nature and are usually sought in two sources: first, in shared experiences across different cultural environments, and second, in the influence of a common language on the available metaphor for describing experiences (Driver and Erickson, 1983). A natural extension of the search for universality is a comparison between the historical development of ideas and their development in young children. Historically, ideas about light have been closely linked with ideas about vision. This point is a reminder that the only direct human experience of light is through vision, and it is in this context that human ideas about light naturally develop. The present aim in looking at the history of ideas about light and vision is simply to discover the range of ideas and explanations on the subject that have been documented in different cultures. Knowing that these ideas have been found plausible by thinking persons at some time and place, lends credibility to the ideas of children. Further, as has been suggested by Nussbaum (1983), comparison with historical development might contribute to understanding the nature of conceptional change in individuals.

Studies in several areas have indicated the existence of parallels betweeen children's conceptions and the history of scientific ideas. For example, ideas about motion have been found to be similar to the impetus theory of ancient India (Bose et al., 1971) and medieval Europe (McCloskey, 1983); ideas about heat, similar to the Caloric theory (Erickson, 1979); and ideas about biological evolution, similar to Lamarckian theory (Deadman and Kelly, 1978; Engel Clough and Wood-Robinson, 1985).

Here it is not suggested that these parallels are sustained in every detail. On the one hand, there are the carefully articulated theories of adult scientists and philosophers, and on the other, the spontaneous conceptions of much younger children. Naturally, the latter do not bring the same conceptual and logical apparatus to bear on the problem, nor have they had access to the same kind of structured experiences, namely, the community of scientists and the culture of the time. Further, the experiences available to today's children are different as a result of living in a technological world. Still, in spite of these important differences, the parallels are likely to be more than superficial.

3.2 Sources of documentation

The earliest documentation of ideas about vision occurred around the 5th century B.C. Information from three different cultures: Greek, Chinese and Indian, in the approximate period 5th to 3rd centuries B.C., drawn from the referenced sources, is summarised in this section. Ideas from ancient Greece have been comprehensively reviewed by Ronchi (1970) and compared with children's ideas by Andersson and Karrqvist (1981). Ancient Chinese thought has been reviewed by Needham (1962). In ancient Indian history, no single review on the subject exists, therefore several sources were consulted (Bose et al., 1971; Mishra, 1936; Chatterjee, 1965; Vidyabhushana, 1981; Ray et. al., 1980; Kutumbiah, 1962; and Bhishagratna, 1963). The difficulties in dating the original Indian sources and the gradual development of ideas over a long period makes for some uncertainty in the exact dates of the ideas discussed here.

Later developments in the subject came about in medieval Arabia and finally in 17th century Europe. These ideas are summarised from Ronchi (1970).

3.3 Fifth to third centuries B.C.

In India, during this period and continuing well into the post-Christian era, there existed several independent systems of philosophy, which can be roughly classified according to the religious systems with which they were associated. The orthodox systems of the Brahmanas constituted Hindu philosophy while the so-called unorthodox systems were represented by the Buddhist, Jaina and the materialistic or atheistic schools (Bose et al., 1971). Very little is known today about these latter ideas.

Regarding ideas about vision, the Buddhists and the Jainas differed from other schools in both East and West, in believing that a sense organ and the object perceived, needs no medium of contact between them. The Jainas believed that an energy or 'shakti' associated with the pupil or the eye helped vision (Chatterjee, 1965). The Buddhists believed that the pupil of the eye was helped by external light and by a desire on the part of the observer to see, and that vision was also determined by the past deeds of the observer (Mishra, 1936). It is interesting how the psychological rather than the physical and physiological aspects of vision were thought to be important here. This idea has been a recurring one in history and even today one sees the same tendency in lay conceptions.

The other schools of thought discussed here all shared the idea that some medium of contact was necessary between the eyes and the objects seen. According to the Samkhya system of Indian philosophy, which is believed to have been in existence since 800 B.C. (Winternitz, quoted in Bose et. al., 1971), the sense organs were supposed to be linked with a subtle, all-pervading matter (ahankarika) and in this way could come into contact with the object of perception. The sense organs, like the pupil of the eye, were regarded not as material substances, but as modifications of this all-pervading matter (Chatterjee, 1965). Another later system, the Nyaya, rejected this view on the grounds that it implied simultaneous perception of all objects in the world (Chatterjee, 1965).

The Nyaya theory was concerned with the epistemological problem of how knowledge is obtained, and therefore, it dealt with the problem of perception. The theory was codified by Gotama who lived around 550 B.C. (Vidyabhushana, 1981). It held that a kind of ray or 'tejas' was emitted from the eyes and reached the objects of perception, an idea that is very similar to the 'visual fire' of the ancient Greeks.

In Greece, during the period fifth to third centuries B.C., three main schools of thought existed. Empedocles (500-430 B.C.) believed that objects emit an 'external elementary fire' which brings the shape and colour of the object to the eye. The eye emits an 'internal elementary fire'. Vision is produced when the two fluxes meet.

Leucippus, who lived in Greece around the same period as Empedocles, exemplified the views of the Atomists. He held that an 'eidola', or a kind of image, detaches itself from the object and passes through the sense organ (in this case, the eye) into the soul.

Concurrently, the Pythagoreans, for example, Archytas (430-305 B.C.), believed that vision was caused by an invisible fire of which the eye was the source. This idea appears to have found support in both Indian and Greek thought of this time. The Indian Nyaya theory, mentioned earlier, justified the idea partly on the grounds that these rays could be seen in special circumstances, as when they emerged from the eyes of cats and other animals at night (Vidyabhushana, 1981; Chatterjee, 1965) and that the character of feline and human eyes must be basically similar (Bose et. al., 1971).

It is interesting that the medical science of this time shared the Nyaya view on the mechanism of perception (Kutumbiah, 1962), and this view was thought to be consistent with what was known of the structure of the eyes from dissections of human and animal bodies. The Sushruta Samhita, a treatise on medicine and surgery compiled around the 6th century B.C. and last revised in the 3rd or 4th century A.D., described the anatomy of the eye (Kutumbiah, 1962; Bhishagratna, 1963; Ray et. al., 1980). A large number of diseases of the eye and their treatment are described here, including the surgical treatment of cataract. However, although the surgeons of this period treated defects of vision on the belief that the pupil of the eye and what lay behind the pupil were responsible for vision, the optical mechanism of the lens and retina was apparently unknown to them.

The Nyaya and the closely related Vaiseshika theories described the properties of the 'tejas' rays which were emitted from the eyes. These rays were different from the rays of the sun in that the properties of colour and touch (heat) were not manifested in them (Mishra, 1936; Bose et. al., 1971). This, according to Hindu philosophy, was justified on the basis of the purpose of the Universe: if the rays from the eyes could have produced heat, beautiful objects would have been burnt when many people looked at them simultaneously especially in the hot season (Mishra, 1936).

These 'tejas' rays were thought to consist of very light particles which travelled very fast at finite speed so that nearer objects were seen sooner than further objects - though the difference in time was believed to be too small to be perceptible (Mishra, 1936). Reflection in a mirror was thought to involve rays from the eyes travelling to the mirror and being reflected off it (Bose et. al., 1971).

A study of contemporary ideas in China (Needham, 1962) shows that the views prevalent here were radically different from all those discussed above, and in fact were very close to the modern view of vision. The Mohist school (4th to 3rd centuries B.C.) believed that light rays were reflected from seen objects and then entered the eye. The Mohists explained the working of the pinhole camera on the basis of such reflected rays coming from the head and feet of an illuminated person and going through the pinhole onto the screen to form the inverted image. The Mohists were familiar with a large number of optical phenomena particularly those related to mirrors. According to Needham, though they must have made careful and extensive use of the experimental method, they were handicapped by their lack of a developed geometry. In Greece, on the other hand, visual ray optics was developed by Euclid into a formalism very close to the geometrical optics of today.

Euclid (4th Century B.C.) supported the 'visual fire' idea of the Pythagoreans, though he transformed it into abstract 'visual rays'. His two main arguments in favour of emission by the eyes were as follows. First, in searching for a small object like a needle or in looking at a page of a book, one does not at once see the needle or all the letters on the page. Euclid argued that this could not happen if the images of all these things were reaching the eye and making an impression. It must be therefore, the eye which is the active emitting organ.

The second argument concerned the shape of the eye. Other sense organs are hollow and happen to be receiving organs. Since the eye has a protruding form, it must be an emitting organ.

Euclid formulated a set of axioms for visual ray optics. He postulated, for example, that visual rays are emitted in the form of a cone with its apex at the eye, its base at the edge of the observed object, and that these rays propagate in straight lines at constant speed. Euclid had developed his ideas about visual rays from observing sunlight entering dark rooms through cracks. Also, he had noticed how the sun's rays could be focussed into a point by a concave mirror. Even then, he did not consider comparing these two types of rays and hence linking light with sight.

3.4 The Arabic School (9th-11th Century A.D.)

Ideas about light appear to have been more or less static for several centuries up until the time of Alkindi (813-873 A.D.). Alkindi knew of the anatomy of the eye, and he had the idea that vision must be caused by something external entering the eye and causing a physiological effect. He concluded from the formation of shadows that rays emanating from luminous bodies travel along straight line paths and affirmed that it must be these rectilinear rays which act upon the eye.

The Arabic school was strong on experimental methods and tremendous progress was made in this era due mainly to Ibn-al-Haithan or Alhazen (965-1039 A.D.). He observed that eyes hurt when a person looks at the sun or at a mirror reflecting light from the sun. He also observed that eyes are blinded on looking at a bright white object and that these effects persist even after closing the eyes. Therefore, light entering the eye from a source, or being reflected to the eye from an object, produces a physiological effect which leads to vision.

Alhazen proposed an optical mechanism for vision in which the cornea refracted rays of light, and the lens (which he regarded as being at the centre of the eye) was the light-sensitive part of the eye.

Although Alhazen's work was widely known in Medieval and post-Medieval Europe, it was Avicenna (980-1037 A.D.) who had the more influence on western thought. Avicenna minimised the physico-physiological aspect of vision and concentrated on the psychological activity of the observer. He opposed the idea of material rays of light and advocated a variant of the 'eidola' theory It is interesting to note the persistence of these notions in history, despite such experimentally well-supported theories as Alhazen's.

3.5 Modern optics (Kepler, 17th Century A.D.)

In the 17th Century, Kepler (1571-1630 A.D.) returned to and developed the ideas of Alhazen. In his Ad Vitellionem Paralipomena, published in 1604, he discussed the nature of light, the geometry of reflection, the formation and position of images, refraction and vision. He introduced the idea of the luminous ray emitted by a source in all directions and travelling out to infinity. He studied the refraction of a narrow cone of light by an aqueous sphere and deduced point-to-point image formation in the eye. He believed that the brain must be able to interpret the inverted image on the retina. Thus, Kepler originated the modern scientific interpretation of the phenomenon of vision in terms of light.

This outline of the various ideas about light and vision proposed by philosophers and scientists, and the many paths taken in the development of these ideas may, hopefully, lead the reader to appreciate that there are several ways in which children also may interpret optical phenomena.

SECTION 4

A REVIEW OF THE LITERATURE ON CHILDREN'S IDEAS ABOUT THE NATURE OF LIGHT

4.1 Ideas about light in space

Children's conceptions about the nature of light have been documented by a number of researchers. Piaget (1974) noted that young children do not admit to the existence of light between a lamp and a circle of light produced by it on a screen some distance away. According to Piaget, the idea that 'I don't see it but I know it is there', comes only at the formal operational stage of the child's development.

Guesne (1985) concluded, from her research and the work of Tiberghien, that most 10-11 year old students conceive of light as a source e.g. an electric bulb, an effect e.g. patch of light, or a state e.g. brightness. They do not recognise light as a physical entity existing in space between its source and the effect it produces. Guesne further found that at age 13-14 years many students do recognise light as an entity in space, and the majority use this notion to interpret shadows. However, the notion is likely to be used only where the light is intense enough to produce perceptible effects at some point in its path, and even then, it may be thought of as simply existing in space without propagating through it. La Rosa et. al. (1984) have suggested that students may talk of light going from point A to point B in the same way as a wire, or a road, 'goes' from A to B.

These conceptions of children about light are summarised in the diagram below:

(Light) associated with source, state or effect only.
↓
Exists in space → 'Exists' in a straight line
↓ ↓
Travels in space (motion) → Travels in a straight line
↓
Travels indefinitely

Several investigators have noted that the concept of light as a physical entity is far removed from the concept in everyday usage. According to Andersson and Karrqvist (1981), what we call 'light' in colloquial speech is mediated by the visual system. The everyday concept of light is, therefore, psychological rather than physical in nature. Examples of such usage are given as, 'the light is bad...' and '... it is light.' The other meaning of 'light', in the English language, is 'a source of light' such as an electric bulb. Andersson and Karrqvist also point out that the subjective, (or psychological) aspect of light and the objective (or physical) one were historically distinguished by the use of two separate terms, 'lux' and 'lumen'.

Children's ideas about the nature of light can sometimes be somewhat more differentiated than the general conceptions discussed above. For example, Watts (1985) in a case study, describes a boy in the fourth year of a British secondary school who talked about 'rays' as 'strands of a rope making up a beam of light', and also about 'light in different modes' i.e. 'natural' and 'electric'.

4.2 Research on children's ideas about vision

Children's ideas about vision have been documented by researchers in Brazil, France, Germany, Great Britain, India, New Zealand, Sweden, Switzerland and the U.S.A., with remarkably similar results. Piaget (1974) noted that very young children make no connection between the eye and the object. While at a later stage, they commonly think of vision as 'a passage from the eye to the object'. The nature of this 'passage' was studied by Guesne (1976 and 1985) and Andersson and Karrqvist (1981 and 1983). Guesne found that for luminous objects, 13-14 year old students might use the 'light coming to eye' model, but for ordinary, non-luminous objects they could use an 'eye is active' model. Guesne identified the latter model in only a minority of the students and found that it involved an abstract notion of the eye being active, thus differing from the 'emanation' theories of the ancient Greeks. Andersson and Karrqvist (1983), on the other hand, found what they called the 'visual ray' idea to be a common one (35-45% of pupils between the ages of 12 and 15 years used it in one or other of three problem situations); but, they also noted that it was rarely used in a consistent way across contexts. Andersson and Karrqvist found that for many pupils, the teaching of optics led to a reshaping of the correct physical explanations (of refraction, for example) in terms of visual rays. They also found that all three types of conceptions of vision of the ancient Greeks were present in students. La Rosa et. al. (1985) have attempted to relate the explanatory models for vision with other conceptions of children about light in terms of distinct interpretative frameworks. Jung (1981) found that it was difficult for students to interpret experiences of vision, and he remarked that there was a decoupling between seeing an object and receiving light from it into the eyes. According to this conception, light is necessary to illuminate objects, but it then remains local to the scene with the observer at a distance detached from it (Watts 1985). Watts (1983) identified this as one of a set of 'alternative frameworks' of children about light.

Another model of vision found in children assumes that light from a lamp or some other source coming to the eye helps vision. Sometimes this light is thought to strike the eye and then go to the object seen. Ramadas (1981) found that in a group of about 170 (13-14 year old) students who had recently studied optics, 5% held the above notion. Crookes and Goldby (1984) also found this notion in a class of students while trialling an introductory lesson on light. Their approach was to let students make their own conceptions explicit and then ask them to design experiments to test these. The students tested out the above model of vision against the accepted one by blocking out the light to the eye and to the object in turn and checking whether either of these affected vision. De Souza Barros (1985) classified the different models of vision used by primary school children and found conceptions very similar to those described above.

Andersson and Karrqvist (1981) made observations on colloquial language that relates to light: common usage does not support the idea of light as a physical entity. Their remarks in the context of vision are quoted below:

> "Thus, as far as vision is concerned, there are many expressions indicating that eyes are active and send out something. We throw glances and give looks. Looks can be felt, can warm us, also make us melt. Looks can be shot too. We try to penetrate fog with our eyes. The comic-strip figure Superman even has X-ray vision and heat vision, which can penetrate walls. This linguistic usage, in combination with a lack of a model of physical light, can create a tendency to explain the link between object and eye by visual rays, looks and such things."
>
> Andersson and Karrqvist, 1981, p.20

An interesting attempt to use the contrast between human vision and Superman's X-ray vision in a classroom discussion with undergraduates has been described by Pittenger (1983). He discussed how this approach can be used to help college psychology students understand the importance to vision of the physical nature of light.

SECTION 5

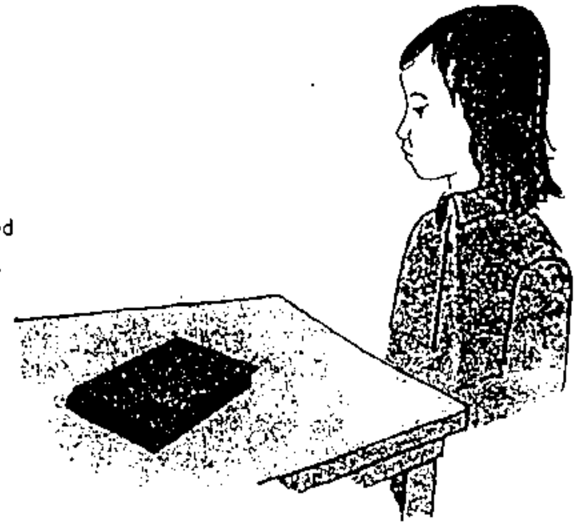
THE RESULTS OF A NATIONALLY ADMINISTERED WRITTEN TASK ON LIGHT AND SIGHT

5.1 The survey

A representative sample of 456 (15 year old) school students of a range of abilities and following a variety of science curricula responded to a question which probed their ideas about light and sight (Figure 5.1). The question asked students to explain what happens between a book and the eyes of a girl who is looking at the book.

A pupil is in a dark room and cannot see anything.

When the light is turned on in the room she sees a book on a table in front of her.



How is she now able to see the book?
Explain carefully what is happening between the book and her eye.
Draw lines on the diagram to help your explanation.

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Figure 5.1: Written question on light and sight

5.2 Analysis of responses

Students' responses were analysed both in terms of written explanations and the diagrams drawn. Different categories of response were identified from the scripts. Tables 5.1 and 5.2 describe each type of diagrammatic response and verbal explanation respectively. The categories of response have been further grouped into three main categories:

(i) scientifically accepted ideas about light and vision

(ii) alternative ideas about light and vision

(iii) ambiguous responses which could be interpreted as either accepted or as alternative ideas.

In Table 5.3 the types of diagrams drawn by students are cross-tabulated with their verbal explanations. In the majority of the cases, the diagram and explanation reveal more about the student's ideas than either one alone. For example, a line going from the book to the eye may represent not light, but an image travelling to the eye. Also a perfectly acceptable verbal explanation such as:

"Light bounces off the book to her eye."

might be accompanied by a diagram showing light going back and forth between the book and the eye. The rays drawn by students do not necessarily represent 'light'; they may symbolise either sight or the path of some sensation. Clearly, care has to be taken in interpreting responses.

It is also useful to know how often students are inconsistent in their responses. In this particular APU question, although there were some cases where there was no obvious link between diagram and explanation, in only seven cases (2%) was there logical inconsistency between the two. (In Table 5.3 see diagrams DA4 and DA5 combined with explanations VS1 and VS2). For this reason, it was possible to pool the information from the diagram and explanation to give a system for overall classification of the responses.

TABLE 5.1: CODING OF TYPES OF DIAGRAM PORTRAYED IN 'LIGHT AND SIGHT' TASK

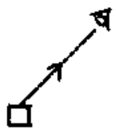
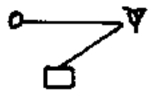
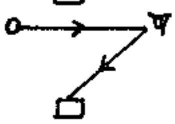
Code		Diagram	% responses (n = 456)
	Accepted ideas		
DS1		Ray(s) reflected from book to eye; sometimes a source shown in diagram	10
DS2		Ray(s) from book enter eye	10
		Total accepted	20
	Alternative ideas		
DA1		Line between external point (not source) and eye	<1
DA2		Line between source-eye and book-eye	1
DA3		Ray(s) directed from source to eye and eye to book	1
DA4		Ray(s) going back and forth between book and eye	6
DA5		Ray(s) from eye to book	8
DA6		Line(s) between external point and eye, and book-eye, often labelled as 'dark' and 'light' respectively. Probably implying that these are lines of sight which stop a short way from the eye when it is dark, and go all the way to the book when the light is turned on	1
		Total alternative	18

TABLE 5:1 (continued)

Code	Diagram		% responses
	Not classifiable as above		
DN1		Line(s) between source or external point-book, and book-eye	4
DN2		Line(s) between book and eye	23
		Total not classifiable	27
	No diagram		
DN3			36

TABLE 5.2: CODING OF TYPES OF WRITTEN EXPLANATIONS OFFERED IN 'LIGHT AND SIGHT' TASK

Code	Mnemonic	Written explanation	% responses (n = 456)
		<u>Accepted ideas regarding light and vision</u>	
VS1	lrbe	Light is reflected from book to eye	17
		"... Light travels in rays and as soon as it hits the book, the rays are reflected off the book towards the pupil*, thus making her able to see the book."	
		"When the light is turned on, her eye immediately receives light reflected from the book..."	
		"... light bounces off the book into her eyes."	
VS2	lbe	Light goes from book to eye	7
		"... light travels in straight line to her eye."	
		"There are lots of atoms flying around from the book, and the light travels from the book to her eyes..."	
VS3	le	Light enters the eye (direction/source not specified)	2
		"Light is refracted on the cornea. This triggers off electrical impulses..."	
		"... light rays go through the eye and to the back of the eye."	
		Total accepted ideas	26

* This could refer to the girl or to the pupil of her eye.

TABLE 5.2 (continued)

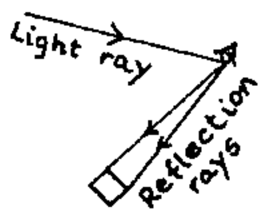
Code	Mnemonic	Written explanation	% responses (n = 456)
		Alternative ideas	
VA1	Ime	The image enters the eye. "... The image of book passes through conjunctiva, aqueous humour, lens, vitreous humour and on to the retina..." "... the picture enters the eye.." "... image is picked up at the back of her eye..."	2
VA2	lse	Light from source to eye helps to see "The light hits the person's eye and reflects her sight to the book on the table" "... light goes to her and she look at it book."	2
VA3	lseb	Light goes from source to eye to book "When the girl switches on the light the light goes to her eyes then on to the book then this enables her to see the book." Or a labelled diagram: 	<1
VA4	bf	Something goes back and forth between book and eye (light, sight or image) "... her eyes immediately spot the book, the book is reflected into her eyes..." "The eyes send out rays and when they hit an object they rebound and she sees a book." "... she can see the book as it is being reflected from her eye to the book and back to her eye again."	4

TABLE 5.2 (continued)

Code	Mnemonic	Written explanation	% responses (n = 456)
		<u>Alternative ideas</u> (continued)	
VA5	leb	Light (or ray) goes from eye to book.	1
		"There are rays from her eyes to the book and images are formed on the retina. When it is dark she cannot see anything because the rays are rays of light. Also her pupils have not adjusted to let a lot of light in, they are still small from when she was in light conditions."	
		"... rays of light will go from her eye to the book and hence illuminate it thus she will be able to see it."	
VA6	vis	The visual system plays an active role	19
		"The lenses of her eye focuses on the book in order for her to see it."	
		"Her eye meets the book and widens on seeing the book. The eye then stays at a constant size while the girl is viewing the book."	
		"... her eyes point at book..."	
VA7	ba	The book plays an active role (e.g. it attracts the eye)	1
		"... the book stuck out because it was an odd thing on the table so she noticed it straight away."	
		"The book would be darker than most of the other objects so the eye is (undecipherable) attracted to dark objects because of being in the dark before the light was turned on."	
VA8	Alt	Other alternative ideas	6
		"It is not exactly the book she sees the moment the light is turned on, but more the reflections of it..."	

TABLE 5.2 (continued)

Code	Mnemonic	Written explanation	% responses (n = 456)
Alternative ideas (continued)			
VA8	Alt	"She can see the book because she can sence it in her mind, and that she can vaigly see it even though it is dark."	
		"She is able to see the book because the room is bright and the book is dark."	
		Total Alternative	36
Noncommittal responses			
VN1	sb	Light helps to see better	12
		"She is able to see the book because the light is turned on and as soon as the light is on she suddenly sees the book as it is the only thing in the room."	
		"... light clears vision..."	
Uncodeable			
VN2	Unc	Uncodeable "Really as you see an object it is upside down but the lens turns it the right way up."	8
		"She is able to see the book by looking out of the corner of her eye when the light was turned on."	
VN3	Ne	No explanation	18

TABLE 5.3: CROSSTABULATION OF DIAGRAMMATIC AND WRITTEN RESPONSES TO 'LIGHT AND SIGHT' TASK

Type of diagram \ Type of explanation		Accepted ideas			Alternative ideas								Non-committal	Uncodeable	No response	Total
		VS1 lrbe	VS2 lbe	VS3 le	VA1 lme	VA2 lse	VA3 lseb	VA4 b/f	VA5 leb	VA6 vis	VA7 ba	VA8 alt	VN1 sb	VN2 unc	VN3 ne	
Accepted ideas	DS1	40	--	1	--	--	--	--	--	3	--	--	--	--	1	45
	DS2	7	14	1	2	--	--	1	--	15	--	1	3	--	1	45
Alternative ideas	DA1	--	--	1	--	--	--	--	--	--	--	--	--	1	--	2
	DA2	--	--	--	--	3	1	--	--	--	--	--	--	1	--	5
	DA3	--	--	--	--	3	1	--	--	--	--	--	--	--	--	4
	DA4	2	1	--	1	--	--	13	--	3	--	2	5	--	1	28
	DA5	1	3	--	--	--	--	2	1	16	1	2	7	2	1	36
	DA6	--	--	--	--	--	--	--	--	5	--	1	--	--	--	6
Non-committal	DN1	16	--	--	--	--	--	--	--	--	--	--	--	--	--	16
	DN2	8	15	--	7	--	--	1	2	32	1	7	18	10	5	106
No diagram	DN3	5	1	5	--	2	--	--	1	14	3	15	21	24	72	163
TOTAL		79	34	8	10	8	2	17	4	88	5	28	54	38	81	456

5.3 Identification of main types of ideas

The frequency of occurrence of the most common ideas are shown in Table 5.4. (This table has been prepared by grouping students according to the ideas expressed in their responses and ignoring the small number whose written response and drawing were contradictory.)

TABLE 5.4: RESPONSE FREQUENCIES FOR MOST COMMON IDEAS OFFERED IN 'LIGHT AND SIGHT' TASK

Ideas	% Students	
	APU sample (n = 456)	Andersson and Karrqvist[1] (n = 166)
Rays go from book to eye	31	30
Light simply helps to see better	12	4
The visual system (eye or brain) is active	19	13
Something goes from eye to book	9	4
Something goes back and forth between eye and book	7	5
Light from source to eye (may be reflected to book) helps to see	2	-
An image enters the eye	2	5
Contrast with dark helps to see	2	-
(Sight) goes further out when light is on	1	-
No response	16	29

[1] From Andersson and Karrqvist (1983); page 395 (Table 2).

Andersson and Karrqvist (1981 and 1983) asked a similar question of 15 year olds in Sweden. In Table 5.4 above, their results are given alongside those for the British sample. Remembering (a) that the question in the Swedish study was phrased slight differently from the APU one (the Swedish version explicitly discouraged consideration of physiological factors), (b) that the criteria for classification of responses may be different (in their case, the categories of responses are mutually exclusive; in our sample, one student may be included in two categories because data from diagrams as well as verbal explanations is used), and (c) that the 15 year olds in their sample had all studied optics whereas the APU sample was a mixed one, the similarity in the types of ideas, and the percentage of students expressing each, is striking.

Another respect in which the two sets of data can be compared is in the percentage of students using the idea that 'light exists and propagates in space'. In the Swedish sample, 30% used the idea in this particular problem; in the APU sample, 33% did.

The similarity in the types and prevalence of ideas used by students in the two countries gives some indication that the ideas derive from experiences which transcend superficial differences in curriculum and language.

5.4 Comparing the ideas used by different groups of students

The scheme for overall classification of ideas is shown in Table 5.5. It is a condensed version of Table 5.3 and its purpose is to enable the interested reader to trace back the original responses from the broad categories which will be used henceforth.

TABLE 5.5: CROSSTABULATION OF TYPE OF DIAGRAM VERSUS TYPE OF EXPLANATION FOR 'LIGHT AND SIGHT' TASK (with numbers of students in each category)

Type of diagram \ Type of written explanation	Accepted ideas (Acc)	Alternative ideas (Alt)	Ambiguous/ uncodeable (Nc)	No explanation	Total
Accepted ideas (Acc)	Acc 63	Acc[1] 18 or Alt 4	Acc 3	Acc 2	90
Alternative ideas (Alt)	Alt 8	Alt 55	Alt 16	Alt 2	81
Ambiguous/uncodeable (Nc)	Acc 39	Alt 50	Nc 28	Nc 5	122
No diagram	Acc 11	Alt 35	Nc 45	NR 72	163
Total	121	162	92	81	456

Using the scheme in Table 5.5, the responses were classified into four overall categories, as shown in Table 5.6. This table shows that 30% of the 15 year olds had accepted ideas about vision, while 37% held alternative ideas.

TABLE 5.6: OVERALL CLASSIFICATION OF NATIONAL RESPONSES TO 'LIGHT AND SIGHT' TASK (Considering both diagram and explanation)

Type of response	Number of students	Percentage (n = 456)
Accepted ideas (Acc)	136	30
Alternative ideas (Alt)	170	37
Ambiguous/uncodeable (Nc)	78	17
No response (NR)	72	16

[1] Alternative ideas of type VA6, i.e. "the visual system is active", were not by themselves sufficient to show that the student had a clear alternative explanation. Therefore, responses of this type, when occurring in combination with an accepted diagram, were put in the 'Accepted' category.

Information on the sex, ability level and curriculum for each student was available for the National sample. Subclassification of the whole sample on these criteria showed that the percentage of students holding alternative ideas on light and vision was remarkably stable across sex, ability levels and type of curriculum followed (i.e. whether or not Physics was included in that year as a subject of study). The percentage of students with accepted, scientific views was, however, apparently more for the high ability group, the Physics group and the boys (the numbers of ambiguous responses and non-response rates being correspondingly lower for these groups). The word 'apparently' is used because the three criteria of subclassification were highly correlated: the high ability group had a high proportion of Physics students and boys. Simple tabulation to separate the variables (see Appendix 7) shows that the effects may be rather complicated and involve interaction between sex, ability and curriculum. These tables, presented in Appendix 7, suggest that:

(i) Alternative conceptions are more common in student groups who have not received physics instruction. However, among those who have been so instructed, alternative ideas are still quite prevalent.

(ii) There is some indication that alternative ideas are used more frequently by girls than by boys of the same ability and curriculum groups.

SECTION 6

STUDENTS' IDEAS ABOUT LIGHT AND SIGHT: THE LOCAL STUDY

6.1 The questions

This section reports results from the local study. In addition to the open-ended written tasks which have already been described in Section 2, this and the following sections, draw on students' responses to a set of four written questions.

The four tasks or questions were given to four classes of 13-14 year olds before and after the students studied a 6-week geometric optics course. A number of the students were interviewed individually about their responses before and after teaching.

The questions are shown in Figures 6.1, 6.2, 6.3 and 6.4.

These questions were presented in three forms: a) with diagram (as shown); b) verbal description only; and c) with actual apparatus present. (Copies of the question sheets in each format are given in Appendix A3.)

Students' responses to these tasks were analysed and the results are reported in this and the following two sections.

1) It is a dark moonless night.
You see a small lamp shining far away.

* Show where there is light in this drawing.

* On this drawing, explain how you are able to see this small lamp shining.

* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

....

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Figure 6.1: The 'moors vision' question

2)

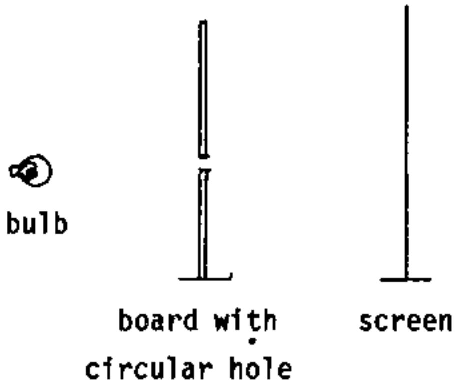


Figure a)
Side view of apparatus

The things in this drawing are shown in side view. They are in a completely dark room. The bulb is switched on.

* What can be seen on the screen?

....

....

....

* Draw this in the square below:

Figure b)
Front view of screen

* Now go back to a) and show where there is light in it.
* Using your completed figure a) answer these two questions:
    1) What happens to the light from the bulb?
    2) Why is it that the thing in figure b) is seen on the screen?

....

....

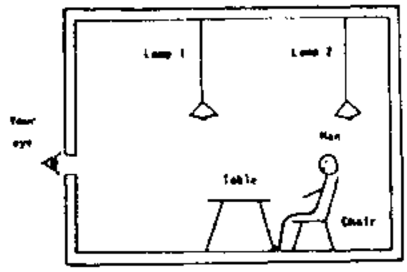
....

....

Figure 6.2: The 'lamp hole' question

3) The two drawings below show a room. There is a round key-hole in the door. You are outside the room, looking in through the hole.

In this drawing, you are standing close to the hole.



* How much of the room will you see?

....

....

....

....

* Give examples of things that you will see and things that you will not see.

....

....

....

....

* Shade the parts of the drawing which you will see.
* Explain how you worked out your answer.

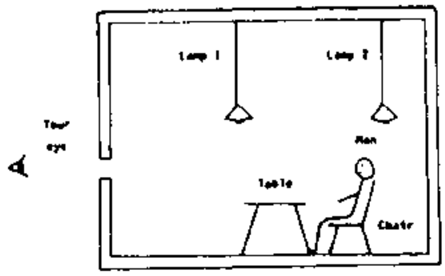
....

....

....

....

In this drawing, you are standing far away from the hole.



* How much of the room will you see?

....

....

....

....

* Give examples of things that you will see and things that you will not see.

....

....

....

....

* Shade the parts of the drawing which you will see.
* Explain how you worked out your answer.

....

....

....

....

If your answers on the two sides above were different, explain the reason for the difference.

....

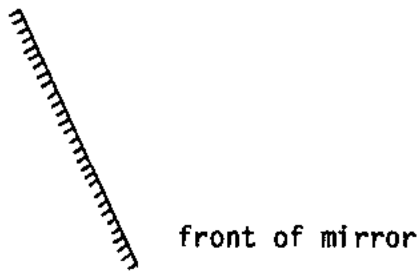
....

....

Figure 6.3: The 'eye hole' question

4) * You use a mirror to reflect light from a bulb into your friend's eye.

* Make a drawing which shows the mirror, the light-bulb and your friend's eye.
* Show where there is light in the drawing.



* Explain what happens between the mirror, the bulb, and your friend's eye.

....

....

....

....

....

* Do you think your friend can see anything in the mirror? If so, explain <u>what</u> he or she can see and <u>why</u>.

....

....

....

....

....

* If you think your friend sees something in the mirror, try to show it in the drawing above.

Figure 6.4: The 'lamp mirror' question

6.2 What are light rays?

In the initial open-ended written task students had been asked:

> "Have you heard about rays of light? What do you think these are? Where are they found?"

In Figure 6.5, some of the answers to this question have been classified in the form of a network. Although a frequency count on these responses has not been done, it is clear from the network that many students regard rays as a special kind of light rather than as a term for any light. Light rays are thought to have special properties e.g. long, thin, flashing, unlike ordinary light. They are sometimes associated with science fiction contexts, as in 'ray guns'. However, the proportion of such responses decreased in the post test. After the course in optics more students seemed to have realised that light rays are formed in ordinary situations too.

Most everyday light phenomena can be explained by geometrical optics; thus it is always appropriate to use the idea of light rays. However, as we will see again in the next section, the fact that rays are not visible, introduces a special difficulty for students. The interview of MIS (pre teaching) illustrates this (I = Interviewer):

MIS	... you can't see them (light rays from a lamp) now, but they would be there ...
I	... What makes you think that it is still there?
MIS	Well, ... it travels through the air, but you can't see it, it's too fine ... too fine to see.
I	... is there some time when you've actually seen rays?
MIS	Yeah. During the night time, when it is dark ... (Now) you can't see 'cos everything is the same ... If it was dark, you could see the light more closely and more further away.
	....
I	... suppose it was dark here, would you be able to see ...(the rays) ... actually going in straight lines?
MIS	No, you wouldn't.
	....
I	Then why do you draw them as lines?

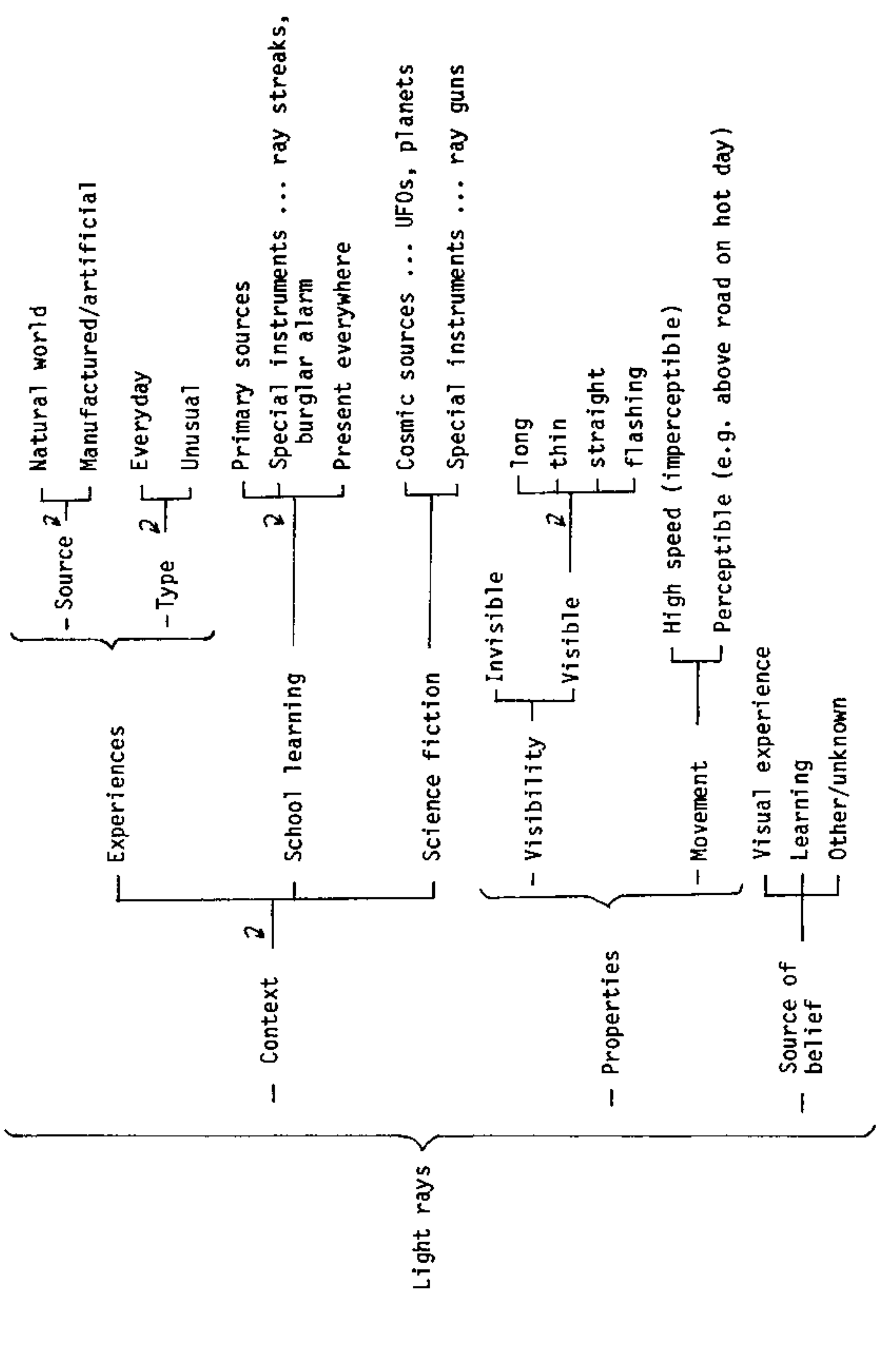


Figure 6.5: Network on light rays

MIS Because of what you would expect to see. You should see them when it's dark ... once you look at the light just at the start ... once you're a bit distance away from them you can't see them at all. You really see the light when it gets to where (it) is going to beam on to (i.e. the patch of light on the screen) ... You can see some of the beams coming out of it as if it were rays ...

....

I Is light always in rays?

MIS Yeah, from the sun and things like that, sun's rays.

I So any light you see is always rays of light?

MIS Depends. Not all light would be ... it's light now outside but we can't see any ... 'cos the rays have just lit the air up. (Later, he changed his statement to, ".. you can't see the rays, but they are here.")

This transcript shows that even when students know about 'light rays' being everywhere, they can find it difficult to reconcile this idea with their intuitive notion of visible beams of light.

6.3 Representing the presence of light

In the 'moors vision', 'lamp hole' and 'lamp mirror' questions students were asked to "show where there is light in the drawing". It was rare for students to indicate this light in any way (e.g. by lines or shading). The reason could possibly be a misunderstanding of the requirements of the question: "show where there is light" might have been interpreted as "show where you can see light". The convention that allows one to show invisible entities in a diagram may not be familiar to students.

Sometimes in the 'moors vision' question, students showed a straight line of light between the lamp and eye or, more often, between the lamp, mirror and eye in the 'lamp mirror' question. They did not show light anywhere else in the diagram. Again, this could be a legitimate misunderstanding of what was required. Normally, in a test, students expect to be asked to solve a given problem, not to express conceptions which are inessential to the problem. They would, therefore, show light only where their solution or explanation required it to be. Another difficulty in the 'lamp hole' task may have been the exercise of showing the geometry of the situation.

Even from the verbal part of the written responses, it was not always possible to judge whether the students thought that there was light, say between the source and the screen in the 'lamp hole' question. A response like, "The light from the bulb reflects on the screen ....." or even, "The light shines through the hole onto the screen", was still ambiguous in the above respect.

Such caution in the interpretation of written responses was found to be justified when the students were interviewed. Of the five students interviewed prior to the teaching of optics, none had shown light along the way between the board and the screen in the 'lamp hole' question. Even so, it was clear from their interviews that at least four of them knew of the existence of light in the intervening space.

For all the above reasons, the discussion in this section on students' ideas about the nature of light is largely based on interview responses. These should, therefore, be looked on as illuminative examples rather than as statistically supported results.

6.4 Interview responses

6.4.1 Light as an entity in space

In the 'lamp hole' context, there was only one student (out of five) in the pre-teaching interviews who did not spontaneously speak of light as an entity in the space between the lamp and screen. He responded as follows:

(Pre teaching)

I   Can you explain why we get this patch of light here?

MAJ   Because of the brightness of the lamp.

In the post test, this student drew a beam of light from the bulb through the hole to the screen. The interviewer questioned him about this and found that he held firmly to a conception of light in space.

(Post teaching)

I   Can you see the light here? (Referring to region between the board and screen in the apparatus set up as in the 'lamp hole' question.)

MAJ   No.

I   When you drew it did you think that you would see it?
MAJ   No.
I   ... So what does that mean?
MAJ   That it indicates where the light goes ...
I   ... How come you can't see it then?
MAJ   Because it is invisible!

MAJ then went on to explain that within a circle of about two feet radius around the 24W lamp, the light is visible, and outside of that, it is invisible. He did not give any further explanation.

Of the nine students interviewed post-teaching, all were convinced of the existence of light in space in the task context. However, none thought that it would go on indefinitely. The common response was that it would get dimmer and finally fade away. But nearer the lamp, they defended their contention in various ways as follows:

(Post teaching)
I   Why can't you see light between the lamp and the paper?
IEH   ... it's light in the room, and so it wouldn't, you can't shine another light coming from the light. But if you shine it on the paper you can see more light. ... There isn't anything between the light and the paper, there's only the paper. So you'll only be able to see the light coming down, from all the dust and things that are getting in between it and the light shines on it ... and it's usually dark ... when you do, say, a play or something. They always turn the lights off inside. When they put the spotlights on it shines more ...
I   What exactly does the dust do?
IEH   Well it makes it like ... if it was dark. It makes ... mark in the air, that you'd be able to see the light shining on it.

(Pre teaching)
MIS   ... You can't see them (the rays) now, but they would be there ...
I   What makes you think that it is still there.
MIS   Well, it travels through ... the air, but you can't see it, it's too fine ... too fine to see ... During the day you can't see them ... 'Cos everything around you, like the sky, the

sun, lights the area around ... when it's night ... you can't see them all the way, though, you can only see them through a certain distance till they hit the area which is supposed to light up.

(Post teaching)

I Why does the patch look brighter than the in-between part i.e. where light is travelling in space?

MIS 'Cos all the rays are meeting in one part. That makes it brighter. Much brighter.

These students are convinced that light exists in space even though light cannot be seen. Their conviction is strong enough for them to argue in its favour despite counter-suggestions from the interviewer. However, the basic phenomenon of light being invisible is taken for granted and thought to be unproblematic. This is possibly because the necessary connection between light and vision has not been established. The problem is discussed later in paragraph 6.7.

6.4.2 Deducing the presence of light

The interview responses given above show that students deduce the presence of light from some perceived effect. In the dialogue below, one student makes explicit the criteria used.

(Pre teaching)

LEH As they go through the hole, it hits that board and rebounds all over.

(Post teaching)

I What does the light do?

LEH Shines through 'em, through holes ... It either reflects on t'board or goes t'other way and just makes it brighter.

For this student, the spot on the screen is an obvious indication that there is light in the intervening space. But she also uses more subtle indicators. For example, while talking of the 'moors vision' situation, she says:

(Pre teaching)

I Do you think that there would be any light from the lamp near the person?

LEH I don't know. There might be a little bit ... You might just get a silhouette of the person if you stood behind him ... if you stood near him, you might just see, you know, the figure of him.

I If there wasn't light up to here then what would you see?

LEH I don't know, you might just see the movements, but I don't think you'd see more ...

I So if there wasn't light here you wouldn't see the shape of his body?

LEH No, I think you might just see movement, you know, if he was walking or something ...

The above extract shows that, for LEH, a variety of perceptual clues may be acceptable evidence for the presence of light. There are also warning signals for the teacher. The last part of the extract indicates a view that some perceived effects might occur without the presence of light. Also, the ability to see the source of light does not necesarily help the student to understand that light is near the eye of the observer. These situations are discussed later in paragraph 6.6.

6.5 Light and dark

Another point that comes through in several responses is the recurring comparison of 'light' with 'dark'. Darkness is apparently as important a part of students' conceptions as light. Previous research lends support to this contention.

Piaget (1930) found that up to the age of 7-8 years, children conceive of a shadow as physical substance emanating from an object. Solomon (1985) found shadows were referred to as 'dark light'. However, Weisner and Claus (1985) found that when 8-9 year old children spoke of a shadow coming from or starting from an object they meant it in a perfectly acceptable geometrical or simply correlative sense and not in the sense of an active emission.

In this study with 13-14 year olds, although the above conception of shadow or darkness as a substance was not found, students often spoke of light in relation to dark. In their diagrams it was not uncommon for students to shade in the darkness on the white paper instead of shading in the light as is conventional.

Interestingly, this tendency was negligible among those students who did the 'diagram' and 'actual apparatus' versions of the tests. To recall, in these two versions part of the schematic diagram had been given to the students so that their representations in these tests could not be regarded as spontaneous. Drawings in the 'verbal' version were not guided in this way, and it was in this version that children shaded in the darkness. The prevalence of this response is shown in Table 6.1.

TABLE 6.1: PERCENTAGE OF STUDENTS SHADING IN THE DARKNESS ('verbal' version of test)

Question	'moors vision'		'lamp hole'		'lamp mirror'	
Task occasion	Pre	Post	Pre	Post	Pre	Post
No. of students doing the question	36	39	35	39	27	38
% Shading in darkness	28	15	34	3	0	0

The effect of context is interesting too. The tendency to shade-in darkness was found only in the 'moors vision' and 'lamp hole' questions. On the other hand, in the 'lamp mirror' question 78% of the students responding on the pre-teaching occasion and 98% on the post-teaching one drew the light in their drawing. None drew in the darkness. It appears the dazzling effect of light was the predominant impression. This was less so in the 'lamp hole' situation, and in the 'moors vision' situation such a consideration did not occur at all because the lamp was so far away. The proportion of students shading-in the 'darkness' decreased significantly in the post test for the 'lamp hole' question but did not decrease significantly for the 'moors vision' question. These results may point to another reason for the difference between the two situations. Perhaps the 'lamp hole' test, unlike the 'moors vision' one, was a situation similar to those met with in school lessons, so that the difference between pre and post-teaching responses was significant.

6.6 Light in space

Earlier it was noted that in situations where light produces an effect like a bright patch on a screen, the presence of light between the source and the screen was deduced by students (that is by students in the age group 13-14 years; according to previous research, younger children may still have difficulty conceptualising this). On the other hand, we have noted that the presence of light between a non-luminous object and the eye, given that the object is seen by the eye, was deduced by only one third of the students at age 15.

This result can be compared with that of Stead and Osborne (1980), who used different situations (such as a candle, a lamp, a TV, and a mirror - all being watched by a person) to test for the idea of light existing in space. They found that most students, in the age group 9-16 years did not think of light as travelling out very far from a source and up to the observer, particularly in the daytime. They saw it travelling further out at night. Formal teaching in optics was found to alter these ideas to only a small extent.

Three of the questions in the local study (Appendix 3) involved light and vision. Of these, the 'eye hole' question was one in which the source of light was not explicitly mentioned. Significantly, in this situation, none of the students in the pre-teaching responses, and only one in the post-teaching responses, used the idea of the difference in views being due to light from different parts of the room coming to the eyes. In the 'moors vision' and 'lamp mirror' questions on the other hand, where a source of light was obvious, more students used the idea of light existing between the source and the observer. The percentages of children doing so are shown in Table 6.2.

TABLE 6.2: PERCENTAGE OF STUDENTS USING THE IDEA THAT LIGHT EXISTS BETWEEN SOURCE AND OBSERVER ('verbal' version of task)

Question	Task occasion	No of children doing the question	% using the idea
Moors vision	Pre-teaching	36	3
	Post-teaching	39	33
Lamp mirror	Pre-teaching	27	67
	Post-teaching	38	84

In retrospect, the difference in performance between the 'moors vision' and 'lamp mirror' questions is easy to justify. Although both experiences are common ones, the distance between lamp and eye is much larger in the first case, and the idea that light travels out to such a large distance is difficult to imagine. Perhaps more significant is that fact that in the 'lamp mirror' context, the physiological effect of the light on the eye is very strong. It may be recalled that Alkindi (813 - 873 A.D.) reached the conclusion that light entering the eye produces the physiological effect of vision. (He made inferences from experiences similar to those encountered in the 'lamp mirror' task.) It may be expected that this kind of experience could be a good starting point for teaching about how we see objects. Indeed Andersson and Karrqvist (1981) have suggested that the experience of being 'blinded' by light reflected from a white surface might be a useful one to introduce the notion that even ordinary objects send light to the eyes.

6.7 Is light necessary for vision?

In previous studies there has often been an implicit assumption that children in some way recognise the necessity of light for vision. For example, students have been presented with situations in which light of some kind is present, and then have been asked, whether light is still present (in places where its effect is not obvious), whether it reaches the observer, etc. A hint that such an assumption may not be justified, came from responses in the open-ended test such as:

"light helps to see better", and

"light helps us to see things clearly".

But it was a lesson on optics (first lesson, School 1) which brought this problem clearly into focus. The relevant parts of the transcript are given below (T = Teacher, P = Pupil):

T (Referring to questions on a worksheet.) Now, out of those questions you are asked, I shall explain to you, to some of you, how we see things. Now, if there is no light, can we see?

P (Clamour of responses from students.) No, yes, no, yes...

T If there was no light at all, if somebody put you in a cave in the middle of a mountain, would you be able to see?

P (Again, clamour of responses from students; only one is audible.) Yes, your eyes would be brighter than the dark!

T (Reprimands students for all talking at once.) Right, now, the question I asked you is, if I put you in a cave in the middle of a mountain and walked away, and you had no means at all of making any light of your own, would you be able to see? Wendy!

P If you're kept in there too long, you'd go blind, like fish do... (inaudible).

T That's right, your eyes need light to see. (Again, students all talk at once.)

P After some time your eyes would get accustomed to the dark.

The teacher then went on to explain that when you are in the 'dark' and can see, as in your bedroom, there is actually some light escaping through the curtains and under the door into the room. The teacher continued by describing her experience of being in an underground cave where she opened her eyes wide and yet could not see a thing. From the transcript it is not clear whether the students accepted this explanation. The point is that for most students, particularly those living in towns and cities, the experience of total darkness may not occur, and therefore the necessity of light for vision may not be realised. LEH's post-teaching interview supports this hypothesis. (In her post-teaching response to the open-ended task, LEH wrote, "We can see very faintly at night with no light.".)

LEH	... You can see at night if there isn't a lot of light you can just see where things are...
I	... You said "light helps to see, it brightens things up"... (then) how come you can see if there is no light?
LEH	'Cos there still is light in the night wi' t'moon and everything. ... Not very well, but you can still see.
I	What if there was no light at all? Is it possible to have no light at all?
LEH	(Shakes head negatively, looking sceptical.)
I	No? Why not?
LEH	Mm mrm (I don't know)... I don't know, but I just don't think you can go without light anyway.
	(The interviewer tries to argue against this, but LEH sticks to her statement.)
LEH	(On the moors) you can still see faintly where you are walking...
I	If there's absolutely no light.
LEH	I don't know, I've never been.
I	You've never been anywhere like that.
LEH	No.

Of course, in many countries of the world, in rural and unelectrified areas, the experience of darkness is a common one (especially indoors). In such environments, one could expect, not only a stronger link between students' conceptions of light and vision, but perhaps other deeper differences in their conceptions about light.

6.8 A cautionary note for teachers

The need for students to establish the connection between light and vision is a crucial one. However, this link may be overturned leading to a conception that light comes towards the eye only. An extract from the post-teaching interview with AEH illustrates this point:

I	(Referring to the 'moors-vision question') Mm. So you say that there is light right up to the person's eye.
AEH	Yeah.
I	Is there any light, say just above the person's head? Right here?

AEH Um... I don't know... (laughs) I don't think so, no...

I Um. Is there light a little to the side of the head? Say here? Not near the eyes, but around the ears.

AEH Around the ears? No.

6.9 Person-centredness, or 'eye initiates vision'

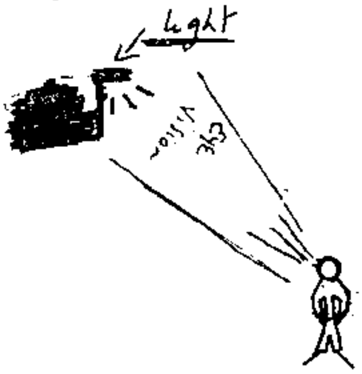
The idea that the eye (or visual system) is the active agent initiating vision has been mentioned in both the history of ideas about vision, and in the discussion of students' ideas. Responses to the National survey task showed that only 9% of the students imagined something definite like 'light' or 'sight' going from the eye to the book. However, an additional 19% indicated, though in a vague way, that the eye or brain somehow initiated the process of vision (see examples of these responses in Tables 5.1 and 5.2). In the local study with 13-14 year olds, it was possible to probe the nature of this conception a bit further, and to get a feel for its persistence despite teaching.

When asked a question like, "why do you see something?", it is perhaps natural to reply, "because I am looking at it". However, this common and unsurprising response is, in its essence, difficult to distinguish from others which appear to be clear 'alternative conceptions' about vision. The following extracts from responses start from this common type and then go on to illustrate aspects of the alternative conception.

CIM (Written response, pre-teaching, to 'moors-vision' question.) "I am able to see this light because I turned around and saw a little shiny light."

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.
* Show where there is light in the drawing.
* On this drawing, explain how you are able to see this small lamp shining.



* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

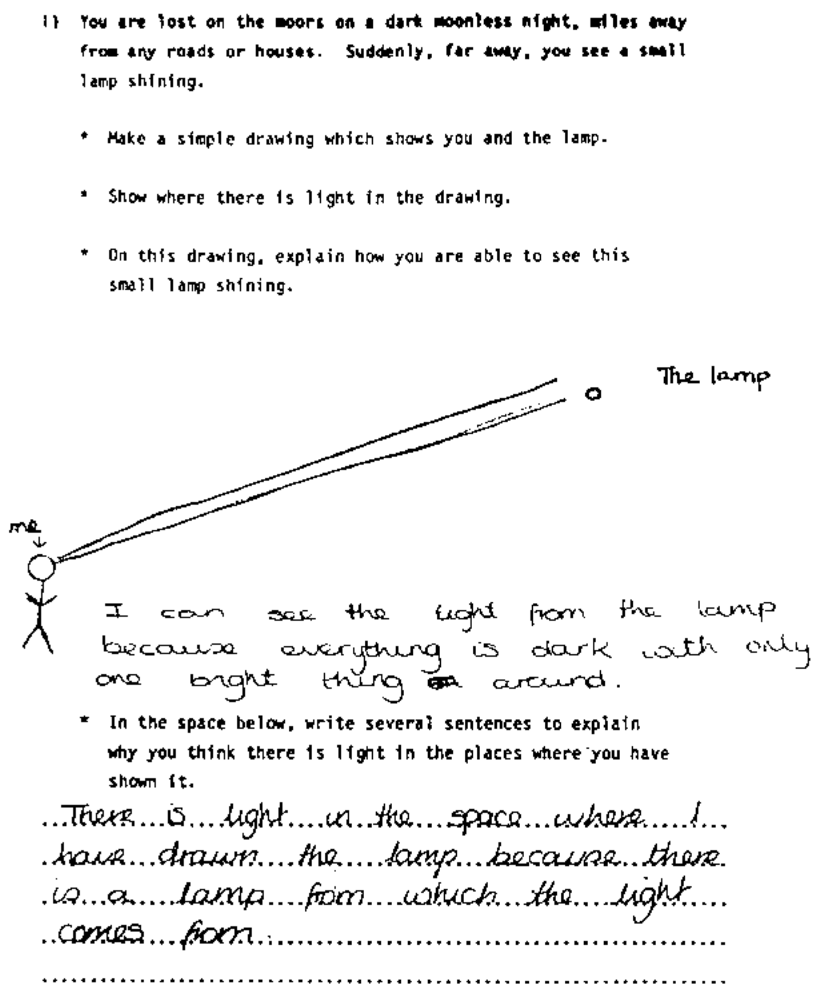
...There...is...light...Where...I have...shown...it...because
...there....is....probably...a....Village...or....Something.
..A..few.....Miles.....away.......To.....see....the........
..lamp.....Shining.....I.....was....looking...in.....that...
Direction...

"There is light Where I have shown it because there is probably A Village or Something a few Miles away. To see the lamp Shining I was looking in that Direction."

Figure 6.6: Pre-teaching responses by LEH to explain vision

LEH (Pre-teaching interview. In her written response to the 'moors vision' question, she had drawn lines in the region around the lamp, and similar lines, labelled 'eye vision', near the eye and going towards the lamp.)
"That was to show his vision looking ... he's looking in that direction and he can see it. That's just to indicate that he can see the light ..." (Now, referring to the rays around the lamp, she says..) "It can indicate that that means the light is shining. And that's sort of rays of it, the light of it."

We can see that LEH has a very sophisticated conception of light rays. She knows that depicted rays from the lamp are not real, they are a symbol. For her, it is equally important to draw rays from the eye towards the lamp. These are also symbolic and they illustrate the act of looking at the lamp. However, she did claim later that there was no light from the lamp near the eyes. Nevertheless, another student, MAS, who had drawn a similar diagram (post-teaching) with short rays around the lamp and longer lines from eye to lamp, was found to have an idea that light came from the lamp to the eyes.



1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.

* Show where there is light in the drawing.

* On this drawing, explain how you are able to see this small lamp shining.

* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

There is light in the space where I have drawn the lamp because there is a lamp from which the light comes from.

"I can see the light from the lamp because everything is dark with only one bright thing around."

"There is light in the space where I have drawn the lamp because there is a lamp from which the light comes from."

Figure 6.7: Post-teaching response by MAS to explain vision

MAS (In the post-teaching interview she refers to long lines between eye and lamp.) Well, it's the line of vision... from the person's eye.

I And what are these lines? (Short lines all around lamp.)

MAS It's the light coming from the lamp...

I You say that there is this light going away from the lamp. How far does it go from the lamp?

MAS I don't know... It should go quite far away... It'll go up to the person's eye.

Apparently, the aspects of vision to do with perception and the effort made to see something are much more real to students than the physical and physiological effect of light going into the eyes. In situations where the latter effect is strong, students have less difficulty in forming that conception (see paragraph 6.6). Conversely, the alternative conception of the eye being active is more likely to be expressed in situations where the physiological effect is not strong, i.e., when the source is far away, or is not self-luminous. A similar finding has been made by Guesne (1985). The following post-teaching interview extracts with IEH, illustrate the point:

I When you see, what is happening in, near your eyes?

IEH The light from the lamp is going to the - to your eyes, and it's making a picture of the light, so that you can see the light.

I How does it do that? How does it make a picture?

IEH It shines on - the retina... and it makes a picture at the back of the eye.

But later, when she is talking of a dim light, in a room, seen by a person at the back of the room she says:

IEH ... They can see the light, it's all dark, but they can see the light. And the light isn't shining to their eye. Their eye is just looking to the lamp... The eye can just look at it and just see all over there... the light isn't shining to their eyes. Their eyes are sort of going to the light, 'cos they're looking at it.

IEH, in her class worksheet, had drawn a diagram showing image formation in the eye. Apparently, she remembered this later, though she could not reproduce the diagram during the interview. (The interval between that particular lesson and the interview was seven weeks.) Similarly, MIS, who had drawn this diagram in class, had only a vague recollection of it seven weeks later. In fact, his post-teaching interview shows the persistence of the 'person active' notion despite strong counter-suggestions from the interviewer.

I What actually happens when you see something?

MIS Um, usually you look at it and think what it is...

I When the person sees the lamp, what's actually happening between the lamp and the person?

MIS Rays of light travel through, the other rays of light travel from the sun... so they just blend into, it looks just the same.

I O.K., when the person sees the light, is anything happening inside the eyes of the person?

MIS Yeah... They're looking at it and thinking what it is and sending thoughts to the brain...

I Is something happening... between the inside and outside of your eye? Is something going back and forth or something?

MIS Yeah, like a camera, inside your eyes, like printing what you see, in front of you.

I So what is going through?

MIS The thing you see, you look at. It's like being transformed to your brain, and it makes like a picture in front of your eyes.

MIS then drew the a diagram (Figure 6.8) to illustrate his statements.

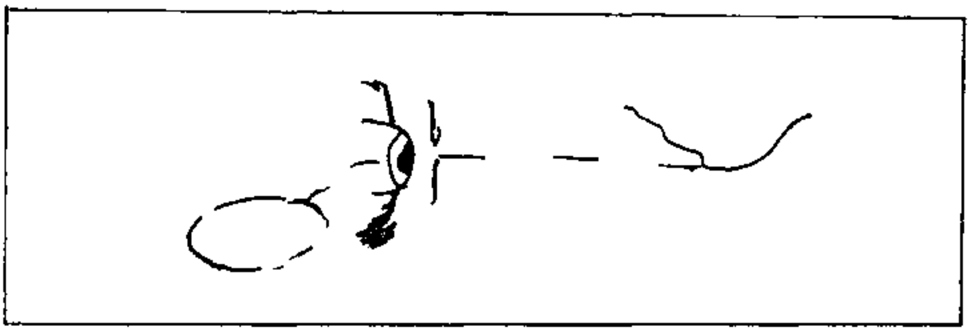


Figure 6.8: Diagram drawn by MIS to show 'vision'

Another student, NAJ, had not been taught the structure of the eye. Even so, she made the connection between light and vision, though in a way which still involved 'thinking'.

I ... What makes you think that the light comes up to you?
NAJ I don't know, just that I can see it.
I If you see it, does it mean that the light is coming to you?
NAJ No! I'm just thinking that it's coming to me because I can see it. Well, I mean when I see it I think that it's coming to me... but I'm not sure.

Of the nine students interviewed after teaching, there was only one who seemed to connect, in an acceptable way, vision with light coming to the eyes. The extract from his interview is given below.

VAD I've made a difference in my drawings (between the pre and post tasks in the 'moors-vision' question) because I didn't really know (in the pretask) much about light, and I thought um the lamp would not come... straight to your eyes it might have bounced. But in the later one (post test) I made it a lot clearer. It comes straight to your eyes.
I What comes straight to your eyes?
VAD Er, the light from the lamp.

Later, he also was found to have an idea of the diminishing intensity of the light, deriving it from the apparent decreasing brightness of the lamp at increasing distances.

6.10 A network summarising students' conceptions of the light-vision connection

The issues brought out in this section on students' conceptions of the light-vision connection, along with some related issues discussed in the previous section, can be summarised in the form of a network (see Figure 6.9).

Since these issues are drawn from previous research as well as tasks and interviews in this study, it is not possible to indicate the prevalence of the various conceptions. As in the case of the other networks, this one cannot be said to be a unique representation of the ideas found. However, it

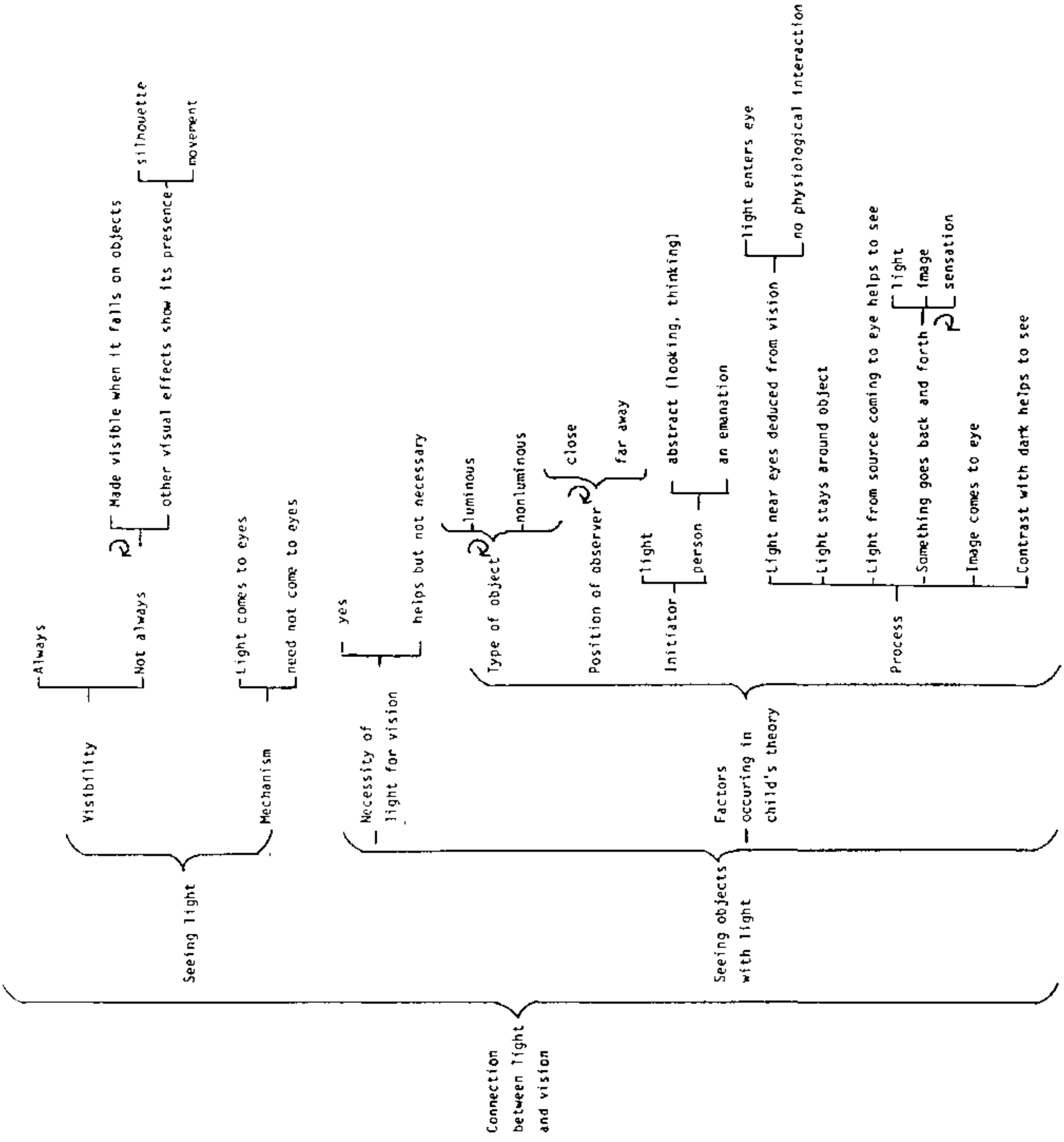


Figure 6.9: Network on connection between light and vision

is presented here to give an overview of the range of ideas that children may have about the connection between light and vision.

The classification heads occurring in the network have immediate pedagogical, as well as research implications. It should be possible, by using these categories as a checklist, to identify sets of conceptions held by a particular student or group of students. An example of such a description might be as follows:

> Light is normally invisible. You see it only if it falls on something, say like dust in the air. It is not necessary for the light to come to your eyes, in order to know that it is there. Only light from a very bright source can come up to your eyes and enter inside, and then it helps you to see the source and things around it. A dim lamp, or a non-luminous object can be seen without light from it coming to the eyes. We see these things because we open our eyes and make an effort to see what is in front of us. It is as if our sight goes from the eyes to the object.

SECTION 7

REFLECTION OF LIGHT AND IMAGE FORMATION

7.1 General conceptions about reflection in mirrors

For young children, mirrors are often a source of amusement, and the "looking glass world" must have intrigued most of us. One author remembers as a child, a whimsical remark from an adult whose home she was visiting: "Why! We have visitors come to stay. Let us switch on all the mirrors". Watts (1985), in a case study of a boy studying physics in the fourth year of a London school, quotes:

> "Mirrors are strange things. They're difficult to explain because you don't really know what makes them work. You know in principle even if you don't know all the physics involved, but I don't know fully why light reacts with it like that (and not with other things)."

The most elementary conception about plane mirrors is that they simply produce images. A person observes the image, but this may be regarded as having nothing to do with light reaching the eye. Such a conception has been found in young children by Jung (1981), Guesne (1985) and Watts (1985). It is consistent with everyday language, in which the term 'reflection' is used for an image seen in a mirror. As Guesne (1985) noted 10-11 year old students say 'a lamp is reflected' in a mirror, though by 13-14 years of age they recognise it is <u>light</u> from a lamp that is reflected by the mirror. However, these students also thought that when this lamp-light falls on a sheet of paper, it stays on the paper. Ramadas (1981) asked 14-15 year old students to distinguish between the reflection properties of a mirror and those of a plain white surface. Many of these students said that light reflected from a mirror would travel out far, while light from a white surface would either stay on or near that surface, or else go behind it. Several students said that a mirror would reflect more of the incident light than an ordinary white surface.

To digress a little, it is striking how all these observations are, in a sense, consistent with everyday experience, thereby making the teacher's job a delicate one. Jung (1981) remarks:

"..... at least part of the common sense frame cannot be discarded as simply false, and thus to be eliminated. Likewise it does not seem possible to explain, or, more moderately, to describe our experiences wholly within the physical frame. Thus the aim of teaching cannot be simply to teach the right conception as against the wrong one. The aim must be to become aware of the difference in context, that makes one frame or the other appropriate."

Returning to reflection, it appears that even students who have studied optics, think that this is a unique property of mirrors. Sometimes, as several responses in Guesne's study show, students might literally assume a billiard ball model for light, and conclude that a hard surface is necessary for the reflection of light. The role of regular reflection in producing an image is not spontaneously realised, though these students may have learnt how to draw ray diagrams.

A conception different from those above was found by Piaget (1974) with 7-8 year old children. When an object was placed behind them so that they could see its image in the mirror, they most frequently explained this by saying that something passed from the eye to the mirror and from there to the object. Also, some of them imagined that, at the mirror, 'what left the eye' and 'what left the object' met each other.

We have already seen that the term 'reflection' is often used to refer to the 'image'. In fact, children speaking both Marathi and English languages often use these terms in a very loose way, to describe a shadow, or an after-image, or just a patch of light. The interview transcript (post-teaching) of one student illustrates this.

AEH (Describing light from a lamp going through a hole onto a screen.) And then there'd be the holes which is the reflection which the light is taking, the reflection this hole here is bringing to the screen...
I ... Where else have you seen reflections?
AEH Like, when the sun is shining on us you see... your own shadow on the ground, or on the walls and things.
I ... That's a reflection?
AEH Yeah.
I Where else?

AEH ... If you are in a classroom, and the sun is shining, and you're using a pen and it's sort of moving around and as you're writing you can see it when the light is on the table (here she was referring to the bright patch produced by light reflecting off metal)....

I Where else?

AEH (pause) I can't think of any more.

This variety of meanings in students' minds has to be taken into account while teaching about reflection.

In the 'lamp mirror' question (Figure 6.4) students were asked to show what happens when a mirror is used to reflect light from a bulb into someone's eye. They they were asked whether the other person would see anything in the mirror. The part of the question regarding seeing was relevant only in the 'verbal' and 'diagram' versions of the test, for in the 'actual apparatus' version, students could actually see an image of the bulb. Many of the written responses stated that light reflected into the eye would lead to dazzle. Very few said that an image would be seen by the other person, perhaps because the expected dazzle would prevent anything being seen clearly. Responses of students in the first two versions is shown in Table 7.1.

TABLE 7.1: NUMBER OF STUDENTS PREDICTING 'DAZZLE' OR 'IMAGE' IN THE 'LAMP MIRROR' TASK

	Pre teaching task		Post teaching task	
Prediction	Verbal version n=27	Diagram version n=25	Verbal version n=38	Diagram version n=38
Dazzle	23	22	38	34
Image	4	3	9	9

Of the five students interviewed before teaching, none had made a written prediction that an image would be formed. During the interview, three of them were shown the 24 watt light bulb and a small lab mirror, and they still maintained that reflecting light into the eye would cause dazzling. MIS thought that the person in whose eyes the light was reflected, could see his own face in the mirror, and was surprised to find that this was not so. CIM expected to be blinded by the light, and when he did not experience this, he conjectured that although the image of the bulb was visible, the light was not going into his eyes.

I Now am I reflecting the light into your eye?
CIM No, not really.
I ... How would you have expected it to happen?
CIM ... just pure light coming straight into me eye. All the light what's letting out, what it's letting out.
I Is the light from the bulb coming into your eyes?
CIM There is some, but not all of it.

(Later, in the post teaching test, he still maintained nothing could be seen if light was being reflected to eye.)

As has been noted in previous sections, students in certain situations conceive of light as something that is dynamic and thus has spectacular effects. In ordinary situations, like seeing an object, or seeing its image in a mirror, this conception of light does not seem to be applied.

The written response of NAJ (pre-teaching) vividly described one such dynamic picture. (See Figure 7.1.)

NAJ (written response) the rays of light between the three things all collide with each other and they all go.

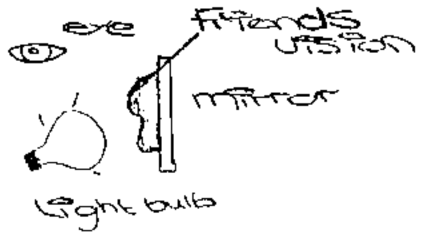
In the interview, this response was probed further.

I ... did you want to say anything after that?
NAJ (Laughs) Don't know what I mean by that! I think they'd all just c... they all... the rays from the three things (lamp, mirror and eye) would just collide with each other and then they'd just probably go... go back out... They all just collide with each other and fall back into place.

4) * You use a mirror to reflect light from a bulb into your friend's eye.

* Make a drawing which shows the mirror, the light-bulb and your friend's eye.
* Show where there is light in the drawing.

a picture to show you a bulb eye and a mirror



* Explain what happens between the mirror, the bulb, and your friend's eye.

...the...rays of light...between ...the three things all... colide with each other and ...then they all go....

* Do you think your friend can see anything in the mirror? If so, explain what he or she can see and why.

...The friend would be able ...to see a bright image ...of the light bulb or a dot. ...She would see this because all the ...light is to powerful for the rays of light that, her eyes had

* If you think your friend sees something in the mirror, try to show it in the drawing above.

so close causing an image.

"The rays of light between the three things all colide with each other and then they all go."

"The friend would be able to see a bright image of the light bulb or a dot. She would see this because all the light is to powerful for the rays of light that, her eyes had to close causing an image."

Figure 7.1: Pre-teaching design by NAJ in 'lamp mirror' task

I Suppose the light bulb was switched off. Would there still be rays of light colliding?

NAJ No, I don't think so. I think... they'd just go and escape land go wherever it's going.

I What would escape?

NAJ Light... Probably the two things... the eye and the mirror... the light that's coming out from there would probably just escape through the gap that's there... from when you turn the light bulb off.

I ... Which gap do you mean, can you show that in the drawing?

NAJ It's not really a gap, but if that light bulb were on, the rays stopping them rays from escaping. That's why they're just going round all the time.

I Ah.

NAJ If you turn that off it just goes round, and it escapes through there then.

Most of the ideas discussed here are reminiscent of the alternative ideas about vision mentioned in Section 5. A distinctive feature of these ideas about vision is an assumption that light does not travel up to the eye, but stays around the object seen. Such a conception cannot be consistent with the idea of an image that is behind the mirror. It will be shown below that this latter idea is a difficult one for students to understand.

7.2 Location of the image

A common conception found in both adults and children is that an image formed by a plane mirror is actually on the surface of the mirror (Hawkins, 1978; Jung, 1981; Ramadas, 1982; Guesne, 1985; Watts, 1985; Goldberg and McDermott, 1986). Jung (1981) describes the work of Weisner and Claus, in which students were able to locate the image in a plane glass plate behind the plate, but while with a sooted plate they were uncertain of the position of the image, they consistently maintained that the image in a plane mirror could not be behind the mirror. A similar response has been found obtained on requesting students to locate the position of a real image formed by a concave mirror or convex lens, when the screen on which the image falls, is removed. For a discussion of this problem, see Goldberg and McDermott, 1987.

In such a situation students see a demonstration, but interpret it in terms of their preconceptions. Counter-suggestions from the teacher do not seem to help. Some attempts have been made to develop suitable teaching methods to overcome this conceptual difficulty. Ramadas (1981 and 1982) asked teachers of some groups of 14-15 year old students to start their lessons on reflection by having students observe the image of a candle in a piece of plane window glass. The students were then asked to put an inverted test-tube over the image so that the candle now appeared to be burning inside the test-tube. (This way of 'catching' the image is simple and does not require an explicit procedure, unlike the parallax method with two pins.) Then a sheet of cardboard was inserted between the test-tube and the glass. The cardboard blocked the test tube but not the image, and the teachers used this observation to explain the nature of the virtual image, which could be seen even though the light from that point could not reach the eye. After this the glass was replaced by a plane mirror and the lesson continued. Though the students enjoyed this experiment and seemed to appreciate the point, the results of comparison with a control group showed, disappointingly, no difference in the frequency of image drawing 'on' or 'in front' of the mirror.

Another pedagogical attempt, made by Wiesner and Engelhardt (1987) working with 13-14 year old students, used a calibrated camera of variable length. Objects at different distances could be observed 'in focus' at different points in the camera. They used this apparatus to demonstrate that the image in the plane mirror was actually at the given position behind the mirror.

In the present study, although a deliberate search for this particular conceptual difficulty was not undertaken, nevertheless it was encountered. In the account of classroom observations in School 1 (Appendix 5) such an incident was observed. When a screen, on which lay a real image formed by a convex lens, had been removed, the students unanimously declared that the image was relocated onto the lens.

The difficulty faced by the students in trying to locate the image in a plane mirror is illustrated by the extracts of interviews with three students (two pre-teaching and one post-teaching) who were asked to show where the image was located.

I ... Would she see the light bulb in the mirror?
NAJ Yeah.
I Where would she see it?
NAJ Just in t'mirror.
I ... Can you point out with the pen?
NAJ On t'mirror?
I Mm.
NAJ Well she'd see it somewhere round here.

The next interview shows the student's conviction that the image could not be inside the mirror.

I So where is the bulb? Can you put a finger?
MIS There. It is on the mirror (puts finger on mirror) ... that's the reflection of the bulb.
I ... So was it around here, on the mirror, or was it a little ... in front of the mirror, or was it a little... behind the mirror?
MIS It's in front of the mirror. You see, it looks as though it's inside it, but it's not! It's there!

and

I Where exactly is that (the image)?
CIM It doesn't exist there, it's just like the mirror's reflecting off it.

From these responses it appears that students' difficulties lie in viewing and conceptualising the depth dimension of images in mirrors. Hawkins et. al. (1978) say that the students' idea of a mirror image resembles a picture painted on a canvas. However, as the study of Goldberg and McDermott (1986) with college students shows, the conception might be more complicated. They found that more than half of their students before their course in optics (and 30% after the course), thought that the position of the image of an object would change with the position of the observer. Many of these students argued that the image lay along the line of sight of the observer looking at the object, i.e., that the observer, the object and the image always lay along a straight line.

7.3 Geometry of mirror reflection

The difficulty with the depth dimension discussed above has consequences for the students' understanding of the geometry of reflection. If the 3-D mirror world is visualised, the same line-of-sight reasoning that is used for the real world, seen through (say) a window, can be applied to determine what and how much one can see in a mirror.

In fact, even when students have learnt to draw incident and reflected rays in a mirror, they find it difficult to imagine how an image can be formed when an object is beyond the edge (but in front) or a mirror, or how a person who is directly facing a mirror, cannot see an image even though the image exists in the mirror. This was found by Ramadas in an unpublished part of the study cited earlier. Goldberg and McDermott (1986) asked college students, which of two observers shown as A and B in the diagram below, could see the image of an object which was placed in the position O.

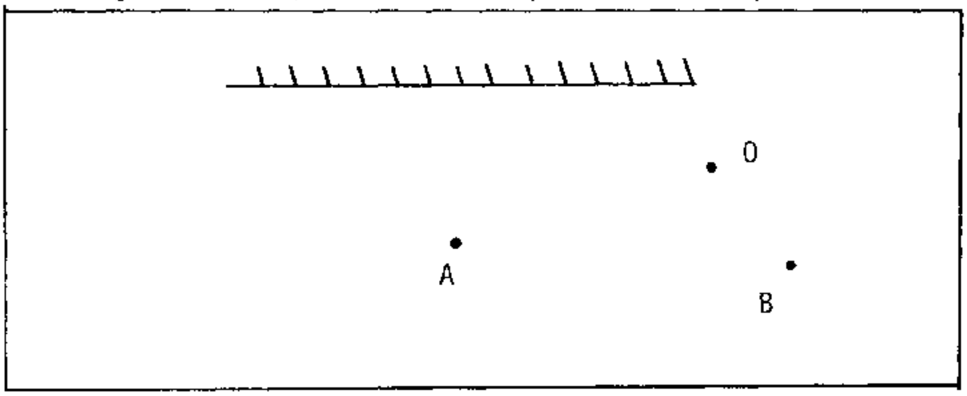


Figure 7.2: Task reproduced from Goldberg and McDermott (1986)

They found that about half the pre-teaching students and three fourths of the post teaching students in an interview situation responded correctly. Of the incorrect answers, the pre-teaching students more consistently used the incorrect line-of-sight reasoning to conclude that B would see the image and A would not, while the post-teaching students used a mixture of the correct and incorrect reasoning, leading to the prediction that both A and B could see the image.

In another task, used by Jung (1981) and Goldberg and McDermott (1986), students were asked what they would do to see more of themselves in a mirror. Formally, the question is a complicated one, requiring more geometry than simple image construction. But it is based on an everyday experience, and could be answered intuitively by using the mirror-world and window analogy. However, most students responded that if you moved back, away from the mirror, you could see more of yourself. Some of these students seemed to imagine the mirror as a kind of 'eye' looking at the person with an angle of view of a fixed size. Further away from the mirror, more of the person would be contained in this angle. Another kind of reasoning imagined the image to fit into the frame of the mirror, so that if the person moved away, a decrease in the apparent size of the image would cause more of it to fit into the mirror (the corresponding decrease in the apparent size of the mirror was overlooked).

These responses show an encouraging tendency for students' to use analogical reasoning and intuitive geometry. Problems arise when they fail to link this reasoning with rules learnt through textbook examples. Another difficulty may lie in learning to use schematic representations for actual situations. This latter problem is dealt with in the next section.

SECTION 8

SCHEMATIC DIAGRAMS

8.1 An earlier study

Since ray diagrams are an example of students' early acquaintance with a schematic form of representation, it may be anticipated that difficulties in understanding and using them may arise. An earlier study with secondary school students in Bombay was concerned with this problem. The results of that study will first be summarised and the aims and then the findings of the present work will follow.

The Bombay Study (Ramadas, 1982) dealt with the written responses by about 300 students on a set of problem-solving tests. Some of these problems were based on situations similar to those students had encountered in their course on optics, while other problems dealt with actual life situations which could be represented by simple schematic diagrams. In some questions, part of the diagram was given and the students were asked to complete it.

Results showed that a major difficulty for students lay in representing the given situation by a schematic diagram. In the first stage, students tended to draw all that they perceived, instead of abstracting essential and pertinent aspects. That is, they drew picture-like sketches instead of schematic diagrams. For example, in a question about refraction of light through water in a lake, many students drew the surface of water as a blur, or with ripples. Some said that since the water would probably be muddy, very little could be seen through it. This tendency, to record all the perceived complexities of an actual situation, persisted even when the situations were already converted into schematic diagrams.

The positive aspect of these observations was that students could visualise a scene well, and they had an eye for detail. Also a large number of students were able to give at least partially correct responses based on their observation, experiences and imagination, without mentioning any physical laws or drawing schematic diagrams. Diagrams, when drawn, were used for the purpose of illustration, rather than used as a tool for analysing the situation.

The descriptive (rather than explanatory) nature of the students' diagrams was apparent in both simple and complex situations. In a textbook-like problem to do with shadows, most students drew the shadow, but fewer showed rays. Fewer still deduced the shadow from the path of the rays, or even showed the shadow connected with the rays.

Some specific problems with ray diagrams involving reflection of light were as follows. Students did not realise that a minimum of two rays were needed to determine the position of the image and that much more light was needed to actually form the image. Most students assumed that one or two special rays were sufficient to get an image in a mirror. If these particular rays were blocked off, no image would be formed. Often, rays contributing to an image point were not shown to start from the corresponding object point, and to be reflected at the mirror. Students who had learnt about convex and concave mirrors had an even more restricted view of ray diagrams - they sometimes showed, even for plane mirrors, light rays passing through a 'focus' and giving an inverted image.

Given a choice of the verbal and diagram modes of expression, most students preferred the former. An intriguing finding was that sometimes they would verbally explain the path of light rays (e.g. as going 'up', 'more up', 'to left' etc.), and choose correctly between a right and a wrong diagram, but they would not themselves draw a diagram. Sometimes their diagrams were inconsistent with their verbal explanations. These findings raise some further questions about students' learning and effective pedagogy. For example, does the difficulty lie in translating from the 'verbal' to 'diagram' modes of expression? Can students visualise a problem situation, given a reasonably complex verbal description? Under what conditions can they use diagrams as an effective mode of communication? What is the relationship between the spontaneous conventions used by students in diagrams, and their conceptual understanding?

Some answers to these questions were sought in the study described below.

8.2 Three versions of the task

8.2.1 Structuring of the problems

In Section 1 three versions, 'verbal', 'diagram', and 'actual situation', of the problem-solving task were outlined. The aim of presenting problems in these three modes to three different (matched ability) groups was to find out how students function in three kinds of situation: (a) when they start from a verbal description only, (b) when the essential aspects have already been abstracted into a schematic diagram, and (c) when the problem of visualisation has been removed. Figure 8.1 shows not only the stages which occur as explicit requirements of solving the problems, but also intermediate hypothetical stages and links in the process. The latter are shown by the dotted boxes and lines. This figure articulates some assumptions about the structure of problem solving.

8.2.2 Response hierarchy

This uniform structuring across problem situations made it possible for us to fit the students' responses into a hierarchy. It is well known (e.g., Piaget, 1930; Peel, 1971) that young children tend to give purely descriptive ('what', 'how') responses to questions of 'why'. Responses of older children include predictions about phenomena, and finally, explanations of some kind. In the study of schematic diagrams, referred to in Section 8.1, it was noticed that a classification into illustratory and explanatory diagrams was appropriate. Thus, an attempt was made to classify the students' responses into a hierarchy along this dimension. The levels in this hierarchy mainly referred to the students' diagrams, except for the levels referring to 'prediction', in which their verbal explanations also needed to be taken into account. The observed hierarchy of responses to each of the four problems was found to fit into an overall hierarchy with ten levels, as shown on the left hand side of Figure 8.2.

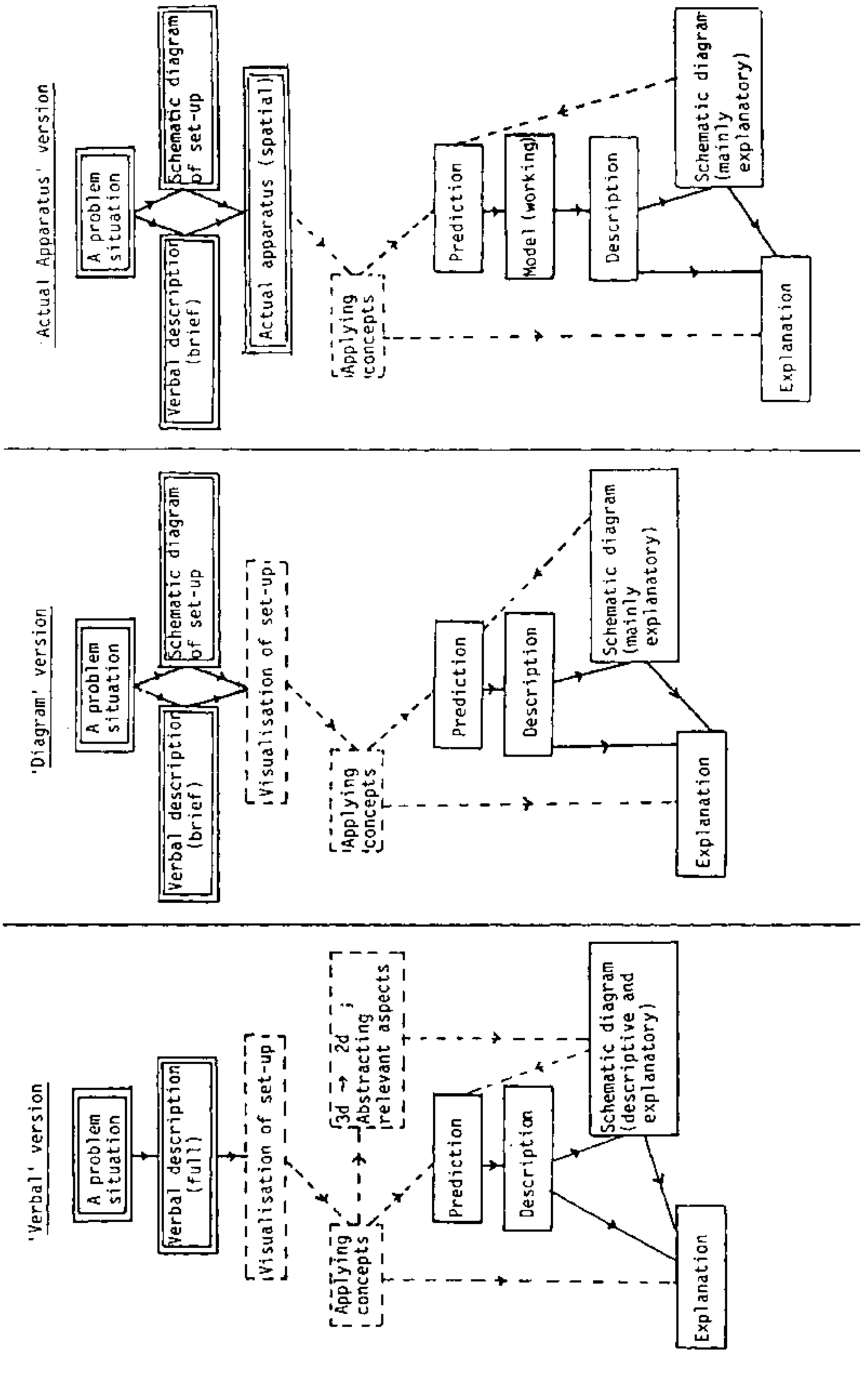


Figure 8.1: Stages of problem solving in each version of the local study on 'light and sight'

			Moors-vision	Lamp-hole	Eye-hole	Lamp-mirror
			qu 1	qu 2	qu 3	qu 4
Descriptive (no explicit model)	Non-predictive	A = Listing components of situation in diagram	Lamp, person	Bulb, board, screen		Bulb, mirror, eye
	Predictive (phenomenological)	X = Partially correct prediction			You see less	
		B = Correct prediction	Lighted area	Spot on screen	How much you see	Brightness, dazzle
Explanatory (with model)	Non-geometrical	C = Non-interpretive model	Rays or variation in shading			Rays
		D = Interpretive, inaccurate model	No connection with eyes or vision starts from eyes			
		E = Interpretive, accurate model	Object-eye connection			Object-mirror-eye connection
	Geometrical and interpretive	L = Model; no measurement		Spatial arrangement	Spatial arrangement	
		M = Model; elements of measurement		Some factors for size	Some factors for size	
		N = Model; accurate measurement		All factors for size	All factors for size	
Descriptive	Predictive	F = Prediction of image				Prediction of image

Figure 8.2: A hierarchy of types of response

The rationale for construction of the above hierarchy, and the consistency of each response level according to logical, causal and empirical criteria, form the subject of a separate paper (Ramadas and Shayer, 1987). Here we simply use the hierarchy as a means for scoring the students' responses along an assumed 'descriptive-explanatory' dimension. Although no single scale could conceivably describe all the responses completely, it is felt that this scale, with its explicit description of levels, extracts a large proportion of the relevant information. Thus it is anticipated that the scores derived from it will provide a meaningful measure of the students' performance on the test.

The full range of levels for each problem, shown in Figure 8.2, was applicable to the 'verbal' version of the test. In this case, each of the four problems was scored on the five levels shown in the figure. Thus the scores on the 'verbal' version could range from zero to twenty. In the 'diagram' version, four of these levels, namely, level A for 'moors vision' and 'lamp hole' tasks, and level L for 'lamp hole' and 'eye hole' tasks, were already given to the students. Thus there were only 16 levels in all and the scores could range from 0 to 16. For a comparison between scores on the verbal and diagram version, only these 16 levels were used. In the 'actual apparatus' version, the 'moors vision' problem was left out and there was a further reduction of the following levels: X ('eye hole'), and B and F ('lamp mirror'), so that only nine levels remained and scores could range from zero to nine. These were the levels used for comparison between all three versions.

8.2.3 Distribution of scores

Table 8.1 shows the mean and standard deviations of scores on the three versions of the tests.

The distributions of the scores for maximum scores 20 and 16 are shown in Figures 8.1 and 8.2.

Table 8.2 shows the significance of the differences between the mean scores on all the versions. It turned out that whether the scale had maximum score 20 or 16 or 9, the significance of differences at the 1% level was unchanged.

TABLE 8.1: MEAN SCORES ON EACH VERSION OF THE LOCAL STUDY TASKS[1]

Version	Number of Students	Max. Score 20		Max. score 16		Max. score 9	
		mean	s.d.	mean	s.d.	mean	s.d.
Vpre	36	8.2	3.5	5.9	3.0	3.1	2.1
Vpost	39	12.2	3.2	9.2	2.7	4.7	1.6
Dpre	37	-	-	8.3	3.4	4.3	2.5
Dpost	38	-	-	11.1	3.4	6.1	2.3
Rpre	9	-	-	-	-	3.9	2.6
Rpost	12	-	-	-	-	6.5	2.3

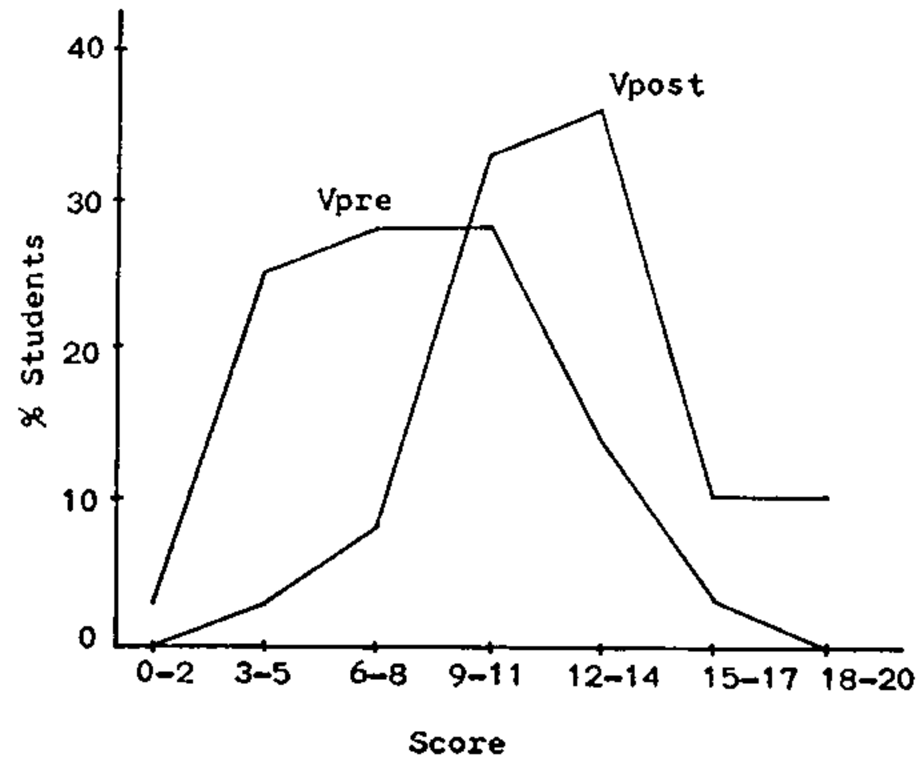


Figure 8.3: Distribution of scores on 'verbal' tasks before and after teaching

1 Only scores in the same column can be compared.

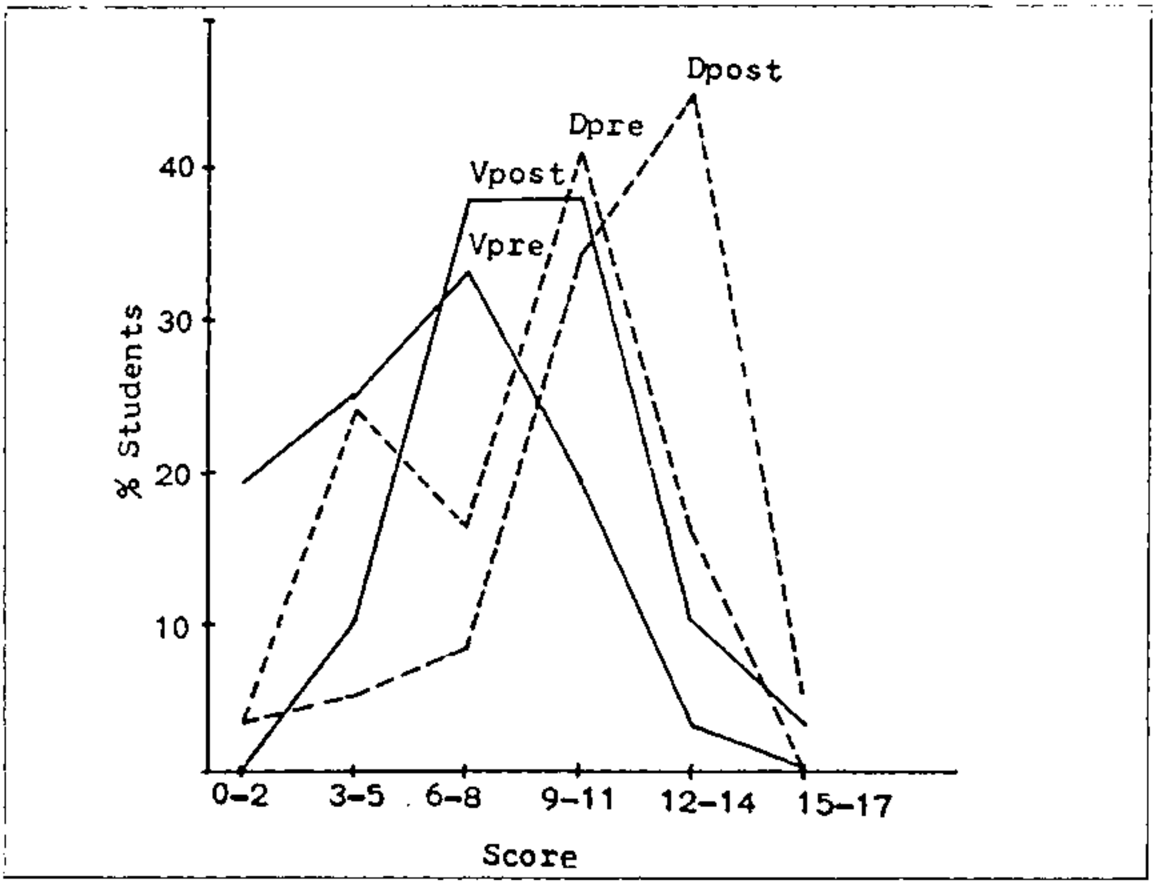


Figure 8.4: Distribution of scores on 'verbal' and 'diagram' tasks before and after teaching

TABLE 8.2: SIGNIFICANT DIFFERENCES (*) BETWEEN MEAN SCORES ON EACH VERSION OF THE TASK BEFORE AND AFTER TEACHING

	Vpre	Vpost	Dpre	Dpost	Rpre	Rpost
Vpre		*	*	*	n.s.	*
Vpost			n.s.	*	n.s.	*
Dpre				*	n.s.	*
Dpost					*	n.s.
Rpre						*

n.s. difference is not significant at p = 0.01

These Figures and Tables show that, with all versions of the test, the post-test performance was significantly better than the pre-test performance. This effect must have been due to the teaching of optics - possibly assisted by exposure to the same tasks that preceded the teaching. It led to an improvement in problem solving in all three modes, 'verbal', 'diagram' and 'actual apparatus'.

8.2.4 Comparison between the versions

The difference in scores between the 'diagram' and 'actual apparatus' versions is not significant either before or after teaching. However, the 'diagram' version has higher scores than the 'verbal' version, both before and after teaching too. Between the 'verbal' and 'actual apparatus' versions, there is no significant difference in the pre-task (although the mean score for the 'actual apparatus' version is higher), but in the post-task the difference becomes significant. Since the sample size for the 'actual apparatus' version is rather small, this result may not mean much. However, it does appear as if the post-task improvement for the 'actual apparatus' version may be more than for the other versions. Actual experience with the situations, followed by the course in optics, may have led to effective learning.

The higher facility of the 'diagram' and 'actual apparatus' versions, in which the conversion into schematic diagrams had been partly done, is remarkable. In these versions, fewer students showed irrelevant elements from the context in their diagram. More of them showed light going out in rays from the lamp, whereas in the 'verbal' version, students were more likely to show the light as a 'pool', or a shaded area. In the 'verbal' verions of the 'moors vision' question, several students interpreted the question, 'Explain why there is light...' to mean, 'Explain why there is a lamp...'. They tried to give a justification or purpose for the lamp being on the moors (e.g. "It is there so that you can see", or, "There may be a hiker on the moors").

Thus, the 'diagram' version was more effective than the 'verbal' version in enabling students to distance themselves from the actual context and to work within an abstracted context consisting of light sources, rays and geometrical projections. Problems in this mode were easier to solve. In comparison, the 'actual apparatus' version was not significantly easier to do than the 'diagram' version. Once the situation was in the abstracted form, a major difficulty was apparently overcome, and further experience with the phenomenon did not directly contribute to better performance. Nevertheless, that experience may have contributed indirectly by making learning more effective and leading to better performance in the post-task.

These results need to be reconciled with other results which show that students find it difficult to work with schematic representations. Gott (1985) found that 15 year olds had equal difficulty setting up an electric circuit given a verbal description, as they had in starting from a circuit diagram. It was much easier for them to set up the circuit correctly from a photograph. In the optics tasks, the diagrams are not an additional requirement, but an intermediate step in the solution, so, giving the diagrams rather than verbal descriptions helped problem solving. However, this explanation still does not account for the fact that the diagrams in optics posed less difficulty than the circuit diagrams in Gott's study. Perhaps the symbols used in the former are more familiar or are closer to the actual apparatus. Another explanation might be in terms of the Piagetian stages of concrete and formal operational thinking. These diagrams, by ordering the elements of the situation, may facilitate the strategies of classification and seriation, so that concrete operational thinkers, who have had difficulties with the 'verbal' version, are able to solve problems presented in 'diagram' form.

8.3 Characteristics of students' diagrammatic representations

8.3.1 Context boundedness

Converting a given situation into a schematic representation requires that the components, which are pertinent to the phenomenon being studied, are extracted and that inessential aspects are ignored. Spontaneous thinking, on the other hand, is context bound. Students need assistance initially to (a) realise that an extraction of essential elements is necessary, (b) know which elements are relevant to the problem, and (c) understand which of the effects would be insignificant enough to ignore. As we mentioned in the earlier section, many students, particularly in the 'verbal' version of the pre-tasks, showed irrelevant contextual elements in their diagrams. The tendency was most pronounced in the 'moors vision' question, and it decreased in the post-teaching responses. Examples of two students' pre and post-teaching responses to this question are given below.

Figures 8.5 and 8.6 are examples of responses by a student who continued to show inessential contextual elements in his drawing, even after the course in optics. (One unexpected idea that the interviewer found with this and another student was the association of 'night' with a moon, though the moon could be hidden by clouds.) However, the inessential details are fewer in the post-teaching responses.

Figures 8.7 and 8.8 are examples of responses by a student who showed a striking change to schematicity between the pre and post-teaching tasks (in this as well as in other diagrams).

8.3.2 Phenomenological drawings

Geometrical optics begins with some assumptions, for example, that light travels in straight lines, that it obeys certain laws of reflection and transmission. These rules are then used in deriving light phenomena. Schematic diagrams are a tool in this process. In contrast, most students first arrive at the phenomenon, usually from a consideration of their own observations and experiences. They, then, use diagrams as means for illustrating, or, at best, justifying their guess.

Consequently both teachers and students consider that their respective diagrams 'explain' the phenomenon. However, they differ in their understanding of what it is that needs an explanation. In geometrical optics, diagrams are drawn so that the paths of the relevant light rays or beams are seen clearly. For example, any apparatus arranged on an optical bench is shown in a sort of schematised side view. However, if for the students the phenomenon (what happens and how it happens) is more important than the explanation in terms of light beams, then it makes more sense to show the apparatus in a front-on view.

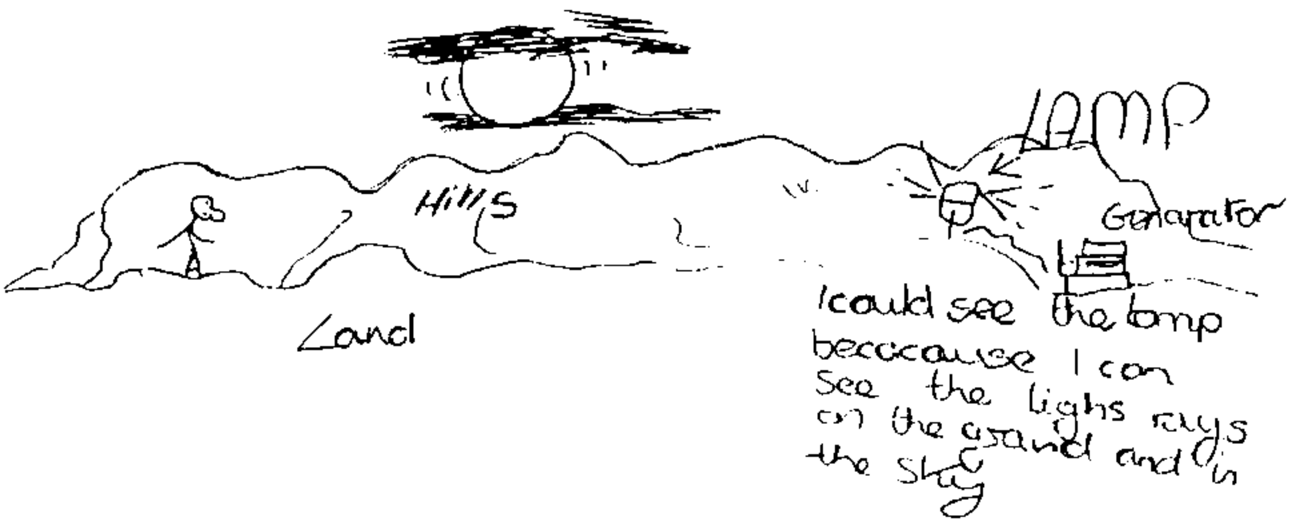
In the 'lamp hole' question, and more so in the 'eye hole' question (verbal versions), it was common for students to show this front-on view. In the latter question, many students depicted, quite accurately, how the view through a key hole would change when the eye was moved further away from the hole. Example of such descriptive, versus explanatory, diagrams are shown in Figures 8.9 and 8.10.

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.

* Show where there is light in the drawing.

* On this drawing, explain how you are able to see this small lamp shining.



* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

I think there would be a lamp in this place because it is to show where there somthing dangrerus around there or there is light from the moon

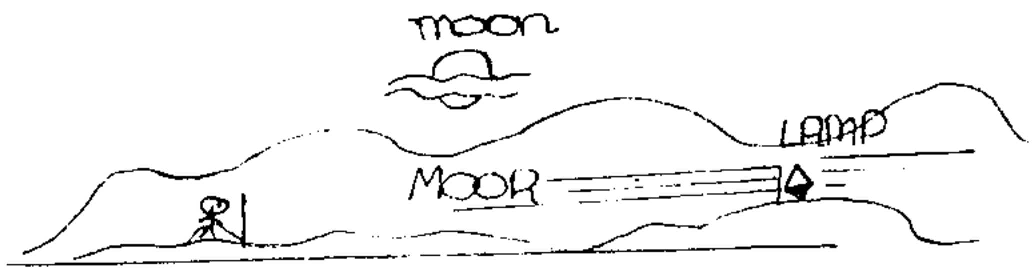
Figure 8.5: Pre-teaching response by MIS to 'moors-vision' task

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.

* Show where there is light in the drawing.

* On this drawing, explain how you are able to see this small lamp shining.



* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

There may bee a lamp there so that people who may be walking can see eg marsh or a large hole at night

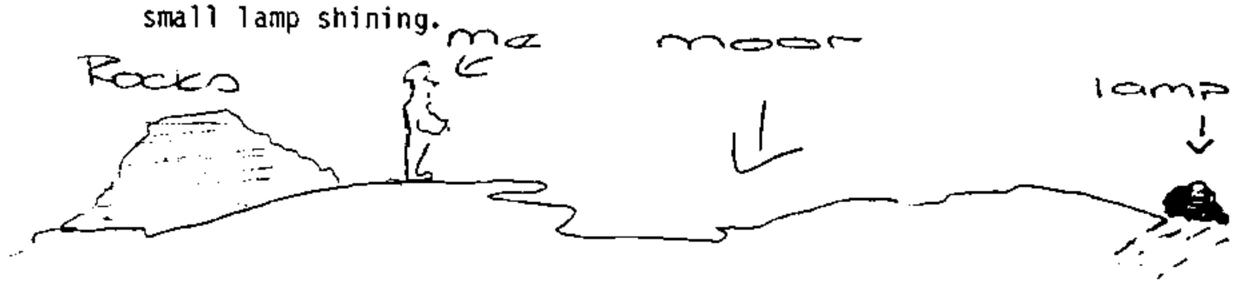
Figure 8.6: Post-teaching response by MIS to 'moors-vision' task

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.

* Show where there is light in the drawing.

* On this drawing, explain how you are able to see this small lamp shining.



* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

The light is just small and in the distance it doesn't cover any of the darkness its just dark with a small light.

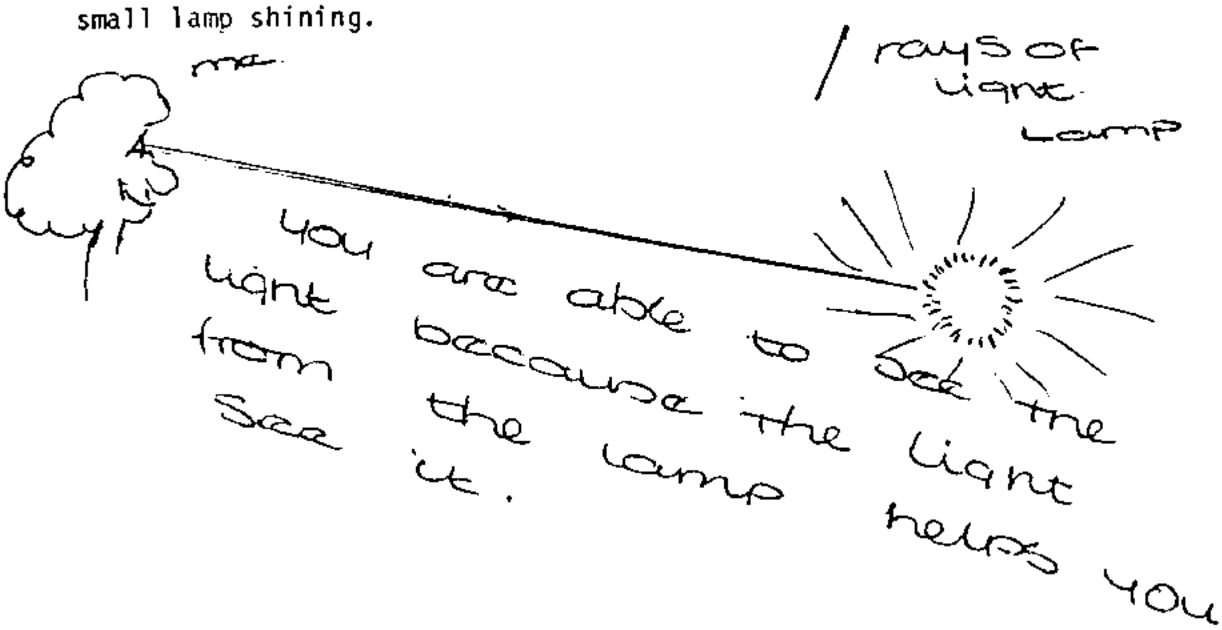
Figure 8.7: Pre-teaching response by IEH to 'moors-vision' task

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

* Make a simple drawing which shows you and the lamp.

* Show where there is light in the drawing.

* On this drawing, explain how you are able to see this small lamp shining.



* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

Its in the places I have Shown because the light can be Seen easier in the dark when there is no other light there.

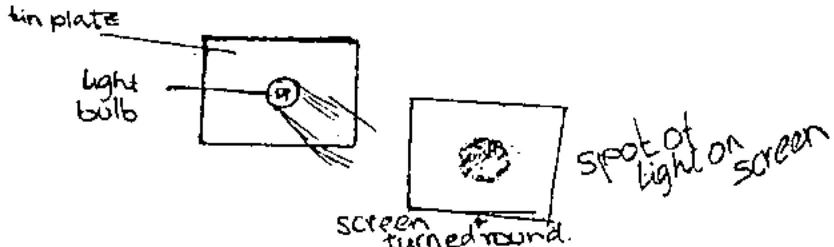
Figure 8.8: Post-teaching response by IEH to 'moors-vision' task

2) **A large, thin board with a hole as big as a 1p piece in it** stands upright in a dark room. A light-bulb, which is switched on, is placed near the hole on one side of the board. A white screen stands on the other side of the board and close to it.

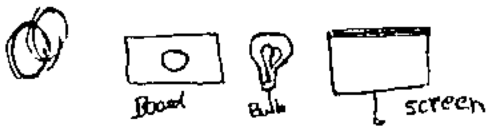
* What can be seen on the screen?

A large circle of light and it will be bigger or smaller the nearer or farther you get away to it.

* Make a drawing to show what can be seen on the screen.



* In the space below, make another drawing which shows the bulb, board and screen.
* Show where there is light in the drawing.



* Using this drawing, answer these two questions:
  1) What happens to the light from the bulb?
  2) Why is it that the thing shown in your first drawing is seen on the screen?

the light from the bulb gets bigger on the scre
I dont know.

2)

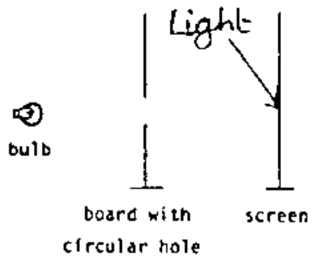


Figure a)
Side view of apparatus

The things in this drawing are shown in side view. They are in a completely dark room. The bulb is switched on.

* What can be seen on the screen?

A circular hole can be seen on the screen

* Draw this in the square below:

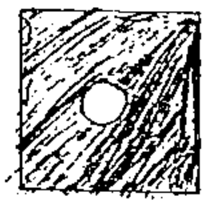


Figure b)
Front view of screen

* Now go back to a) and show where there is light in it.

* Using your completed figure a) answer these two questions:
  1) What happens to the light from the bulb?
  2) Why is it that the thing in figure b) is seen on the screen?

1.) The light from the bulb shines through the circular hole and hits the screen and circular hole shines onto the screen. 2) see number 1.

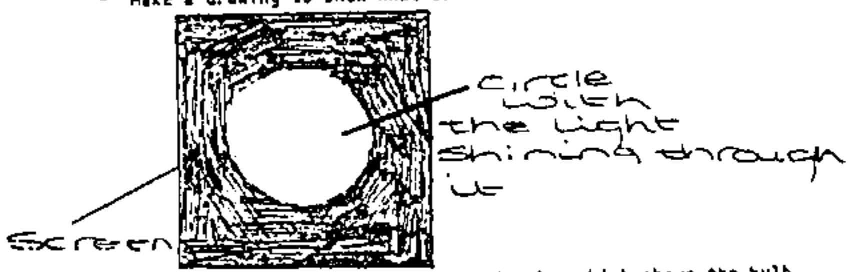
Figure 8.9: Examples of descriptive diagrams

2) A large, thin board with a hole as big as a 1p piece in it stands upright in a dark room. A light-bulb, which is switched on, is placed near the hole on one side of the board. A white screen stands on the other side of the board and close to it.

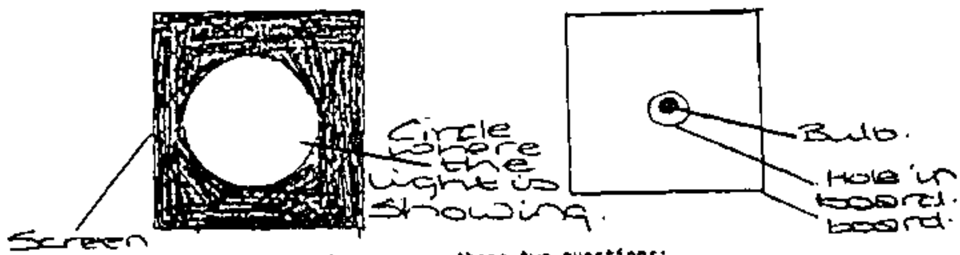
* What can be seen on the screen?

...A...light...hole....can...be...seen ...on...the....Screen.....................

* Make a drawing to show what can be seen on the screen.



* In the space below, make another drawing which shows the bulb, board and screen.
* Show where there is light in the drawing.



* Using this drawing, answer these two questions:
    1) What happens to the light from the bulb?
    2) Why is it that the thing shown in your first drawing is seen on the screen?

1) the...light...from...the...bulb goes through...the...hole...and enlargens on...the...Screen......................

2) The...thing...on...my...first...drawing is...seen...on...the...Screen...because it reflects over the screen.

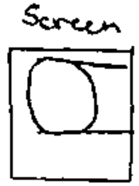
Figure 8.9: Examples of descriptive diagrams (cont..)

2) A large, thin board with a hole as big as a 1p piece in it stands upright in a dark room. A light-bulb, which is switched on, is placed near the hole on one side of the board. A white screen stands on the other side of the board and close to it.

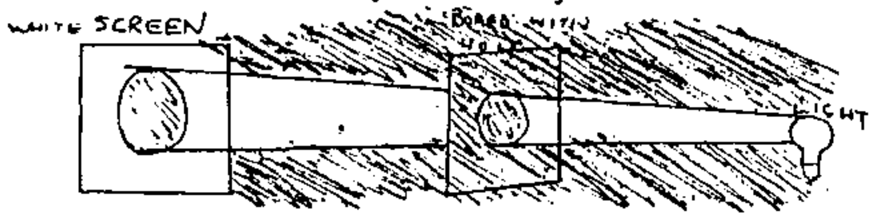
* What can be seen on the screen?

On the screen would be a white dot bigger than one pence piece

* Make a drawing to show what can be seen on the screen.



* In the space below, make another drawing which shows the bulb, board and screen.
* Show where there is light in the drawing.



* Using this drawing, answer these two questions:
  1) What happens to the light from the bulb?
  2) Why is it that the thing shown in your first drawing is seen on the screen?

① The light gets darker when it is further away from the bulb.
② The other peice of the board where there is no holes is blocking the light

2)

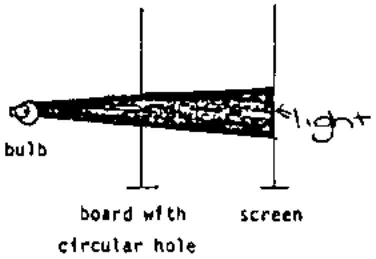


Figure a)
Side view of apparatus

The things in this drawing are shown in side view. They are in a completely dark room. The bulb is switched on.

* What can be seen on the screen?

On the screen a circular hole will be shown when the light is switched on.

* Draw this in the square below:

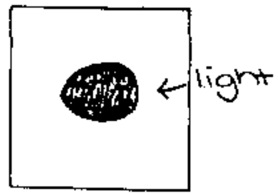


Figure b)
Front view of screen

* Now go back to a) and show where there is light in it.

* Using your completed figure a) answer these two questions:
  1) What happens to the light from the bulb?
  2) Why is it that the thing in figure b) is seen on the screen?

1) The light projects through the circular hole making a round shape of light on the screen.
2) The thing in figure b) is seen on the screen because of the light

Figure 8.10: Examples of explanatory diagrams

Very few students interpreted their answers in terms of light rays reaching the observer. For 'eye-hole', when explanations were given, they were in terms of field of view, rather than light rays. With this provison, the percentage of students drawing 'explanatory' diagrams, is shown in Table 8.3.

TABLE 8.3: PERCENTAGE OF STUDENTS GIVING EXPLANATORY DIAGRAMS IN VERBAL VERSION OF THE TASK

Type of diagram	'lamp hole' task		'eye hole' task	
	Pre-teaching n=36	Post-teaching n=39	Pre-teaching n=36	Post-teaching n=39
Explanatory	44	82	6	23
Descriptive/none	56	18	94	76

In the post-task, many students sought a reconciliation between diagrams that combined a description of the phenomenon, with an explanation in terms of light rays. Figure 8.11 is an example of such a response.

In fact, as the students got a better idea of the requirements of the problem, their interpretation of the questions and hence their responses changed even during the course of one interview.

So far discussion has focussed on a mismatch between students' perception of problems and the requirements of geometrical optics. Sometimes students internalised the schematic habit so well that there was a mismatching of their perception with the task stated requirement, 'Show where there is light in the drawing'. The following transcript illustrates this.

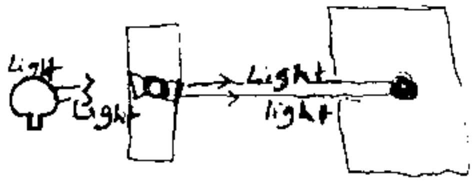
MAS (Referring to the post teaching diagram in Figure 6.7) ... they're the long lines, but shorter.

I What do you mean by that?

MAS That they're rays of light coming from the lamp... but they're not its full length... (I: Why ... not?) ... I didn't think I would need to draw them any bigger.

2) A light bulb is placed between two large thin upright boards which are facing each other. Each board has a hole as big as a 1p piece at the same level as the light bulb. On the other side of one of the boards, and close to it, stands a white screen.

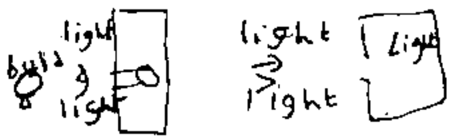
* In the space below, make a drawing which shows the bulb, the two boards and the screen.
* Show where there is light in all parts of the drawing.



* What can be seen on the screen?

....The....hole..........WERE.....the...light.
...goes....thrawgh..................................

* Make a drawing to show what can be seen on the screen.



* Using both drawings, answer these two questions:
    1) What happens to the light from the bulb?
    2) Why is it that the thing shown in your drawing is seen on the screen?

......it...goes......thRough...the hole...
...in the....wood:..............................

....

....

....

Figure 8.11: Combining description with explanation: Post-teaching response by MAJ

8.3.3 Three dimensional representations

We have seen how students' diagrams for 'lamp hole' and 'eye hole' tasks portrayed the situations in a front-on rather than a side view. For the 'lamp hole' task, it was inevitable that the objects should be shown, that is, the bulb, the board and the screen overlap in this view, and if the screen was in the front, it would eclipse the other two objects. There was also the problem of depicting the third dimension in such a view. Various approaches were adopted by students' to tackle these problems. While a few diagrams replicated the actual field of vision so that distant objects were hidden by those in front, many others portrayed full outlines of all objects in the task field so that some objects were regarded as transparent. Sometimes the transparency convention was used consistently, and at other times selectively.

For example, MAJ in the pre-test showed a front-on view (Figure 8.12). In the figure on the left, the board was behind the screen, but smaller than it so that their outlines did not overlap. Also, the screen was shown to be transparent to the outlines of the bulb and the hole. However, in the figure on the right, MAJ showed the screen removed so that not only were the bulb and the hole seen, but also the light coming through the hole. (He gave these explanations during the interview).

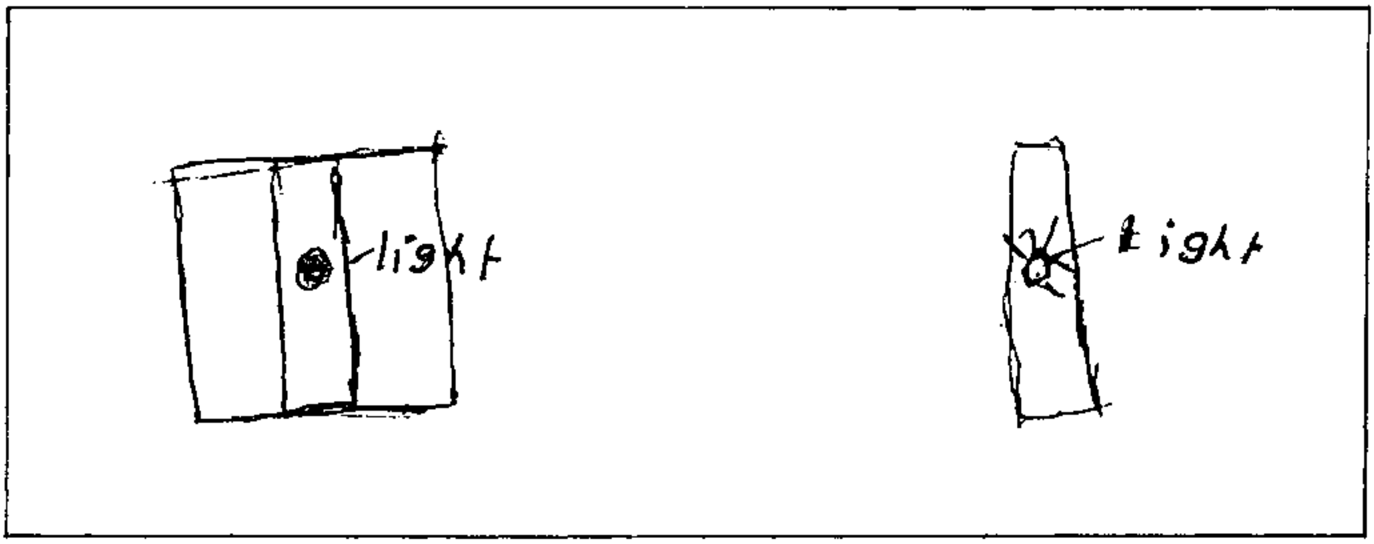


Figure 8.12: Conventions to represent 3-d: Pre-teaching diagram by MAJ

In another case, a student showed the apparatus in a front-on view, and next to that drew the screen flipped around to show the patch of light. LEH, in her interview (pre teaching), was asked how she would use a diagram to convince another person that a circular patch of light could be seen. She solved the problem by drawing three different diagrams: a side view with screen and board each shown as unbroken straight lines, a front-on view, and a view of the screen only. In the side view, she indicated the hole by showing light emerging through a part of the board.

Such spontaneous conventions show that students were actively grappling with the problem of three dimensional representation. In this, very few students attempted to draw a front-on photo-semblance. Rather, their diagrams showed what they knew to be there, and not what they might have actually seen. In principle, this is consistent with the aim of diagrams as used in science. It is noteworthy that although the depicted objects frequently showed overlap, full outlines were usually drawn clearly. This characteristic of early drawing by children has been observed by Goodnow (1977).

During the interviews, students were asked to show the correspondence between their diagrams and the actual apparatus. This they could always do. They could also talk meaningfully in terms of manipulating the objects in the diagrams. However, they could not always say which view they had depicted in their diagram, nor, sometimes, could they position themselves (with respect to the apparatus set up before them) to indicate their perspective.

8.3.4 Intuitive geometry

Earlier in this section it was mentioned that many students were able to draw the change in view through a key-hole when the eye was moved further back. Clearly, they were using some intuitive concepts of geometry, albeit in a non-quantitative way. For the 'lamp hole' task, where students were asked to show the size of the patch on the screen, very few seemed to take account of the distance between the bulb and the hole. It was somewhat more common to show the size of the patch in relation to the size of the hole, and to the distance between the hole and the screen. The size of the bulb was a factor that none of the students took into account. However, when, during interviews, students were asked to justify the size of the patch, they seemed to take better account of the distances, though still implicitly, not actually by showing the full path of the light in their diagrams. Figure 8.14, shown in paragraph 8.3.5, is an example of such a diagram.

In Appendix 5 it may be observed that students' diagrams of shadow often did not show geometrical projection. Also in diagrams exploring the working of the pinhole camera, they often showed rays from the top and bottom of the object crossing at a point different from the pinhole. Three of the students were asked during the interview to explain why no upside-down image was seen with a large hole. They did not know. The importance of geometrically accurate diagrams did not seem to be appreciated by several students.

In this subject area, the important concept is that of light travelling in straight lines. However, this idea is sometimes misinterpreted by students, as, for example, by MIS. His idea of 'light in straight lines' and 'light at an angle' is shown in Figure 8.13(a). His consequent misinterpretation of the Snell's law of refraction is shown in Figure 8.13(b).

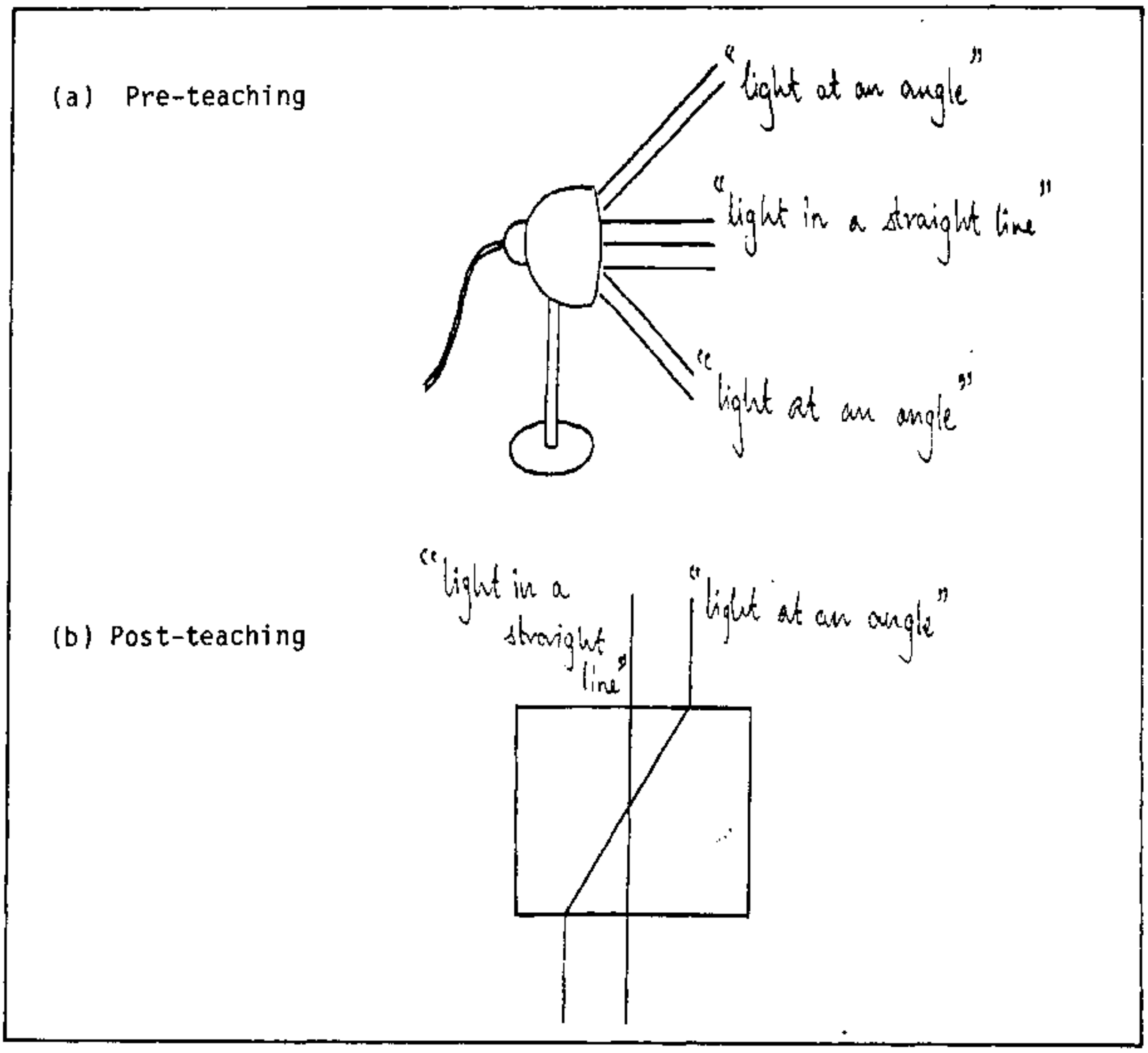


Figure 8.13: Misinterpretation of 'light travels in a straight line' idea: copy of diagrams drawn by MIS

8.3.5 Conventions and conceptions

Although students' are often not conversant with accepted diagrammatic conventions, they do use their own conventions in diagrams. To what extent these spontaneous conventions reflect students' conceptions about the phenomena, is the subject of this section

In Section 6.5, we saw that students' have a spontaneous tendency to shade in the darkness on a white paper, instead of shading in the light. Further, whether it is the light or the dark that is shaded in, is dependent on the context of the question. In 'lamp mirror', where the dazzling effect of the light was taken by students to be the predominant consideration, none shaded in the darkness.

However, it cannot be assumed that students always interpret diagrams in a literal way. For example, in the pre-tests, students asked to 'show where there is light', tended to draw a small pool, or a shaded area around the lamp. The subsequent interviews showed that they did not really imagine the light to be confined to this area. The area was interpreted merely as the brightest part around the lamp. Sometimes, other techniques, like variation in shading, or long and short rays, were used to make the representations more precise.

In the post tasks, students were more likely to show light going out in rays. For 'lamp mirror', it was common to show a cone of rays. Here again, the students' interpretations could be either literal or non-literal. The interview transcript of LEH quoted in Section 6.9 indicates that she interpreted the rays as a symbol for a lamp that was shining. Similarly, the cone of rays, common in the 'diagram' version of the test, at times seemed merely symbolic, totally unrelated to the students' prediction of the phenomenon. This happened only with a minority of the students, who drew the cone for 'lamp hole', but said that on the screen there would be "just light", or "light and dark patches", or "nothing".

On the other hand, some students, who drew the cone, interpreted it very literally, sometimes actually expecting to see it in the 'actual'situation. One such student was AEH (post teaching). The transcript which follows shows how she distinguished rays of light from just 'brightness'.

AEH (post teaching) There's light around this hole, and coming from the light, the rays of light, to the actual light.

I Hmm. Above the hole, here?

AEH Well, no. There will be the actual light, shining, but there won't be light, the rays. These are rays (emphasis) of light, which go from the light through to the hole, and to the white screen... (above the hole) ... it's just light, ... just the brightness from the lamp.

It transpired later, during the interview, that this conception was derived from a memory of the smoke box experiment, where she remembered having seen a cone of rays in one direction only.

A similar conception was found in the interview with NAJ (post teaching).

I Can you draw the light from this red bulb, between the board and bulb? How it runs.

NAJ How it travels?

I Yes.

NAJ Or just where it is?

From this enquiry it was clear that she drew a distinction between the way that travelling light had to be represented (by long, straight lines denoting projection of a cone), and the way that other (stationary?) light was shown (see Figure 8.14).

I If you had to show where it is, how would you show that? You would show it differently?

NAJ I'd show it by using little lines.

8.3.6 Teleogogical reasoning

In ray diagrams, there is an obvious causal sequence of events along the path of a ray of light. When light meets some obstacle, its path, from that point onwards, is modified. This causal sequence is often not recognised by students, who, in their spontaneous diagrams, may violate the causality principle. A related tendency is to explain a phenomenon in terms of its purpose, rather than in terms of the reason for it happening. We saw an example of this in paragraph 6.8, when a student thought that although light must come to a person's eye, it would not come to the ear. An object (the eye) was supposed to influence the path of light before the light had reached it. The following interview transcripts illustrate such teleological reasoning in the context of 'lamp hole'.

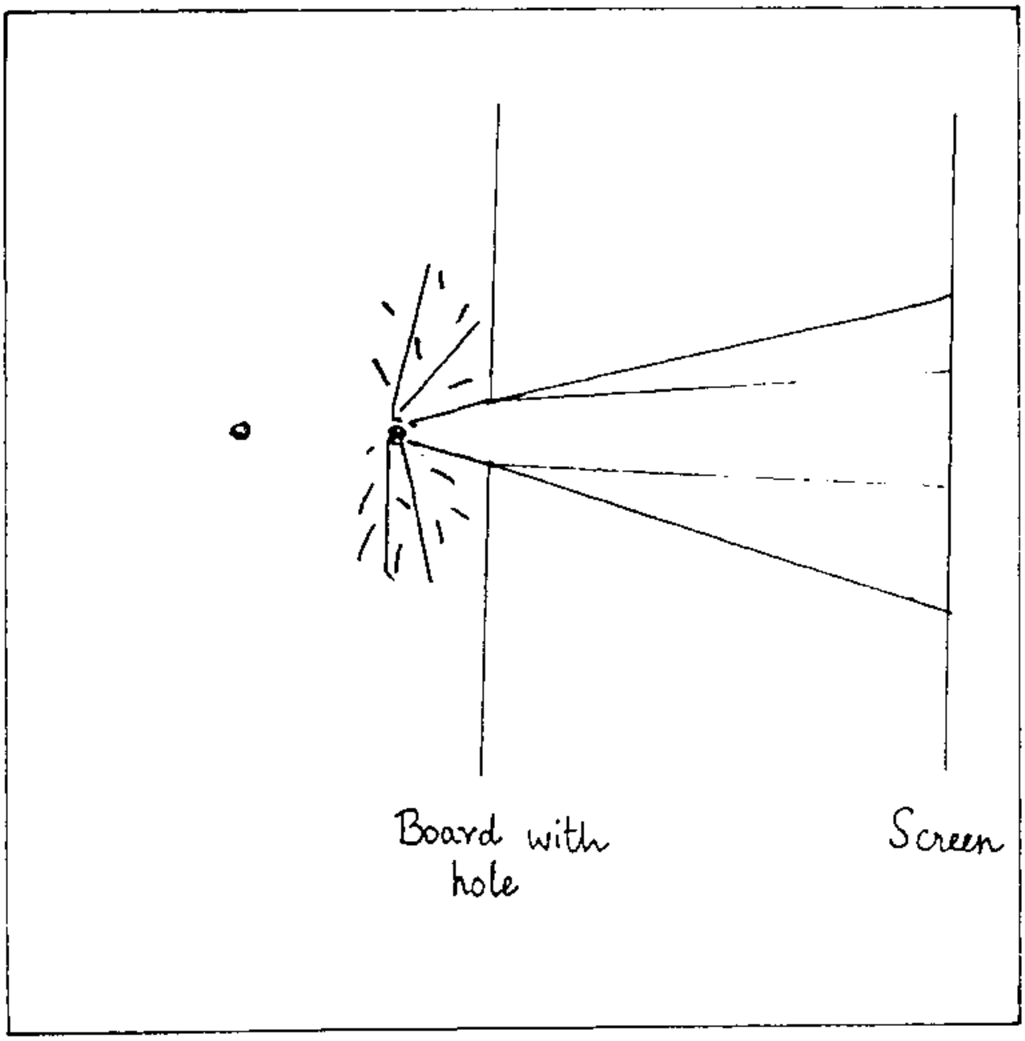


Figure 8.14: How light travels, or where it is. Diagram drawn by NAJ

NAJ (pre-teaching) (The interviewer had asked her how large the patch of light on the screen would be, in comparison with the hole.) Bigger than what it is there. It tends, like to grow ... then it'll tend like to close up then it'll open up so it can all get through (the hole) and then 'cause it's got plenty of room again it can like open out. (She drew a diagram to show this.)

An identical conception was found with AEH (post-teaching). With NAJ too, the conception persisted after the course in optics.

NAJ (post-teaching) And then it comes out (light comes out through the hole) ... and... because it does not have to stay small any more it largens (sic) out... because there's no more gaps for it to go through.

I Can you tell me how much it'll widen out?

NAJ ... Like in the pictures, ... the light... expands to fit the screen at the front.

Such student thinking has implications for the teaching of science. We hope that this report has gone some way towards charting out some of these areas of darkness.

SECTION 9

SUMMARY OF IMPLICATIONS FOR TEACHING AND LEARNING

In the preceding pages children's experiences, language and ideas that have a bearing on 'light' and 'sight' have been documented and discussed. If the teaching and learning of 'light' as a science topic is to take account of these, then a number of classroom strategies would seem appropriate.

1. <u>Introducing 'light' and 'sight' as classroom topics</u>
The character and range of children's associations and experiences revealed in Section 2 of this study suggest that similar tasks could be used to introduce the topic of 'light' in the classroom. A summary of individual's perceptions of 'light' together with their memorable experiences of it could be regarded as a resource for classroom discussion. In the process of comparing and classifying their experiences it is likely that several questions will arise. Puzzling issues may emerge such as, whether there are different kinds of light; whether light travels (if so, how far and how fast?); whether light is like material substance or not; whether it can be hot or cold; whether it has direction (if so, can its direction be changed?); how we see objects; how we see colour; the nature of shadows, images, darkness and so on. Such questions may be selected and sequenced for investigation in subsequent lessons thereby constituting a course of study that originates from the developing experiences and interests of children. Further, teachers may be encouraged by the finding (also mentioned in Section 2) which indicates that children generally have a positive attitude to this topic - an attitude that does not diminish after classroom study.

2. <u>Assisting the development of children's ideas concerning light interactions with objects and eyes</u>
In common with other studies this one has shown that around the age of 13 - 14 children generally begin to regard light as something other than a label for a light source or the effect of that source on a particular location. However, the development of the idea of light as an 'entity-existing-in-space' emerges slowly; only about one-third of national samples of British and Swedish children appeared to hold this idea (see

Section 5). It would seem that when children observe a bright light source and a bright patch appearing on a screen they may deduce that 'light-as-an-entity' must traverse the space between source and effect. Although bright sources may assist this development, it remains difficult for children to imagine that light from non-luminous sources travels to the eye. The difficulty would appear to arise from entrenched 'person-centred' and 'active-eye' ideas. In order to address such ideas experiences with light sources of different intensities could be provided. Starting with very bright sources and good reflecting surfaces, and proceeding to successively less intense sources and to surfaces of less reflective power, children could be encouraged to consider the existence of light betwen the source, object and eye on each case.

3. Assisting children to differentiate the meaning of terms

The frequent synonymous use of terms such as 'image', 'reflection' and 'shadow' in children's responses would indicate that help with the differentiation of these and other 'light-terms' is necessary. It is suggested that when children use terms that have been adopted by science from daily-life language, their meanings should be probed so that the nature of the conceptual 'gap' may be assessed and some attempt made to reduce it.

For instance, in Section 6 it was shown that children's conception of light rays included qualities such as visibleness, long length, narrowness, glare, etc. However, in geometrical optics, light rays are simply a method for representing the path taken by light.

4. Assisting the development of ideas concerning 'reflection' and 'image formation'

It was shown in Section 7 that, in general, children's initial idea of a mirror is that it 'just produces images'; they make no reference to any part being played by light. Later, when they attribute a function to light, children tend to localise the light between the object and the image, not extending its passage to the eye. The learning activities suggested above should assist the development of both the idea of objects-as-secondary-sources (or reflectors) of light and the further passage of light to the eye.

The location of the image is another area of difficulty for children - they generally hold that the image must be in the same plane as the mirror. Such a view may be countered by providing learning activities that result in an image apparently being 'trapped' behind the mirror, see Section 7. Similar strategies may be adopted in the case of curved mirrors and lenses where again there is a widespread impression that an image lies within the mirror or lens.

5. Guiding the change from a 'pictorial' representation to a 'schematic' one

In several sections of this study the characteristics of children's pre-teaching 'optics' diagrams were recorded. In general they were found to be picture-like, detailed and exhibit a front-on perspective. As a result they often portrayed superimposed, transparent unit parts together with inessential contextual elements and some additional imagined elements. If children are to represent optical situations by standard schematic ray diagrams, then a considerable change in personal orientation and the selection of elements as well as in the use of conventions is required. This study showed that possibly the greatest problem was 'where to start'. It seems that a teaching programme would need to address a number of aspects including: adjustment to side-on orientation, abstracting essential features, appreciating 'light rays' as conventional representations and appreciating the nature of images.

This discussion constitutes a brief introduction to ways of dealing with some of the learning problems that necessarily arise as children attempt to grapple with a school-science view of 'light phenomena' when they have already generated alternative conceptions of their own.

In writing the report we have continued to be intrigued by the problems and issues that have faced scientists over the centuries in coming to an understanding of the topic of light and sight. We have found the historical perspective has given us insights into the journey of thought that children are invited to take in science lessons.

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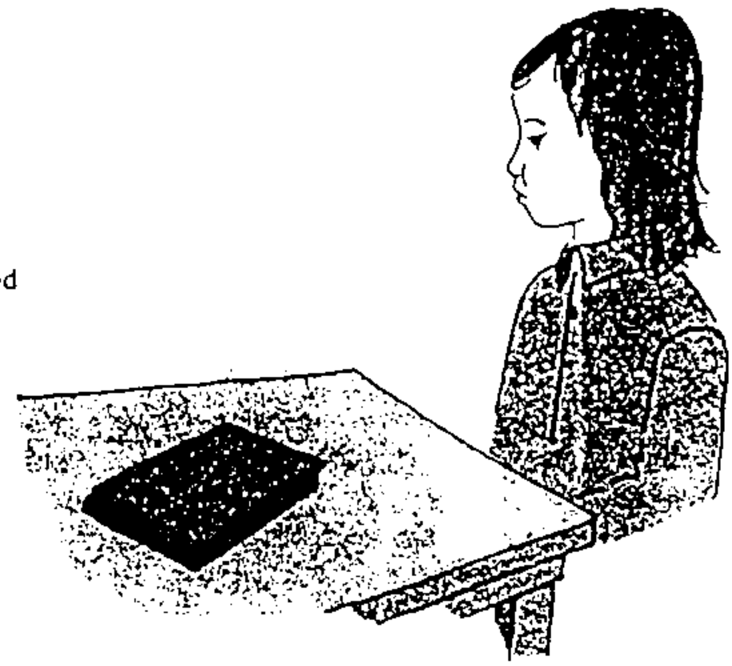
APPENDIX 1

NATIONALLY ADMINISTERED QUESTION ON 'LIGHT AND SIGHT'

A pupil is in a dark room and cannot see anything.

When the light is turned on in the room she sees a book on a table in front of her.



How is she now able to see the book?
Explain carefully what is happening <u>between the book and her eye</u>.
Draw lines on the diagram to help your explanation.

APPENDIX 2

OPEN-ENDED TASK ON LIGHT

1. What are the things you think of when the word 'light' is mentioned?

2. Are there any things that have happened to you to do with light which you remember vividly?

3. What kind of feelings does 'light' bring to your mind?

4. Have you heard about rays of light? What do you think these are? Where are they found?

APPENDIX 3

COPIES OF CLASS TASKS ON LIGHT AS ADMINISTERED IN THREE FORMS

Verbal

Diagram

Actual Apparatus

A.3.1 Pre-task

'Verbal' version

VERB

Children's Learning in Science Project

These questions are to find out how you think about problems. Your ideas are important to us, so try all the questions. Only simple drawings are needed here, so have a go at them even if you think you are no artist.

* Use a pencil and ruler for drawing.

* Label your drawings.

Name ....

School .... Class ....

Science subjects studied ....

Date of birth .... Today's date ....

1

Question 1 'moors vision'

1) You are lost on the moors on a dark moonless night, miles away from any roads or houses. Suddenly, far away, you see a small lamp shining.

   * Make a simple drawing which shows you and the lamp.

   * Show where there is light in the drawing.

   * On this drawing, explain how you are able to see this small lamp shining.

   * In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

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Question 2 'lamp hole'

2) A light bulb is placed between two large thin upright boards which are facing each other. Each board has a hole as big as a 1p piece at the same level as the light bulb. On the other side of one of the boards, and close to it, stands a white screen.

* In the space below, make a drawing which shows the bulb, the two boards and the screen.
* Show where there is light in all parts of the drawing.

* What can be seen on the screen?

....

....

* Make a drawing to show what can be seen on the screen.

* Using both drawings, answer these two questions:
    1) What happens to the light from the bulb?
    2) Why is it that the thing shown in your drawing is seen on the screen?

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Question 3 (Question 4 in post-test) 'eye hole'

3) You are looking into this classroom through a round key-hole in the door.

a) First, you keep your eye as close to the hole as possible.

* How much of the room do you imagine you will see?

* Give examples of things that you will see and things that you will not see.

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b) Next, you move your eye about 5cm. back from the hole.

* How much of the room will you see now?

* Give examples of things that you will see and things that you will not see.

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(This question is continued on the next page)

(Continued from page 4)

* Make a drawing to show situation a) on page 4.
* Use this drawing to explain why you see whatever you see in situation a)

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* Make a drawing to show situation b) on page 4.
* Use this drawing to explain why you see whatever you see in situation b)

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Question 4 (Question 3 in post-test) 'lamp mirror'

4) * You use a mirror to reflect light from a bulb into your friend's eye.

* Make a drawing which shows the mirror, the light-bulb and your friend's eye.

* Show where there is light in the drawing.

* Explain what happens between the mirror, the bulb, and your friend's eye.

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* Do you think your friend can see anything in the mirror? If so, explain what he or she can see and why.

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* If you think your friend sees something in the mirror, try to show it in the drawing above.

'Diagram' version

DIAG

Children's Learning in Science Project

These questions are to find out how you think about problems. Your ideas are important to us, so try all the questions. Only simple drawings are needed here, so have a go at them even if you think you are no artist.

* Use a pencil and ruler for drawing.

* Label your drawings.

Name ....

School .... Class ....

Science subjects studied ....

Date of birth .... Today's date ....

1

Question 1 'moors vision'

1) It is a dark moonless night.
You see a small lamp shining far away.

* Show where there is light in this drawing.

* On this drawing, explain how you are able to see this small lamp shining.

* In the space below, write several sentences to explain why you think there is light in the places where you have shown it.

Question 2 'lamp hole'

2)

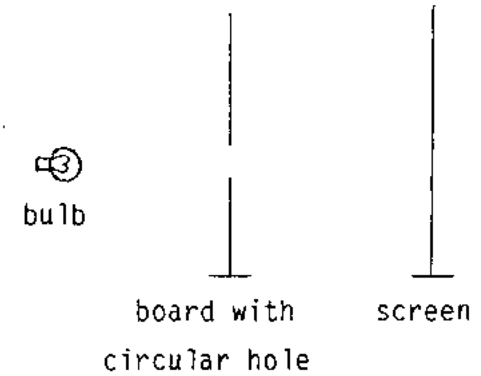

Figure a)
Side view of apparatus

The things in this drawing are shown in side view. They are in a completely dark room. The bulb is switched on.

* What can be seen on the screen?

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* Draw this in the square below:

Figure b)
Front view of screen

* Now go back to a) and show where there is light in it.

* Using your completed figure a) answer these two questions:

1) What happens to the light from the bulb?
2) Why is it that the thing in figure b) is seen on the screen?

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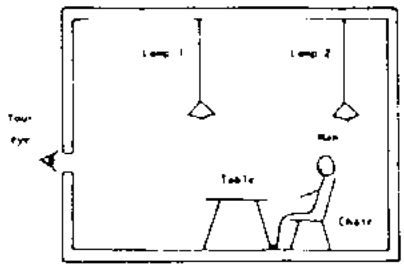
Question 3 (Question 4 in post-test) 'eye hole'

3) The two drawings below show a room. There is a round key-hole in the door. You are outside the room, looking in through the hole.

In this drawing, you are standing close to the hole.



* How much of the room will you see?

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* Give examples of things that you will see and things that you will not see.

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* Shade the parts of the drawing which you will see.
* Explain how you worked out your answer.

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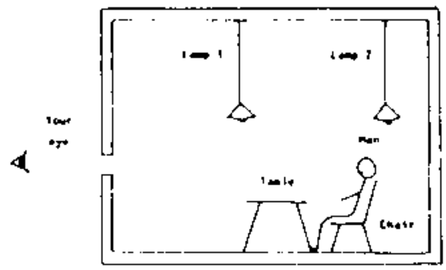
....

In this drawing, you are standing far away from the hole.



* How much of the room will you see?

....

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....

....

* Give examples of things that you will see and things that you will not see.

....

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* Shade the parts of the drawing which you will see.
* Explain how you worked out your answer.

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If your answers on the two sides above were different, explain the reason for the difference.

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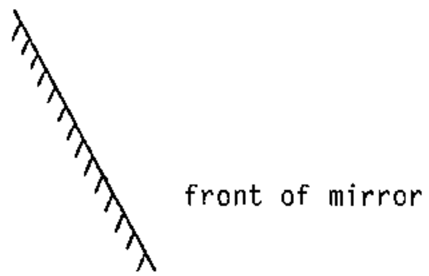
Question 4 (Question 3 in post-test) 'lamp mirror'

4) * You use a mirror to reflect light from a bulb into your friend's eye.

* Make a drawing which shows the mirror, the light-bulb and your friend's eye.

* Show where there is light in the drawing.



* Explain what happens between the mirror, the bulb, and your friend's eye.

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* Do you think your friend can see anything in the mirror? If so, explain <u>what</u> he or she can see and <u>why</u>.

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....

* If you think your friend sees something in the mirror, try to show it in the drawing above.

5

'Actual Apparatus' version

MODL

Children's Learning in Science Project

These questions are to find out how you think about problems. Your ideas are important to us, so try all the questions. Only simple drawings are needed here, so have a go at them even if you think you are no artist.

* Use a pencil and ruler for drawing.

* Label your drawings.

Name ....

School .... Class ....

Science subjects studied ....

Date of birth .... Today's date ....

1

Question 1 'lamp hole'

1)

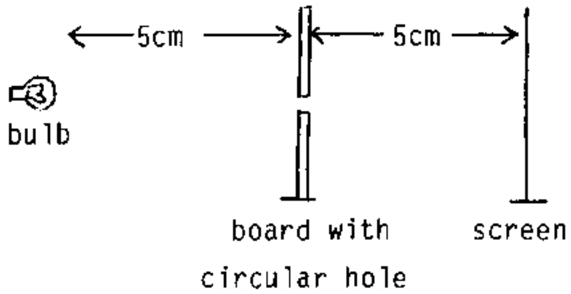

Figure a)
side view of apparatus

* The three things in this drawing are in front of you.
* Set them up as shown in the drawing.
  Do not switch on the bulb
* Answer these questions first:
* What do you expect to see on the screen when the bulb is switched on?

....

* Draw this in the square below:

Figure b)
Front view of screen

* Now switch on the light.
* What do you see on the screen?

....

....

* Draw it in the square below:

Figure c)
Front view of screen

* Now go back to figure a) and show where there is light in it.
* Using your completed figure a), answer these two questions.
  (1) What happens to the light from the bulb?
  (2) Why is it that the thing in figure c) is seen on the screen?

Explanation:

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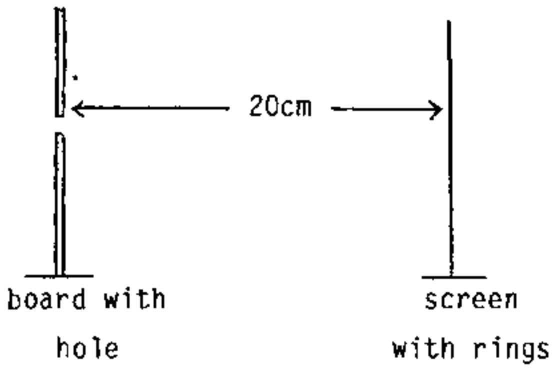
Question 2 'eye hole'

2)



* Place the board and screen as shown in the drawing.
* Do not look through the hole yet.
* Guess how many rings you would see if your eye was close to the hole.

  ....

  Guess how many rings you would see if your eye was about 20cm away from the hole.

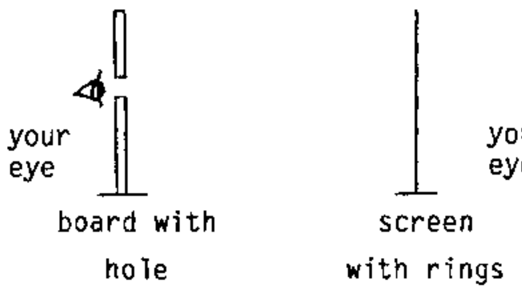
  ....

* Now look through the hole.
* Answer the following questions.
* With my eye close to the hole, I can see .... rings.

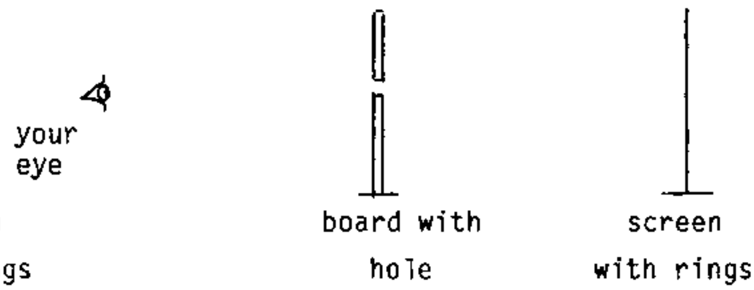
  List them by colours ....

* With my eye about 20cm away from the hole, I can see .... rings.

  List them by colours ....
* Does it make a difference how far away you keep your eye? ....
* Explain your answer using the two drawings below.
* You may add things to the drawings if that helps your explanation.



Eye close to hole.



Eye away from hole.

Explanation:...

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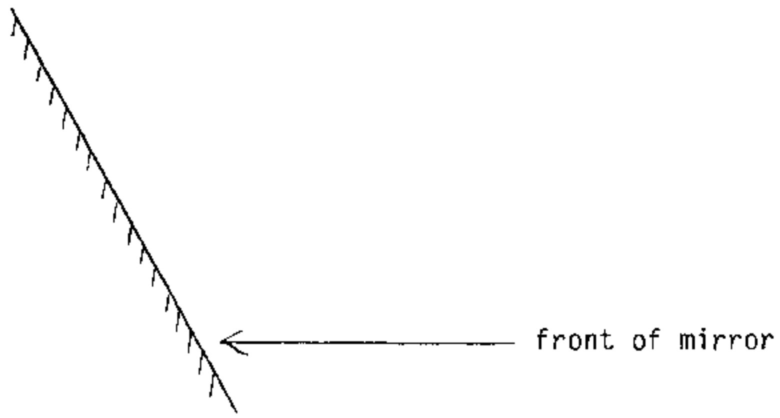
Question 3 'lamp mirror'

3) * Use a mirror to reflect light from a bulb into your own eye.
   * A side view of the mirror is shown below.
   * Add the bulb and your eye to this drawing.
   * Show where there is light in the drawing.



* Explain what happens between the mirror, the bulb, and your eye.

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* Can you see anything in the mirror? If so, what can you see?

....

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* Why do you see whatever you see? Explain your answer.

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* If you can see something in the mirror, try to show it in the drawing above.

POST-TASK (only question 2 differed from pre-task)

Question 2 'lamp hole' (VERBPOST)

2) A light bulb is placed between two large thin upright boards which are facing each other. Each board has a hole as big as a 1p piece at the same level as the light bulb. On the other side of one of the boards, and close to it, stands a white screen.

* In the space below, make a drawing which shows the bulb, the two boards and the screen.
* Show where there is light in all parts of the drawing.

* What can be seen on the screen?

....

....

* Make a drawing to show what can be seen on the screen.

* Using both drawings, answer these two questions:
  1) What happens to the light from the bulb?
  2) Why is it that the thing shown in your drawing is seen on the screen?

....

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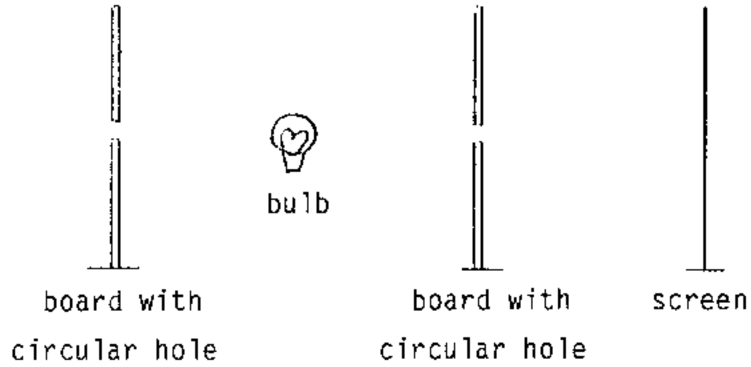
3

Question 2 'lamp hole' (DIAGPOST)

2)

Figure a)
Side view of apparatus



The things in this drawing are shown in side view. They are in a completely dark room. The bulb is switched on.

* Show where there is light in all parts of the drawing.

* What can be seen on the screen?

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....

* Draw this in the square below:

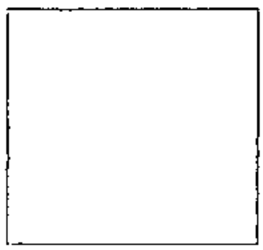

Figure b)
Front view of screen

* Using your completed figure a) answer these two questions:
    1) What happens to the light from the bulb?
    2) Why is it that the thing in figure b) is seen on the screen?

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3

2) Question 2 'lamp hole' (MODLPOST)

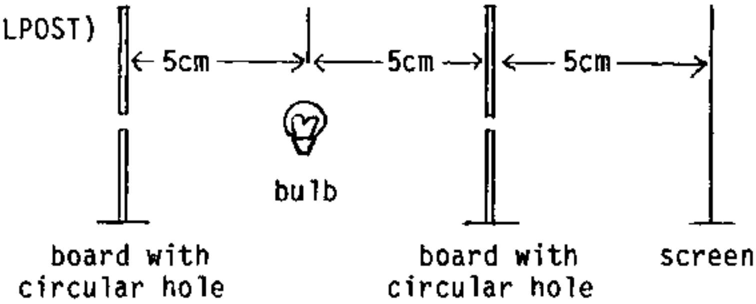

Figure a)
Side view of apparatus

* The four things in this drawing are in front of you.
* Set them up as shown in the drawing.
  Do not switch on the bulb
* Answer these questions first:
* What do you expect to see on the screen when the bulb is switched on?

....

* Draw this in the square below:

Figure b)
Front view of screen

* Now switch on the light.
* What do you see on the screen?

....

....

* Draw it in the square below:

Figure c)
Front view of screen

* Now go back to figure a) and show where there is light in all parts of the drawing.
* Using your completed figure a), answer these two questions.
  (1) What happens to the light from the bulb?
  (2) Why is it that the thing in figure c) is seen on the screen?

Explanation:

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APPENDIX 4

TABLE A4.1: COMPOSITION OF INTERVIEW SAMPLE

Code name of student	Age[1]	Sex	School	When Interviewed[2]
CIM	14y 1m	M	2	Pre and post teaching
LEH	13y 11m	F	2	
MAJ	14y 1m	M	2	
MIS	14y 2m	M	1	
NAJ	14y 1m	F	2	
AEH	14y 2m	F	1	Post teaching only
IEH	14y 1m	F	1	
MAS	14y 1m	F	1	
VAD	14y 8m	M	1	

1 At time of first interview.
2 Interval between first and second interviews was 9-14 weeks.

APPENDIX 5

SUMMARY OF COURSES IN OPTICS

A5.1 Classes involved in the study

Of the four third-year classes involved, two were in School 1, which was a secondary school in a small town belonging to the Bradford Local Education Authority. This school had previously been a Grammar School, but had changed to Comprehensive. Both the classes in this school were of 'medium ability' and were taught by the same teacher.

The other two classes were in School 2, which was a large Comprehensive located in Leeds. This was an urban school, unlike School 1, which was closer to the countryside. One of the classes in School 2 was of 'high ability' while the other belonged to the 'low ability' stream. Thus, a range of ability levels was covered in the whole sample. The two classes in School 2 were taught by two different teachers.

For follow-up of the teaching in optics, we concentrated on two of the four classes, one in School 1, and the other in School 2. In School 2, it was the high ability class that was selected, although the low ability class was also visited.

Even though the earlier plan had been to study the classroom proceedings in some detail in order to link these with performance in the pre- and post-test, this plan was later found to be too ambitious, the constraint being on the time required for visits and the analysis of recorded data. The account which follows is therefore rather sketchy, consisting essentially of a list of topics covered during the courses, along with a few, hopefully, relevant remarks.

A5.2 Optics course in School 1

The course consisted of 11 lessons spread over six weeks, which included two weeks of Easter vacation. A set of 12 work-sheets was used during the course. The laboratory experiments were mainly derived from the Nuffield approach. Standard pieces of Nuffield equipment were used.

An introductory lesson dealt with the importance of light for vision, its property of travelling in straight lines and the relevance of this to not being able to see around corners and through obstacles. The connection between light and vision was emphasised by the teacher at this time, and repeated at a number of points through the course. Prisms, colour and rainbows were also discussed. Some interesting issues that came out in this preliminary discussion were as follows:

a) A number of students thought that it might be possible to see dimly even with no light present (see Section 6.7).

b) There was some discussion on whether light diverging from a lamp could be said to travel in straight lines ('straight line' was interpreted as 'parallel beam'). Night-time long-exposure photographs of cars moving in curves were thought by a student to be evidence for light 'bending'.

c) Students wanted to know the reason for transparency of materials. They observed that the eyelids were partially transparent and were interested in discussing after-images, their colour and persistence. The subject of 'light' apparently held several points of interest for the students.

The second lesson started with a brief discussion of shadows with a diagram showing formation of a shadow by a point source of light. However, although the teacher emphasised the straight line propagation of light leading to a faithful projection of the cross-sectional shape, the diagrams copied in their worksheets by the students often did not show a geometrical projection.

This was followed by work with pinhole cameras. Cardboard boxes with translucent paper on one side were supplied to the students and they had to put in the pinholes and observe the images with one, two and several pinholes, a large hole, and finally, a lens. Most students seemed to have made the necessary observations, although, again, the importance of geometrically accurate diagrams in explaining these observations was probably not realised by most students.

The next three lessons dealt with (1) the lens camera, (2) the eye, its structure and similarity with the camera, and (3) explanation of long and short sight and range of accommodation. These lessons could not be visited.

Following this was a session involving dissection of a bull's eye. Three of the girl students felt squeamish about this and opted for doing other work. There was some discussion on Mrs. Thatcher's recent operation for a detached retina. Students wanted to know how the retina was 'got back in', whether a laser was used and if lasers could blind you. Refraction of light in a large flourescein-filled model of the eye was demonstrated by the teacher.

In the next lesson, the teacher demonstrated the refraction of light by a convex lens, using a smoke box. One limitation of the apparatus was that the light beam was visible only up to the focal point. Some points at which students seemed to be having trouble were as follows:

1) As long as the image was seen on a screen, its position was unambiguous. However, when the paper screen was removed, students could not locate the position of the image. In fact, all of them said that the image was now <u>on</u> the lens.

2) There was a confusion between 'focal point' and 'image point'. the fact that these were different when the object was not at infinity, was apparently not appreciated. Students were also heard to make statements such as, "you have to be at the focal point to see the image", and "the focal point is on the retina".

The discussion on lenses was continued into the next lesson, after which the 'ray streaks' apparatus was demonstrated. The latter activity took up a whole lesson. In the next lesson, the students (in groups of four) used the apparatus to study refraction of light through a glass block. These three lessons could not be visited, but the last was recorded on tape by the teacher so some comments can be made.

1) The teacher spent about 15 minutes introducing the refraction of light with the help of various examples like seeing through glass of non-uniform thickness, heat haze, mirage and harpooning fish. In each case, light <u>appearing</u> to come from a certain place because of its bending was emphasised, thus reinforcing the implied connection between vision and light entering the eye. However, the students' talk during this period seemed to be about the novel phenomena rather than their explanation.

2) In the rest of the lesson, the talk centred largely on organisational matters and the mechanics of getting the apparatus set up.

3) Some students appeared to have observed correctly that the 'ray' of light was bent 'where it touches the glass'. However, this was not the case universally. MIS, who was one of the more attentive students, in response to the question, 'where is the ray bent?' wrote, 'in about the middle of the glass block'. This phenomenon of students' 'observations' being at variance with reality is probably known to most teachers.

Prisms and rainbows were introduced towards the end of this lesson and this topic continued into the next lesson, in which the students again worked with the 'ray streaks' apparatus. Coloured filters were used in the path of the light beam and their effect on the colour constitution of the dispersed light was observed. Next, the class used a stand and two convex lenses to construct a simple telescope. There was great interest in using the telescopes to watch a game being played on the school grounds.

In the last lesson the class studied plane and curved mirrors. The ray streaks apparatus was used. However, the connection between 2-d experiments with cylindrical mirrors and their 3-d equivalents, was not dealt with.

A5.3 Optics course in School 2

The account of the optics course in School 2 is even sketchier than that of the course in School 1, the reason being that one observer had to be away from Leeds for two thirds of the period of the course.

The course consisted of six double lessons spread over eight weeks, which included exams and a test. No worksheets were used, although students wrote out observations, results, answers to questions etc. in their notebooks. Again, in this school, the laboratory experiments were largely based on the Nuffield approach and standard Nuffield equipment was employed.

The first lesson of the course was observed in both the classes selected in this school. It dealt with the straight line propagation of light, which was demonstrated with a powerful beam of light that could produce shadows at the back of the darkened classroom. The geometrical similarity, of the shapes of various cardboard cut-outs kept normal to the beam, with the shapes of their shadows on the wall, was emphasised. Light going through three colinear holes was demonstrated. Afterwards, the class worked with pinhole cameras in much the same way as described with School 1, apart from the fact that there was more emphasis in School 2 on faithful reproduction of experimental results as diagrams in the students' notebooks. However, in all the classes observed, the geometrical accuracy of explanatory diagrams remained a weak point with most students. Most often, the rays from the top and bottom of the object were shown to cross at a point different from the pinhole, before going on to the screen of the pinhole camera.

Some peripheral remarks about the two classes in School 2 are made here. The 'high ability' class needed much fewer instructions to get started and to get through their work, and their lessons also had fewer interruptions related to disciplinary matters. However, the 'low ability' class demonstrated more instances of lateral thinking in their responses. Perhaps this was related to the fact that it took them some time to get to the 'right' response. To take just one example, while the 'high ability' class unanimously recognised the shape of one of the shadows as a 'wine glass', the 'low ability' class gave a larger variety of responses, like 'beaker', 'black wine glass', 'goblet', 'egg cup' and 'egg timer'. There were other instances of free association, like 'umbra', 'Humber river' and 'umbrella'. Although sometimes a distracting nuisance for teachers, this tendency in the low ability class might be, in some ways, educationally advantageous.

In the second lesson (which could not be visited) students used a ray streaks apparatus to study reflection in plane and curved mirrors. They traced the incident and reflected beams and measured the angles in the case of the plane mirror.

The third lesson was devoted to photography. The teacher had earlier taken some photographs of the class and in this lesson the film was developed. Some volunteers from the class came up to do the developing. Students seemed to enjoy this activity immensely. The teacher explained to the class how light could do work (photography being one example) and therefore, was a form of energy. The relationship to the working of the eye was not pursued.

The fourth, fifth and sixth lessons, again, could not be visited. In the fourth lesson, students used ray streaks apparatus to study the periscope and then, refraction through a glass block. The latter was demonstrated by setting up a narrow beam of light and then inserting the glass block in its path. The sudden lateral shift of the beam was striking. The same apparatus was used in the next two lessons to study refraction through convex and concave lenses of different focal lengths, and then dispersion through a prism. The class also constructed a simple refracting telescope.

APPENDIX 6

A6.1 NETWORK NOTATION

The notation used in the networks of Figures 2.1, 6.5 and 6.9 in the text is described here. This description is brief and is limited to that part of the notation and terminology which is relevant to our particular networks. Readers interested in details of the technique may consult Bliss, Monk and Ogborn (1983).

From the left hand side a network starts with broad categories, or more generally, descriptors. In our case these are descriptors of children's responses. In network terminology they are called 'terms'. Towards the right hand side, the network goes into progressively finer distinctions, denoted by terms which on the extreme right of the network resemble the actual responses of the children.

The simplest kind of subdivision of the terms is into categories of responses. A category on the left in a network can be divided along some dimension into smaller, mutually exclusive categories immediately to its right. In this case, the 'terms' on the right are actually sub-categories and are denoted by the use of a vertical straight line, or 'bar' as below (example in Figure 2.1):

```
                           ┌ Feelings expressed
Feelings towards light --──┤
                           └ Expression of absence of feeling
```

Sometimes the terms on the right do not correspond to division along a single dimension, but instead are different possible dimensions of the child's responses. These are represented as enclosed in a bracket, or 'bra'. Unlike the bar, which implies that only one of the terms on the right can describe the response, the bra implies that all the terms enclosed in it have to be considered for the description. An example of the bra (taken from Figure 6.9) is given below:

Seeing objects with light (factors which matter in children's construction of a theory of vision)

- Type of object
- Position of observer
- Initiator
- Process of vision

The bar and bra represent two possible types of relationships between terms. While the terms themselves describe the children's responses, the relationships between them, denoted by the bars and bras, might well be mistaken for being merely logical and semantic connections. The way to make these connections more faithful to the actual data is by use of 'recursion' and of 'restrictive entry conditions'. The latter do not concern us here, so we do not describe them. However, the concept of 'recursion', which has been used in all our networks, needs to be explained.

Recursion is denoted by a circular arrow at the entry to a bar or bra. It implies that one must pass through that part of the network more than once in order to fully describe the responses. The example below is taken from Figure 6.9

Seeing light
- Always visible
- Not always visible
  - Made visible when it falls on objects
  - Other visual effects show its presence

In this example, the recursion arrow shows that both the possibilities following it, though semantically distinct, may occur together in one child's thinking.

APPENDIX 7

A7.1 RESPONSES TO LIGHT AND SIGHT QUESTION CLASSIFIED BY SEX, ABILITY AND CURRICULUM

For 420 out of the 456 students in the APU sample (age 15), data on sex, curriculum and ability level was available, as described below.

1. Sex of student: Of the 420 students, 217 (52%) were girls and 203 (48%) were boys.

2. Curriculum followed in school: For our purpose, it was sufficient to classify the students according to whether their curriculum did or did not include Physics as a subject of study. Of the 217 girls, 67 were studying Physics while 150 were not. Of the 203 boys, 146 were studying Physics and only 57 were not. Overall, 51% of the students had Physics as a subject of study.

3. Level of ability: In the APU surveys, the indicator of ability level was taken to be the number and level of subjects selected by the students for their school-leaving examinations. The specific criteria and the number of students in each category are given in Table A7.1.

TABLE A7.1: ABILITY LEVEL OF STUDENTS RESPONDING TO LIGHT AND SIGHT TASK

Ability level	Criterion for classification	Number of students	Percentage
1 (highest)	Taking 5 or more 'O'levels	157	37.4
2	Taking between 3 and 5 'O'levels	60	14.3
3	Taking 5 or more CSE's	39	9.3
4	Taking between 1 and 5 CSE's	115	27.4
5 (lowest)	Taking no external examinations	49	11.7

In the Tables which follow, the data on the numbers of students expressing (a) accepted ideas, (b) alternative ideas, (c) non-committal or uncodeable ideas and (d) giving no response at all, are classified on the three counts given above. Essentially, all the data are contained in Tables A7.2 to A7.6. However, the numbers of students in each cell of these tables are often too low to give meaningful statistics. Therefore, in Tables A7.7 and A7.8, the ability levels have been reduced to two (upper and lower) and the data are presented as the percentage of students in each category. The consolidated percentages with students classified by sex alone and by curriculum alone are presented in Tables A7.9 and A7.10.

TABLE A7.2: ABILITY LEVEL 1 (TOP)

Type of response \ Number of students	Physics		Non-Physics		Total	Percentage
	Girls	Boys	Girls	Boys		
Accepted	15	38	16	2	71	45
Alternative	10	17	16	7	50	32
Noncommittal or uncodeable	1	6	7	1	15	10
No response	4	4	12	1	21	13
Total	30	65	51	11	157	100

TABLE A7.3: ABILITY LEVEL 2

Number of students / Type of response	Physics		Non-Physics		Total	Percentage
	Girls	Boys	Girls	Boys		
Accepted	1	10	6	1	18	30
Alternative	5	8	12	2	27	45
Noncommittal or uncodeable	0	1	6	1	8	13
No response	0	1	5	1	7	12
Total	6	20	29	5	60	100

TABLE A7.4: ABILITY LEVEL 3

Number of students / Type of response	Physics		Non-Physics		Total	Percentage
	Girls	Boys	Girls	Boys		
Accepted	1	6	5	4	16	41
Alternative	3	6	5	1	15	38
Noncommittal or uncodeable	0	1	2	0	3	8
No response	0	1	3	1	5	13
Total	4	14	15	6	39	100

TABLE A7.5: ABILITY LEVEL 4

Type of response \ Number of students	Physics		Non-Physics		Total	Percentage
	Girls	Boys	Girls	Boys		
Accepted	5	10	4	3	22	19
Alternative	6	10	19	9	44	38
Noncommittal or uncodeable	5	8	13	5	31	27
No response	4	3	9	2	18	16
Total	20	31	45	19	115	100

TABLE A7.6: ABILITY LEVEL 5

Type of response \ Number of students	Physics		Non-Physics		Total	Percentage
	Girls	Boys	Girls	Boys		
Accepted	0	0	3	0	3	6
Alternative	4	6	3	4	17	35
Noncommittal or uncodeable	2	5	3	3	13	27
No response	1	5	1	9	16	33
Total	7	16	10	16	49	101

TABLE A7.7: UPPER ABILITY LEVEL (1+2+3)

Type of response \ Number of students	Physics Girls n=40	Physics Boys n=99	Non-Physics Girls n=95	Non-Physics Boys n=22	Total n=256
Accepted	43	55	28	32	41
Alternative	45	31	35	45	36
Noncommittal or uncodeable	3	8	16	9	10
No response	10	6	21	14	13

TABLE A7.8: LOWER ABILITY LEVEL (4+5)

Type of response \ Number of students	Physics Girls n=27	Physics Boys n=47	Non-Physics Girls n=55	Non-Physics Boys n=35	Total n=164
Accepted	19	21	13	9	15
Alternative	37	34	40	37	37
Noncommittal or uncodeable	26	28	29	23	27
No response	19	17	18	31	21

TABLE A7.9: TYPES OF RESPONSE CLASSIFIED BY SEX

Percentage responses	Girls n=217	Boys n=203	All n=420
Accepted	26	36	31
Alternative	38	35	36
Noncommittal or uncodeable	18	15	17
No response	18	14	16

TABLE A7.10: TYPES OF RESPONSES CLASSIFIED BY CURRICULUM

Percentage responses	Physics n=213	Non-Physics n=207	All n=420
Accepted	40	21	31
Alternative	35	38	36
Noncommittal or uncodeable	14	20	17
No response	11	21	16