Learning and Teaching Science:

Linking Cognitive Development and Curriculum Design

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Declaration

This Thesis contains no material which has been accepted for the award of any other degree or diploma in any institution and, to the best of my knowledge and belief, contains no material previously published or written by another person except where due reference is made in the text.

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Abstract

It is well documented that many school students come to science class with a variety of 'alternative conceptions' and that these remain largely untouched by teaching. This thesis describes research work that determined, analysed, and developed strategies to promote students' understanding of two physics topics. This research looked at the learning and teaching of science from both a cognitive and a curriculum perspective.

The principal aims of this research were to investigate students' understanding of 'light' and of 'sound' in terms of theoretical cognitive models, to design and implement instructional units on these topics that would facilitate the development of a scientific understanding, and to monitor changes in the levels of understanding, over the period of the investigation, in terms of the theoretical models. 'Light and seeing' was the focus of the preliminary investigation or pilot study; 'sound and hearing' was the main focus of the research.

There were two main components of this research. The first was a **psychological** component that utilised a theoretical framework, based on the SOLO Taxonomy of cognitive functioning, for students' developing understanding of the concept. In the study of 'light and seeing', the theoretical model of Collis, Jones, Sprod, Watson, and Fraser (1998) was used. In the study of 'sound and hearing', the theoretical model was formulated by the researcher. The second component was a **curriculum** component in which constructivist Teaching Units for both topics were developed, structured in such a way as to follow the pathways postulated in the theoretical models of cognitive development. It was the linking of cognitive developmental theory and curriculum design in science education that set the present research apart from the work of other researchers.

Conclusions were drawn from this research as to the usefulness of the theoretical models of cognitive development and of the Teaching Units closely aligned with the theoretical models. These can be applied both to teaching and to curriculum development. They have the potential to provide teachers with the tools to improve, not only their teaching, but also the understanding of their students, in the concept areas discussed in this thesis as well as in a wide variety of other science concept areas. The potential also exists for the use of the theoretical models for assessment purposes, and to provide profiles of student achievement.

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Chapter 1

Introduction

1.1 Why this study?

Cognitive developmental theory has long been of interest to educationalists (Demetriou, Gustafsson, Efklides, & Platsidou, 1992). The theorists attempt to specify the cognitive competence of the student at the successive phases of his/her development. The educationalists attempt to organise the curriculum such that it offers maximum benefit to the student. The ideal situation is a collaboration between the two. In the present research this collaboration is undertaken, and cognitive developmental theory is linked to curriculum design in science education. It is the linking of these two major areas of science education that sets this research apart from the work of other researchers.

This study was prompted, in the first instance, by the researcher's own observations that some of her science students had 'unusual ideas' about why things happened. These 'unusual ideas' turned out to be well documented in the 'alternative conceptions' literature (see Pfundt & Duit, 1991). In addition, as research was currently being undertaken at the University of Tasmania into 'alternative conceptions of vision', this seemed an ideal place to start. The Principal of the independent girls' school at which the researcher was employed as a science teacher readily agreed to allow the research to take place and for the students to be used as the subjects of the investigation. As the research was undertaken during the students' normal teaching program, parental permission was not required. Students were given the option of completing the questionnaire or not, and were told that their responses were strictly confidential and would not be used for purposes other than this research. The University Ethics Committee also gave approval for the investigation.

Despite the ideas concerning science phenomena that students hold being well documented in a number of areas, little has been done to instruct teachers in how to address these ideas and how to teach in order to facilitate learning and to promote understanding. In order to get students to construct new knowledge in the face of strongly held beliefs, it is necessary to identify teaching strategies that encourage and assist students to change their beliefs. According to Fetherstonhaugh and Treagust (1992), students may participate in instruction in an area of science, perform well in a test, yet not undergo any meaningful change in their conceptions of the particular topic. If conceptual change does take place, it may be short-lived and students may revert to earlier, more firmly held beliefs.

The ideas concerning science phenomena that students hold prior to instruction or develop during instruction are well documented in physics content areas such as heat, motion, the particulate nature of matter, and light. However, according to White (1994) and to Lijnse (1995), for the most part, this research does not yield clear advice on how to teach these topics. According to Dykstra, Boyle, and Monarch (1992), alternative conceptions are not addressed by standard instruction either in the physics classroom or in introductory physics textbooks. Hewson and Thorley (1989) state that, even when teaching occurs, reported research rarely provides sufficient evidence to gauge the status of students' conceptions following a teaching interaction. This too was the researcher's observation in a search of the current literature.

Learning is about changing an individual's conceptual knowledge (Hand & Prain, 1995); teaching is about facilitating that change. Much of the cutting-edge research in the domains of the cognitive-psychological approach to learning theory, classroom learning, and the improvement of teaching, has been based on the learning and teaching of science and mathematics (Phillips, in press). Research has identified student understandings of a broad range of science topics, although, more recently, attention has shifted to the application of constructivist teaching/learning approaches. In addition, there is growing recognition of the role of the social and cultural aspects in learning science as well as the personal constructivist aspects.

This study set out to explore students' understanding in two physics content areas with the purpose of illuminating and addressing some of the problems of learning and teaching science in schools. It is believed that if teachers are aware of what students already know and how it is they have made sense of their prior experience, then they (the teachers) may be able to make more informed decisions about how to organise their teaching in order to facilitate further learning and to promote understanding. The identification of students' alternative conceptions combined with teaching designed to confront and eliminate these in classroom settings has the potential to improve teaching and learning. It has the potential also to inform curriculum development and to help teachers guide students in the construction of the accepted 'scientific' meaning.

The teaching in the present research employed a constructivist strategy to facilitate the development of an understanding of the selected science concepts. Thinking about science from a constructivist perspective helps science educators to decide what might comprise a science curriculum (Tobin & Tippins, 1993). According to Tobin and Tippins, whatever science knowledge is constructed by students will be an interpretation of experience in terms of prior knowledge. Therefore, teachers must consider what experiences should be provided to the student in order to facilitate learning, how they can assist the student to interpret these new experiences in terms of their prior knowledge, and, finally, how they can help the student to move forward in conceptual terms.

If curriculum units are to be designed specifically to help students to undergo conceptual change, then some means is needed to measure the extent of that change and to map its progress. As Demetriou et al. (1992) point out, if effective teaching involves cognitive change in which the student moves to a higher level of understanding, then understanding the dynamics of cognitive development must surely assist teachers to develop effective teaching methods. In the present research, theoretical cognitive models for the development of an understanding of the physics concepts were used to inform the design of the curriculum units, and to monitor changes in levels of understanding resulting from participation in these units. As stated at the beginning of this section, this linking of cognitive developmental theory and curriculum design had not previously been undertaken, and it is this that is the key feature of the present research.

1.2 Principal aims of the research

The principal aims of this research were to investigate students' understanding of 'light' and of 'sound' in terms of theoretical cognitive models, to design and implement instructional units on these topics that would facilitate the development of a scientific understanding, and to monitor changes in the levels of understanding over the period of the investigation in terms of the theoretical models. 'Sound and hearing' was the main focus of the research; 'light and seeing' was the focus of the preliminary investigation or pilot study that preceded the research into 'sound and hearing'. 'Light and seeing' was a logical area in which to commence the present investigation for two reasons. Firstly, the topics 'light' and 'sound' are often taught together as there are a number of conceptual similarities that underpin their accepted scientific explanations. In addition, as mentioned in Section 1.1, research into students' understanding of vision was being undertaken at that time by Collis and his co-researchers, published subsequently in Collis, Jones, Sprod, Watson, and Fraser (1998). These researchers had developed a theoretical model for the development of an understanding of vision, as well as a questionnaire to determine students' understanding, both of which were used in the preliminary investigation and which served as models for a similar study of 'sound and hearing'.

Thus the principal research questions addressed were:

- can a theoretical model be proposed for the development of an understanding of 'sound and hearing' ;
- can the theoretical model be used to inform the design of a curriculum unit that will facilitate the development of understanding of the topic; and
- can the development of understanding be monitored in terms of the theoretical model.

A Teaching Unit on 'light and seeing' was developed by the researcher, closely linked with the model of cognitive development of Collis et al. (1998). This linking of cognitive development with the design of a Teaching Unit had not been done by these researchers. The preliminary investigation thus provided valuable experience in structuring lessons in alignment with a theoretical model, and in using a theoretical model to monitor changes in students' levels of understanding. This experience was then applied to the principal focus of the present investigation, which involved the formulation of a theoretical model for the development of an understanding of 'sound and hearing', the design of a Teaching Unit on 'sound and hearing' that closely followed the theoretical model, and the monitoring of students' developing understanding in terms of the theoretical model.

1.3 Main components of the research

The research consisted of two main components. The first of these was a psychological component in which, in the case of 'sound', the researcher established a theoretical model for students' development of an understanding of 'sound and hearing'. This theoretical model was based upon the Structure of Observed Learning Outcome (SOLO) Taxonomy of cognitive functioning developed by Biggs and Collis (1982; updated 1991). The responses of students to a questionnaire specifically designed by the researcher to determine their understanding of 'sound and hearing' were interpreted in terms of the theoretical model. Using this model it was possible to determine the cognitive levels at which the students were observed to be functioning. It was, therefore, also possible to observe changes in the levels of students' understanding over the course of the investigation, and as a result of their participation in the teaching module. The psychological component of the preliminary research into 'light and seeing' utilised the theoretical model and questionnaire of Collis et al. (1998).

The second component was a curriculum component. Students' responses to the questionnaires, analysed in terms of the theoretical cognitive models, were used to inform the design of Teaching Units, one on 'light and seeing,' the other on 'sound and hearing', that would lead students to a scientific understanding of these topics. The Teaching Units were structured in such a way that they were aligned with the theoretical models of cognitive development and, as the instruction and activities proceeded, it was intended that students would progress along the theoretical pathways to a scientific understanding of the two physics concepts. The investigations into both 'light and seeing' and 'sound and hearing' were carried out with two different groups of students over two consecutive years. The Teaching Unit on 'light and seeing' was implemented by the researcher in the first year and, in the second year, without any changes being made, by a student teacher, with the researcher as observer. The Teaching Unit on 'sound and hearing' was implemented by the researcher in both years, and small modifications were made prior to the second year.

As stated in Section 1.1, the Teaching Units were based on a constructivist view of learning and teaching at the heart of which is the notion that learning involves the active construction of knowledge by the learner. This process of constructing knowledge is influenced by the learner's prior knowledge and by his/her social setting. A constructivist teaching strategy was utilised but without losing sight of the fact that there was a body of knowledge to be learned. This is the crux of the dilemma for the science teacher, how to balance the curriculum to be taught with the concept of constructivism as a process by which students deal with content.

The theoretical models together with the allied Teaching Units would be available then for practising teachers to use with their students. The theoretical models could be adapted also to other areas of the science curriculum and used both to design curriculum units and to monitor students' development of an understanding of the particular concepts.

1.4 Overview of the sequence for the practical component

The practical components of the research into 'light and seeing' and 'sound and hearing' were carried out in the following sequence. The same sequence was employed for both areas. Firstly, the prior knowledge of the target group (Year 9 students, aged 13–14 years) was determined using the questionnaire designed to elicit their understanding of the topic. Responses to the questionnaire were interpreted then in terms of the theoretical model of cognitive development. The results of this analysis were, in turn, used to devise a teaching module appropriate to the target group that took into account their prior knowledge and 'alternative conceptions'. As mentioned in Section 1.3, the teaching module was closely aligned to the theoretical model. Upon completion of the teaching sequence, the questionnaire was given again to the students in order to determine whether the teaching unit had been effective. Did the students now have a clearer understanding of the concepts taught and did they hold the accepted scientific view? In other words had cognitive development or conceptual change taken place? Six months later for 'light and seeing', and five and twelve months later for 'sound and hearing', the questionnaire was given again to the students in order to determine how stable their understanding was; that is, did they still hold the 'scientific notion' or had they reverted to their previously held notions? The practical component of the investigation thus consisted of the following principal phases: a pre-instruction phase, an intervention or instruction phase in which the Teaching Unit was implemented, an immediate post-instruction phase, a delayed post-instruction phase, and, in the case of 'sound' only, a 12-month delayed post-instruction phase.

1.5 Structure of the thesis

Following the Introduction, Chapter 2 contains a review of recent literature in the field of interest for the present research. Sections 2.2 to 2.5, inclusive, contain a review of the literature dealing with theories of learning, constructivism, alternative conceptions in science and their implications for the science curriculum, and the cognitive aspects of children's conceptions of science. Included in Section 2.5 is a detailed discussion of the model of cognitive functioning upon which the theoretical models used in the present research are based. Section 2.6 deals with the literature on students' conceptions of 'light', which sets the scene for the preliminary investigation into 'light and seeing'. Section 2.7 contains a review of recent research into 'sound', which leads into the major focus of the present research, namely an investigation of 'sound and hearing'. Section 2.8 discusses the nature of the research project, and some relevant aspects of teaching pedagogy not covered elsewhere in the chapter.

Chapter 3 discusses the preliminary investigation into students' conceptions of 'light and seeing'. The chapter details the two major components of the investigation, namely the psychological and the curriculum components, the methods used to analyse students' responses to the questionnaire and to determine the observed levels of cognitive functioning, the design of the Teaching Unit on 'light and seeing', and the outcomes observed with the target groups of Year 9 students, over two consecutive years.

Chapters 4 and 5 deal with the principal focus of the present research, the investigation into students' understanding of 'sound and hearing'. Chapter 4 discusses in detail the methods used in the investigation, the preliminary investigations that led to the design of the questionnaire used to elicit students' understanding of 'sound and hearing', the techniques used to analyse students' responses and to determine their levels of cognitive functioning, the development of the theoretical cognitive model that formed the basis of this research and its testing by application to students of a range of ages and stages of development, and the design of the Teaching Unit used in the instruction phase of the investigation.

Chapter 5 details the results obtained with the target groups of Year 9 students. Outcomes observed with the two different groups, over two consecutive years, are discussed and compared. Changes made to the Teaching Unit as a consequence of the first investigation, and implemented with the second group, are discussed also.

Chapter 6 contains a discussion of the findings of the research and includes comments, evaluations, comparisons with the work of previous researchers discussed in Chapter 2, and suggestions for future research. The potential for the application of the cognitive models and the Teaching Units by teachers desirous of improving their teaching and the understanding of their students, is discussed also.

1.6 Limitations of the investigation

Over the period of this research, the researcher was working as a science teacher at an independent girls' school. The students provided a readily accessible source of subjects for the investigation and the school willingly gave its consent for the research to be undertaken.

As the school comprised both primary and secondary students, the researcher had access to a wide range of age groups for the developmental stages of the investigation into 'sound and hearing', as well as to the target groups of Year 9 students.

The nature of the school meant that the size of the groups used in this investigation were smaller than was desirable from a statistical perspective, and the students were possibly more able and perhaps more motivated than might have been encountered at other schools. The researcher had no control over the size of the class groups, which were smaller than expected in the second year, nor over the allocation of students into the groups. However, the benefits of the ready access to the students were considered to outweigh the disadvantages of the small groups.

Despite these limitations, the potential of both the theoretical models and the associated Teaching Units for use by teachers in improving not only their own teaching but also the understanding of their students appears considerable. Teachers would thus have the tools to comprehend students' understanding, to design instructional strategies to promote their understanding, and to analyse the success of these strategies. The researcher believes that the findings of this investigation could be applied to larger groups of students encompassing a wider range of abilities, and could also be extended to areas of science other than those covered in the immediate investigation.

Chapter 2

Review of the literature

> "Unless we know what children think and why they think that way, we have little chance of making an impact with our teaching no matter how skilfully we proceed."
>
> (Osborne & Freyberg, 1985, p.13)

2.1 Introduction

This chapter contains a review of recent literature in the areas of interest for the present research. Since this research involves the linking of cognitive developmental theory and curriculum design in science education, it is important to examine the literature relevant to these areas and to the particular physics content areas selected for the investigation. Sections 2.2 to 2.5, inclusive, contain a review of the literature dealing with theories of learning, constructivism, alternative conceptions in science and their implications for the science curriculum, and the cognitive aspects of children's conceptions of science. The section on constructivism includes an overview of the constructivist view of learning and teaching and its relevance to science education, as well as criticisms of constructivism. Section 2.5 includes a detailed discussion of the model of cognitive functioning upon which the theoretical models used in the present research are based. Section 2.6 deals with the literature on students' conceptions of 'light' as well as referring briefly to the theoretical cognitive model for the development of an understanding of vision used in the present research. This discussion sets the scene for the preliminary investigation into 'light and seeing'. Section 2.7 contains a review of recent research into 'sound' which leads into the major focus of this study, namely an investigation of 'sound and hearing'. Section 2.8 discusses briefly the nature of the research project and some relevant aspects of teaching pedagogy not mentioned elsewhere in the chapter, such as the technique of questioning and the use of analogies. Section 2.9 contains a brief conclusion to the chapter.

2.2 Theories of learning

Skinner (1957) hypothesises that all learning is conditioned by external events, either consciously or unconsciously, which leads to the notion that learning can be controlled by positively reinforcing appropriate behaviour. This conditioning approach to learning develops further with the contribution of social learning theory and the realisation that some learning occurs by imitation and modelling (Bandura, 1969). However, according to Groundwater-

Smith, Cusworth, and Dobbins (1998), a behaviourist approach might apply for simple tasks, but it is unlikely to be successful for complex learning.

Piaget (1959) proposes a four-stage theory of intellectual or cognitive development. He emphasises the notion that children construct their own tools for understanding and discovering the world through interaction with their environment. As novel experiences occur the child adapts by relating each new experience to familiar ones (*assimilation*). At times, however, the experience requires an adjustment by the child to cope with something new (*accommodation*). The interplay between assimilation and accommodation, known as *equilibration*, results in mental structures that are progressively more decentred.

Ausubel (1967) explores the role of the child's internal cognitive structures in learning. He suggests that as items are learnt the learner organises and stores them in larger units or *schema* that allow the knowledge to be retrieved as required. New knowledge is integrated with past knowledge and the schemata expanded. Previously stored knowledge affects how the new information is interpreted. Schema theory thus attributes great importance to the learner's active involvement in the learning process.

In the last thirty years there has been a growing realisation that learning is a collaborative process (Groundwater-Smith et al., 1998). A *social constructivist* or *socio-cultural-historical approach* to learning emphasises the importance of shared interaction, collaboration, and negotiated meanings. Vygotsky (1978) focuses on the importance of the socio-cultural dimensions and of language as important characteristics of learning. One of the major elements of Vygotsky's theory is his notion of *the zone of proximal development*. This he defines as the distance between the current developmental level of a child as determined by independent problem solving and the level of potential development as determined through problem solving in collaboration with adults or more capable peers. He emphasises the importance of the role played by adults in guiding learning for children. Children are constantly on the verge of acquiring new learning and a teacher's task is to place learning within the zone of proximal development.

Vygotsky (1978) suggests that formal learning (for example, learning at school) and everyday learning (for example, learning in the home) are interconnected and interdependent. For learning to be worthwhile, an effective relationship must exist between the everyday world and the school world (Moll, 1990). Teachers, parents, and peers must interact, share ideas and experiences, and solve problems. This interdependence in social contexts is central to a Vygotskian analysis of instruction. Children can often complete activities in collaboration that they could not complete on their own and gradually they learn to perform them independently. This is an interesting contrast to Piaget's notion that children should not be engaged in activities that are beyond their current level of development.

Vygotsky's notions of scaffolding, guided discovery, and of the importance of the interaction between the child and his/her environment to facilitate understanding, is essentially a *constructivist* approach. However the degree of guidance is more pronounced than with Piaget's idea of constructivism in which there is little emphasis on direct teaching (Pressley, Harris, & Marks, 1992). There are, however, many similarities between Vygotsky's and Piaget's theories for the classroom. Both emphasise the importance of active involvement by children in learning, of peer interaction, and of situating the learning experiences in the real world of experiences for children. However, where Piaget favours unstructured experiences and self-initiated discovery, Vygotsky emphasises the need for guidance and assisted discovery to *lead* development.

Vygotsky (1978) also emphasises language as a major means by which cognitive development occurs. Piaget, in contrast, believes that cognitive development occurs independently of language development, and facilitates the acquisition of language.

According to Lemke (1990) learning is essentially a social process and language is an important element of this process. Learning science means learning to 'talk science'. It means learning to communicate in the language of science and to act as a member of the community of people who do so. Science teachers belong to a community of people who speak the language of science. Students, at least initially, do not. Because communication and teaching are social processes, they depend on attitudes, values, and social interests, not just on knowledge and skills.

Driver, Asoko, Leach, Mortimer, and Scott (1994) stress that the significance of social constructivism for learning is not just in terms of fostering the construction of individual meaning, but also in terms of the ways this can foster the introduction of the learner into the conventions and symbolic world of science. According to Gunstone (in press), it is social construction and its impact on the nature of learning that is crucial in discriminating constructivist classrooms from 'discovery learning' classrooms.

Lemke (1982) maintains that the effective language of the classroom is the shared language of pupils and teachers, a constantly changing hybrid of common parlance with the language teachers and pupils use in other settings (for example, in textbooks, in discussions with peers). Frequent explicit explanations that introduce new concepts and new ways of talking may initially do little more than attract the attention of the students to the words. However, Lemke believes that every moment of the discourse during which a particular thematic system is in use is rich with implicit cues to the structure of that system and its connection to other systems.

Talking to one another, in small group work or even in side conversations, gives students an opportunity to talk science in a different way, free of some of the pressures of talking science with the teacher. Students' own ideas, including alternative notions, are able to be discussed openly and freely (Lemke, 1990). Tobin (1990) emphasises the importance of the social dimensions of learning. He maintains that individuals working alone, or collaborating with peers, is a good way for learners to deal with their own prior knowledge as they learn new science concepts. Discussions with others often sort out understandings and clarify meanings.

A major research theme in instructional psychology emphasises students' self regulation of their own learning (Bereiter & Scardamalia, 1993). This notion is particularly interesting in the context of conceptual change. Research in reading (Scardamalia & Bereiter, 1984), writing (Scardamalia & Bereiter, 1987), and intentional learning (Bereiter & Scardamalia, 1989; Chan, Burtis, Scardamalia, & Bereiter, 1992) has shown the importance of a problem-centred approach to learning. Two contrasting approaches to understanding new concepts in unfamiliar domains have been identified: *direct assimilation* that involves fitting new information directly into existing knowledge, and *knowledge building* that involves learners treating new concepts as something that they need to explain (Bereiter & Scardamalia, 1993). These are similar to Piaget's notions of *assimilation* and *accommodation* discussed earlier in this section.

Chan, Burtis, and Bereiter (1997) propose that the contrasting approaches of direct assimilation and knowledge building provide a useful framework for examining the persistence of naive or 'alternative' conceptions and the process of conceptual change. They argue that alternative conceptions tend to persist because students process new information by directly assimilating it into their existing knowledge, often based on everyday experience. Alternatively, students who use a knowledge-building approach are more likely to experience conceptual change. The role of knowledge-building in fostering learning is consistent with current notions that conceptual change involves knowledge restructuring (Chi, Slotta, & de Leeuw, 1994). Learning is no longer viewed simply as the transfer of knowledge from the teacher to the learner, but rather as the learner actively constructing knowledge on the basis of knowledge already held (Duit & Treagust, 1998).

2.3 The constructivist view of learning and teaching

Phillips (in press) maintains that constructivism is a currently fashionable 'magic word' in education; Duit (1993) regards it as a 'fashionable and fruitful paradigm' for guiding educational research and practice. The debate over constructivism is a long and involved one (see Phillips (1995) for a succinct presentation of 'the good, the bad, and the ugly' of constructivism). This section will discuss the opinions of some of the principal researchers in the field and will present an overview of constructivism in its many forms, including criticisms of constructivism, and its relevance to science. The discussion will not dwell on the many varieties of constructivism (Good, Wandersee, & St. Julien (1993) mention fifteen 'faces' of constructivism) as often the differences are only slight, a matter of philosophical debate, and will not have any bearing on this research. As much of the research in constructivism is in the field of science and mathematics, the general discussion of constructivism will include frequent references to findings in these areas.

2.3.1 The many faces of constructivism and their implications for learning and teaching

Much of the cutting-edge research in the domains of the cognitive-psychological approach to learning theory, classroom learning, and the improvement of teaching, has been based on the learning and teaching of science and mathematics (Phillips, in press). This is reflected in the comprehensive collection of research articles on constructivism edited by Steffe and Gale (1995). There is growing recognition of the role of the social and cultural aspects in learning science as well as the personal constructivist aspects. This is illustrated in the writings of Solomon (1987), Tobin (1990), and Driver et al. (1994). Therefore, this discussion of the many faces of constructivism will include frequent references to science.

The constructivist view of learning has its roots in the long-standing epistemology of the interpretive or Verstehen tradition (Weber, 1949) that has at its centre the importance of meaning as 'constructed' by individuals in their attempt to make sense of the world. The constructions are seen as tentative models that are continually tested against experience and, if necessary, modified. This tradition is concerned with the intents, beliefs and emotions of individuals as well as their conceptualisations, and recognises the influence that prior experience has on the way phenomena are perceived and interpreted (Driver & Oldham, 1986).

A *traditional* view of learning puts the learner in a passive role as absorber of information; the teacher is the active transmitter and the curriculum is that which is taught or transmitted to someone else. A *constructivist* view of learning suggests new meanings for the concept of 'curriculum'. The curriculum no longer can be seen as a body of knowledge to be transmitted as is usually detailed in teaching syllabuses. Constructivists consider it inappropriate to prescribe conceptual learning outcomes in detail (Driver, 1989a). Instead the curriculum can be viewed as including the meanings constructed by the students, a series of learning tasks and strategies, the context in which the learning occurs, and the thinking skills used by students for conceptual development (Bell, 1991; Driver, 1989b). Rather than prescribing detailed learning outcomes, it is seen as more appropriate to describe the learning opportunities and tasks that will enhance the likelihood of conceptual change within a knowledge area.

These learning sequences can be summarised as involving students gaining an awareness of their ideas, the creation of cognitive dissonance, the construction of new conceptions and/or the restructuring of existing conceptions, and the acceptance of the new ideas (Osborne, 1982). A constructivist curriculum would contain more guidelines as to how to develop students' conceptions, and in what general knowledge areas, and less prescribed scientific knowledge.

Effective learning occurs when individuals *construct* their own knowledge and understanding through interaction with the environment. This environment includes *interpersonal* (social networks - families, peers, schools) and *intrapersonal* (the individual's existing knowledge, attitude, motivation) variables, and external conditions and experiences (McInerney & McInerney, 1994). Learning is seen as an adaptive process, one in which the learner's conceptual schemes are progressively reconstructed so that they are in keeping with an increasing range of experiences and ideas. It is seen also as an active process of 'sense making' over which the learner has some control (Driver, 1989b). This perspective differs from that of Piaget in that it emphasises the development of domain specific knowledge structures rather than the development of general logical capabilities.

Moshman (1982) considers there are three major types of constructivism. The first is *endogenous constructivism*, based on Piaget's theory, that emphasises the *intra*personal aspect and stresses the importance of child-centred discovery rather than direct teaching. The second type is *exogenous constructivism* that places greater emphasis on the role of external factors in learning, such as teaching through modelling and explanation. Thirdly, there is *dialectical constructivism* that advocates *guided discovery* assisted by teachers, adults, and peers. This third type is Vygotsky's notion of constructivism which also emphasises the importance of interaction between the child and his/her social environment to facilitate meaningful learning, but with less direct teaching than exogenous constructivism.

Treagust, Duit, and Fraser (1996) describe constructivism as consisting of two basic principles, one psychological and the second epistemological, and emphasise that knowledge cannot be separated from knowing. Treagust et al. maintain that these two principles, which make up von Glasersfeld's (1990) *radical* constructivism, include many facets of Piaget's genetic epistemology and often serve as a reference position for discussions of constructivism in education. The first principle states that students construct their own understandings from the words or visual images they receive, and, consequently, students' prior knowledge is important. The second principle states that the learner constructs explanations of experiences and of 'reality' in a personal and subjective way.

Phillips (in press) divides constructivists into two broad camps. The first consists of *psychological constructivists* who regard constructivism as the construction of knowledge by individuals. This camp includes Piaget and von Glasersfeld and others, such as Vygotsky and the social psychologist, Gergen (1994), who regard social factors as playing a major role in an individual's construction of knowledge. The second camp consists of *social* *constructivists*, including Dewey, who stress the socio-political influences on the construction of a discipline such as physics or chemistry. This second broad area of constructivism is sometimes also called *social constructionism.* Phillips points out that not all psychological constructivists are psychologists - the crucial thing is that their focus is on the way in which individuals construct their own understandings.

Von Glasersfeld (1984) describes his version of psychological constructivism as radical constructivism to contrast it with constructivism built on prior knowledge. He writes that his form of constructivism is radical because "it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an 'objective' ontological reality, but exclusively an ordering and organisation of a world constituted by our experience" (p. 24). That is, knowledge about the world outside is viewed as human construction. A reality outside the individual is not denied; rather it is claimed that what we know about reality is our own personal construction (Duit & Treagust, 1998).

Both social constructivism and psychological constructivism have important implications for education (Phillips, in press). As one considers the pedagogical implications of constructivism, the focus of teaching moves from proficiency at content delivery to assisting individuals in their interpretation of concepts (Dana & Davis, 1993).

Good, Wandersee, and St. Julien (1993) see constructivism as a powerful and unifying force in the practice of science education. Treagust et al. (1996) contend that the constructivist view has become the leading theoretical position in education and has become a powerful driving force in science and mathematics education. If, as stated by Tobin and Tippins (1993), the aim of teaching is "to build a classroom that maximises student learning" (p. 7), then Treagust et al. (1996) maintain that constructivism acts as a powerful theoretical referent for this aim. Tobin (1993) believes that thinking of science from a constructivist perspective helps science teachers to decide on the structure of a science curriculum.

Interestingly, Gunstone (in press) does not agree with the view of constructivism as a dominant theoretical influence. Rather he claims that science teachers have used theoretical positions from areas other than constructivism to address the problems observed in their classrooms. Gunstone maintains that, rather than being driven by theory, teachers have been merely users of it. The major concern of teachers was not what form of constructivism they adhered to but rather whether or not their students better learned the concepts of science. This difference of opinion concerning the 'theory' of constructivism appears related to one of the criticisms listed by Bell and Gilbert (1996), namely the search for the 'grand theory'. Criticisms of constructivism are discussed in Section 2.3.2.

If students are to change their conceptions or to construct new conceptions, they must first clarify their own views about the particular phenomenon under discussion. Nussbaum and Novick (1981) suggest one needs to create a 'critical situation' (for example, a question or problem) that requires students to invoke and clarify their own conceptions or frameworks. By debating their existing conceptions, students are encouraged to state their ideas clearly and concisely. Leder (1992) suggests that instructional activities should be designed to give rise to genuine problems for students. Such problems constitute opportunities for them to reflect and reorganise their current ways of thinking.

To produce conceptual change, students need not only to appreciate alternative views but also to perceive them as more intelligible, plausible, and fruitful than their present viewpoint (Posner, Strike, Hewson, & Gertzog, 1982). In addition, Claxton (1984) suggests that conceptual change requires a supportive environment where an individual's ideas are valued.

A contribution to the development of a constructivist approach to learning science has been made by Osborne and Wittrock (1985) based on the generative learning model of Wittrock (1974), initially applied to reading. This model stresses the importance of what learners bring with them to the learning situation and recognises the active construction of meaning that goes on constantly as individuals interact with their environment. A number of researchers, including Driver and Oldham (1986), Minstrell (1989), and Scott, Asoko, and Driver (1992), have emphasised the important role that students' prior knowledge plays in learning, and that there should be a major reconsideration of the teaching of science in schools to take this into account. This is summed up by Ausubel (1968): "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi).

Galilli, Bendall, and Goldberg (1993) believe that if teachers do not take into account students' prior knowledge then vestiges of that knowledge may emerge later as a source of difficulty. In addition, according to Driver (1989b), the context in which science is learnt influences the learning outcomes and the ability to use knowledge appears to depend on the context in which that knowledge was acquired.

An individual's knowledge, therefore, is not considered as a set of discrete 'bits' but as a series of structures, and learning involves the development and change of such structures. A central question for educators becomes how to elucidate the processes by which such changes occur (Driver & Oldham, 1986).

Driver and Oldham (1986) developed a prototypical model for a constructivist teaching sequence, shown in Figure 2.1. It aims to encourage the active construction of meaning by starting from students' own ideas and providing opportunities for building on and modifying these towards the scientific understanding. The sequence comprises five phases: orientation, elicitation, restructuring, application, and review. The restructuring phase involves the clarification of current ideas, the exposure to conflict situations, and the construction and evaluation of new ideas.

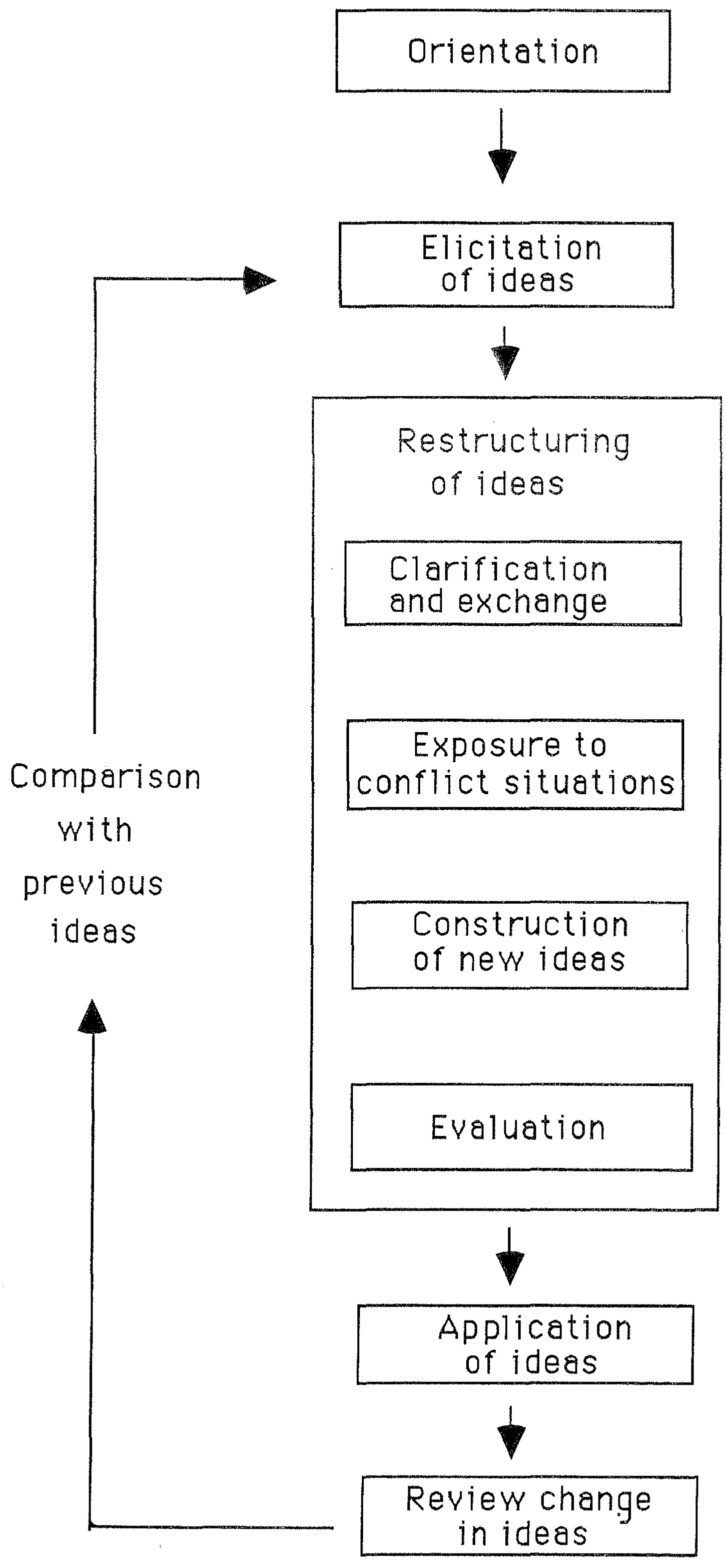


Figure 2.1: A constructivist teaching sequence
(Driver & Oldham, 1986, p.119)

Duit and Confrey (1996) maintain that Driver and Oldham's constructivist teaching sequence is paradigmatic for many other attempts to take students' pre-instructional conceptions into consideration in a serious way. In such approaches there is always a phase in which students' ideas are elicited and discussed in class before the science view is presented. A key feature in the phase of contrasting students' ideas and the science conceptions is negotiation in which the teacher is a facilitator rather than a transmitter of knowledge. In the role of facilitator, the teacher encourages students to engage actively in the personal construction of meaning. For this, sufficient time must be allowed for students to share, reflect on, evaluate, and restructure their ideas.

It is important to have children's starting points as well as intended science learning goals in mind when designing a science curriculum (Driver, 1989b; Driver, Squires, Rushworth, & Wood-Robinson, 1994). Teaching science with children's thinking in mind depends upon careful planning in which continuity of curriculum is designed for progression in pupil's ideas (Driver et al., 1994). Curricular continuity, however, cannot guarantee progression. Its role is to structure ideas and experiences for learners in a way that will help them to move their conceptual understanding forward in scientific terms.

The basic problem for constructivist teaching is how to design teaching such that it guides students to construct in freedom the very ideas that one wants to teach (Lijnse, 1995). Freudenthal (1991) calls this learning process 'guided reinvention'.

2.3.2 Criticisms of constructivism

Over the last decade or so, constructivism has increasingly been adopted by researchers, curriculum developers, and teachers, particularly in science education, as a view of learning and knowing by students and teachers (Bell & Gilbert, 1996). However, according to Suchting (1992), this consensus was reached, to some extent, by avoiding a debate about its central ideas. Although, according to Duit (1994), constructivism has provided a powerful and fruitful research perspective on learning in science education, the plethora of interpretations of constructivism have led to a number of criticisms. Bell and Gilbert (1996) list the main criticisms as:

> concern for the loosely defined terms, ontological issues of realism and relativism, making sense, theory adjudication, science curricula, progression in the curriculum, the capabilities and learning styles of students, the search for the 'grand theory', the social dimension to the practice of science and the learning of science, the role of the teacher, the scope of the utility of constructivism, the status of constructivism with teachers, the impact on teacher development and links to progressive education (p. 51).

This is not the place to address each of these criticisms. However, one issue that is perhaps more critical than others (at least for this research) will be noted briefly. In teaching science, it is important that students learn the bodies of knowledge that "the scientific community regards as currently warranted" (Phillips, in press). Phillips cites concepts such as Newton's Laws of Motion or Einstein's formula, that students could not construct for themselves. This reflects the concerns of Bell and Gilbert (1996) for 'theory adjudication, science curricula, and progression in the curriculum', mentioned in the preceding paragraph, and perhaps even 'the capabilities of students'. It is highly unlikely that students who have no knowledge of relativity will 'construct' Einstein's Theory. This same concern has been expressed by other 'constructivists'. The researcher believes that this is the area in which constructivism 'falls down' (to borrow Solomon's (1994) words).

In her paper 'The Rise and Fall of Constructivism', Solomon (1994) suggested that the theory of constructivism was a useful tool even if it had become "a bit logically disreputable in parts" (p. 13). According to Solomon, the enormous success of Driver and Easley's (1978) paper on constructivism was largely responsible for the launching of constructivism in science education. Much of the vocabulary used in Driver and Easley's paper was familiar to researchers but when it was put together and picked up by others in the field it achieved two objectives:

(i) the phenomenon of the persistence of entrenched misconceptions (to use the old terminology) has been *redescribed* as a range of coherent scientific explanations which have been constructed and tested against experience; and

(ii) a new field of study has acquired a new vocabulary which focuses attention on the pupils' own ideas (Solomon, 1994, p. 4).

What constructivism described had been observed by practitioners. Students had often brought their own ideas to lessons, but it was not thought remarkable and was dismissed as 'students often have difficulty with this'. Now students' ideas became the focus of research, thus providing an example of the usefulness of a constructivist approach to education.

Constructivism was at its peak in the 1980s, and Pfundt and Duit (1991) provide a comprehensive list of research in the field. During this time, three new aspects emerged: the theory of personal constructs formulated initially by Kelly (1955) in which he claims that every person constructs the world by differently testing out his/her constructions against experience; the notion of 'children's alternative conceptions', which is discussed in Section 2.4; and the social construction of knowledge, which claimed that different meanings in different languages accounted for many of the common school misconceptions. Each of these aspects generated useful information concerning student understanding of science, and, for this, constructivism was a 'useful tool'.

Solomon (1994) maintains that constructivism, in the sense that it was used within science education, had always skirted around the actual learning of an established body of knowledge. It described, in new language and metaphors, the alternative ideas and meanings that many pupils held and the environment in which such ideas would be expressed. This was part of the theory of constructivism. What constructivism had not described was that science had been built up into a knowledge system by a consensual process, which was not that of the life-world, by scientists who had established ways of monitoring its manufactured knowledge. Changes to theory do occur but they are not brought about by school students who have difficulty in comprehending science textbooks (Solomon, 1994).

Driver (1989b) expresses this same opinion when she states that learning involves individuals being initiated into the 'ways of seeing' that have been established by the scientific community. Such 'ways of seeing' cannot be 'discovered' by the learner. The challenge for the science teacher involves helping students to make sense of scientific 'ways of seeing' or 'ways of knowing' (Leach & Scott, 1995) in terms of their existing knowledge. As Mathews (1994) points out,

> many science educators are interested in finding out how, based on constructivist principles, one teaches a body of scientific knowledge that is in large part abstract (depending on notions such as velocity, acceleration, force, gene), that is removed from experience (propositions about atomic structure, cellular processes, astronomical events), that has no connection with prior conceptions (idea of viruses, molten core, evolution), and that is alien to common sense, and in conflict with everyday expectations and concepts. (p. 166)

This is a major dilemma for the science teacher who must come to terms, both practically and theoretically, with the tension between the curriculum or content to be learned and 'constructivism' as a process by which students deal with content (Russell, 1993).

Solomon (1994) describes constructivism as a fruitful redescription, built on the notion of the pupil as already a scientist. Its achievements have been many. However, if learning is described as opening windows to quite new views, or a game with totally unfamiliar rules, then the constructivist redescription will fail.

The constructivist debate is an interesting one but if constructivism is simply taken to mean good, innovative, and stimulating teaching where students' ideas are acknowledged and respected and where teachers do not dominate the classroom, then constructivism is certainly a 'useful tool' as stated by Solomon and can provide valuable insights into improving science teaching and student understanding of concepts. Gunstone (in press) says,

> there are a number of researchers in science education who describe themselves as 'constructivist' who apparently do not discriminate between 'radical constructivism' and less contentious positions. While this may not be a sensible stance, it certainly shows that a particular form of constructivism is not driving their thinking.

Despite the many arguments concerning constructivism, it does serve as a 'useful tool' (Solomon, 1994). Phillips (1995) maintains that constructivism is 'good' because of the emphasis that various constructivist groups place on the importance of the active participation by the learner, together with the recognition (by most of them) of the social nature of learning.

2.4 Alternative conceptions of science and their implications for the science curriculum

Since the early work of Piaget (1929) researchers have been aware that children sometimes have conceptions about the world quite different from accepted scientific conceptions and that these 'misconceptions' often affect the ways that children understand and respond to classroom science instruction (Eaton, Anderson, & Smith, 1983). It is the similarities and differences between children's science and scientists' science that are of central importance in the teaching and learning of science (Osborne & Freyberg, 1985).

Various names have been suggested for children's conceptions, including 'intuitive knowledge' (Strauss, 1981), 'alternative frameworks' (Driver, 1981), and 'children's science' (Gilbert, Osborne, & Fensham, 1982). The term 'alternative conception' is preferred by many researchers to the term 'misconception'. As Wandersee, Mintzes, and Novak (1994) explain,

> not only does it refer to experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible, but also it confers intellectual respect on the learner who holds these ideas - because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions, for example, scientific conceptions. (p. 178)

Because the term 'misconception' means a mistaken understanding of something - one that is commonly held by learners, is difficult to 'teach away', and is at variance with current scientific knowledge - a number of researchers contend that its use not only contradicts constructivist views of knowledge but also implies that such ideas have a negative value and should be quickly eradicated (Wandersee et al., 1994). Students' ideas should not necessarily be considered wrong, only different. As Leder (1992) points out, rather than being 'wrong', students frequently display partial or naive understanding that may be applied rationally and consistently.

Kuiper (1994) disagrees with the use of the term 'framework', as used by Driver (1981), as it implies a coherence in student ideas. He claims that, in general, students do not have an 'alternative framework', rather they have a loose set of incoherent ideas and one cannot, therefore, assume that students can be challenged in their ideas in the way proposed by Posner et al. (1982) (see Section 2.3.1) and used by Driver (1989b). Kuiper (1994) prefers the term 'student ideas' that are seen as 'units' of a student's understanding of a concept. He claims that education should be directed at each individual student idea and at trying to help students transform their somewhat scattered understanding into a more coherent whole.

In the present research, the terms 'alternative conception' and 'alternative framework' have both been used as each has a slightly different meaning. 'Alternative conception' is seen as similar to Kuiper's 'student ideas'. The researcher supports the notion of the 'alternative framework' being built up of a number of 'alternative conceptions'. Students may possess a loose set of incoherent ideas or 'alternative conceptions' as Kuiper suggests or they may possess a 'framework' of linked incorrect or imperfect ideas. It is as students acquire a scientific understanding of concepts, which may involve 'conceptual change' as advocated by Posner et al. (1982) and Strike and Posner (1985), and link these scientific concepts together, that they build a framework of understanding.

Certain characteristics of these 'alternative conceptions' have been identified in a wide range of empirical studies (Pfundt & Duit, 1991). Children of different ages and backgrounds may hold similar 'alternative conceptions'; often the ideas are not used consistently across what may appear to scientists as similar contexts. The nature of what students consider to be an acceptable explanation may also differ from a scientific view (Solomon, 1984).

One important finding that is of major significance for effective science teaching is that some of the ideas held by children about the natural world are firmly held and often persist despite what appears to be effective teaching. In order to explain this, Solomon (1983) distinguishes between the symbolic and life-world domains of knowledge and documents the difficulties students have in relating the two. She argues that where children's old ideas involve 'everyday notions' and new ideas involve 'scientists' explanations', pupils are likely to retain both kinds of 'knowledge'. They need to be able to think and to operate in both everyday and scientific domains, but they should be able also to distinguish between them. Cosgrove and Osborne (1985) contend that, although this is true for some concepts (for example, 'animal', 'plant', 'living'), it may not be valid for others (for example, 'force', 'electric current'), where everyday notions are neither necessary for everyday communication nor useful for explanatory purposes once the scientific perspective is fully appreciated and understood.

Interestingly, in their paper, Muthukrishna, Carnine, Grossen, and Miller (1993) contradict the findings of earlier researchers (for example, Anderson & Smith, 1987; Gunstone, Champagne, & Klopfer, 1981) that children's alternative conceptions are extremely resistant to change and must be directly addressed during instruction for conceptual change to occur. Muthukrishna et al. claim that clear explanations and extensive application confront students' alternative conceptions without directly addressing them and are effective in eliminating the alternative conceptions without spending valuable instructional time invoking and addressing them individually. However, their research does not include a 'control' group and the post-test was carried out only six and ten weeks after instruction, so the 'long-term' outcome of their investigation is not demonstrated.

The importance of identifying alternative conceptions is that they can interact, in unanticipated ways, with teaching that attempts to encourage students to build more useful scientific conceptions (Adams, Doig, & Rosier, 1990). Sometimes, when learning science at school, students make inappropriate links to their prior knowledge, and hence the meanings they construct are not those intended by the teacher (Bell, 1985; Tasker, 1981).

Wittrock (1974) argues that students inevitably construct their own purpose for a lesson, form their own intentions regarding the activities they will undertake, and draw their own conclusions that may or may not be the same as those intended by the teacher. Tasker and Osborne (1985) contend that it is by appreciating the perceptions that the learner brings to the lesson that teachers can reduce the disparities between teacher intentions and student learning.

The existence of children's 'alternative conceptions' has tended to be ignored or at best inadequately considered in the development of science curricula. It is extremely rare to find curriculum guide material that explains to teachers the likely views of children in their classrooms, and the way in which these views could most readily be modified. Rather the implication that underlies many science curricula is that the learner possesses no significant knowledge of a topic prior to instruction. Alternatively, if the learners do have some prior ideas related to a topic that is going to be taught, then it is assumed that these ideas can be directly and easily replaced (Freyberg & Osborne, 1985).

Almost three decades ago, Ausubel (1968) suggested that "unlearning of children's preconceptions might well prove to be the most determinative single factor in the acquisition and retention of subject matter knowledge" (p. vi). More recently, Eaton, Anderson, and Smith (1983) suggested that the way students understand and respond to classroom science instruction is often affected by the 'alternative conceptions' that they hold. It would seem important, therefore, that teachers and curriculum developers should draw on some of the studies of students' alternative conceptions to create teaching sequences that would challenge the ideas pupils are currently holding. However, this approach is only possible if one has first established the nature of such alternative conceptions (Driver, 1983).

Driver and Easley's (1978) paper recommends studying students' ideas in a general way for the purposes of curriculum design and classroom teaching. However, as Driver and Oldham

(1986) found, understanding students' ideas is not synonymous with having a method of instruction that will change them.

Driver (1981) suggests that teachers should be aware of children's alternative conceptions and use them to advantage in the classroom. The logical order of teaching a scientific topic may not correspond with the order of psychological development in learning and therefore teaching programmes should be designed to correspond better with the developmental path of student understanding. Opportunities should be provided also for students to disprove alternate conceptions and to think through the implications of observations and measurements made in science lessons.

Lijnse (1995) maintains that curriculum development so far, has not resulted in much real progress as far as meaningful learning of science is concerned. In his opinion 'developmental research' is needed in which curriculum development is coupled to classroom research of teaching-learning processes. As a large proportion of research on science education is theoretically embedded in a cognitive science perspective, as well as in modern philosophies of knowledge, its outcome has been largely in terms of more general strategies and theories. Therefore, additional research that starts from a more content-specific framework is required.

The aim of the present research is to link curriculum development to cognitive developmental theory. Therefore, the following section discusses the cognitive model utilised in this research.

2.5 The cognitive aspects of children's conceptions of science

This section deals with the cognitive aspects of children's conceptions of science, and the relationship between students' ideas and the cognitive levels at which the students are functioning. The development of the cognitive taxonomy selected for use in the present research is discussed.

A major research interest in science education is in the development of abstract academic abilities "without taking cognisance of modes of functioning other than those which appeared directly related to their attainment, such as the problem-solving abilities related to 'everyday' intelligence" (Collis & Biggs, 1991, p. 187). Teachers are encouraged to regard development as progress through a limited number of stages, distinguished largely by the level of abstraction of the elements of thought with which the individual is able to cope at the time. Within each stage the individual goes through a similar cycle of learning to reach the top level of that stage at which point he or she is able to move to the next higher stage.

Biggs and Collis (1982; updated 1991) propose a developmental model, the Structure of Observed Learning Outcome or SOLO taxonomy of cognitive functioning, similar to Piaget's stages of development. The SOLO theory focuses on modes of intellectual functioning, which is an important break away from the Piagetian stage of development notion. The SOLO taxonomy is essentially a model for describing the level and quality of learning "both within and across the curriculum" (Biggs & Collis, 1989, p. 151), that is, within a single subject, as well as across different subjects. It is based upon the observation that learners display a consistent sequence or 'learning cycle' in the way in which they go about learning a variety of tasks (Biggs & Collis, 1982). Learning grows along at least two dimensions: (a) the level of abstraction, or mode, of the content learned; and (b) the cycle of increasing complexity that learning undergoes within any given mode.

The SOLO model is a 'response' model. That is, the responses of the student in a particular context enable inferences to be made as to the mode of thinking of the student. This may not represent the student's optimal mode nor can it be inferred that this will be the mode of response that will be used in a different context. However, the responses enable the teacher to determine how far learning has progressed towards expertise, with reference to any particular mode, and may, therefore, be used to classify the outcomes of learning within any given mode (Biggs & Collis,1991).

The level of abstraction that a learner demonstrates when handling the elements of a task is associated with the 'mode' of that learning episode. Biggs and Collis (1991) distinguished five modes of cognitive functioning, progressing from intuitive to concrete actions to abstract concepts and principles, which begin to appear sequentially from birth and which remain operational and continue to develop throughout life. Each of these modes as it emerges is postulated not to replace its predecessor, as is suggested in Piagetian theory, but to coexist with it, thus enhancing considerably the modal repetoire of the mature adult as compared to that of a young child (Collis, 1991).

The five modes of the SOLO model have the following distinctive features:

- **Sensorimotor** (from birth). This mode is associated with the performance of skilled motor activities such as grasping, crawling, walking, running in the early years, and sailing a boat, playing golf in later years. This mode relates to tacit knowledge. Individuals can carry out skilled acts even though they may not be able to tell others how they do them.
- **Ikonic** (from around 18 months). This mode is associated with intuitive knowledge, that which is perceived or felt directly and which involves the imaging of objects or events. It begins after the first year of life and is a prerequisite for the development of oral language. One of its earliest manifestations is the 'mythic' stage where children explain reality in terms of stories. The mature version of this mode is evident in literature, drama

and the performing arts. It is also employed in mathematical or scientific problem solving where the solution is first visualised and symbolic representation is used to communicate that solution to colleagues. This mode develops throughout life and should play an important role both in and outside school. This is the basic mode for intuitive thinking.

- **Concrete symbolic** (from around 6 years). This mode involves the use of symbol systems such as written language, mathematics, maps, and musical notation. These symbol systems have referents in the material world and facilitate the communication of declarative knowledge. Learning to master these symbol systems and apply them to the real world is the major task in primary and secondary schooling because this is the mode in which the cognitive aspects of everyday living are conducted.
- **Formal** (from around 14 years). This is the mode where theoretical constructs, not having an empirical referent, are able to be manipulated. The thinking process changes to one involving hypothesis formulation and propositional reasoning and the individual is able to consider not only what is 'real' but also what is 'possible'. This is the mode in which the theoretical knowledge necessary to have a workable grasp of an abstract academic discipline is gained. This is the commonly expected level for successful university entrance (Collis & Biggs, 1983).
- **Post formal** (from about 20 years). In this mode individuals must have an overview of their discipline such that they can challenge its basic tenets and conduct research to advance understanding in the area. This is typically the mode of functioning of research higher degree students (Collis & Biggs, 1983).

Associated with each mode, five basic levels of responses to a stimulus situation, in increasing order of complexity, can be distinguished (Biggs & Collis, 1989): **prestructural (P)** which represents no use of relevant aspects of the mode in question; **unistructural (U)** which represents the use of only one relevant aspect of the mode; **multistructural (M)** in which several disjoint aspects are processed, in sequence; **relational (R)** in which several aspects of the mode are related into an integrated whole; and **extended abstract (EA)** which makes use of higher order principles and may take the whole process into a new mode of functioning at the unistructural level.

As the focus shifts from unistructural to relational, the levels associated with the SOLO Taxonomy demonstrate the following properties:

- a growing complexity in understanding;
- an increased ability to consider more information;
- an increased ability to accept complexity;

- an increased ability to recognise and resolve conflict (the inability to recognise conflict is considered unistructural); and
- an increased ability to delay in responding and to forego closure.

Figure 2.2 (adapted from Biggs & Collis, 1989) shows the transition between modes of functioning. The middle three levels, unistructural, multistructural, and relational, fall within the mode in question or the target mode, the first, prestructural, and the last, extended abstract, fall outside it. Prestructural responses belong in the previous mode, indicating that learning is at a level of abstraction too low for the task in question. Extended abstract responses are at a level of abstraction that is extended into the next mode, and which becomes the first, or unistructural, level of that next mode.

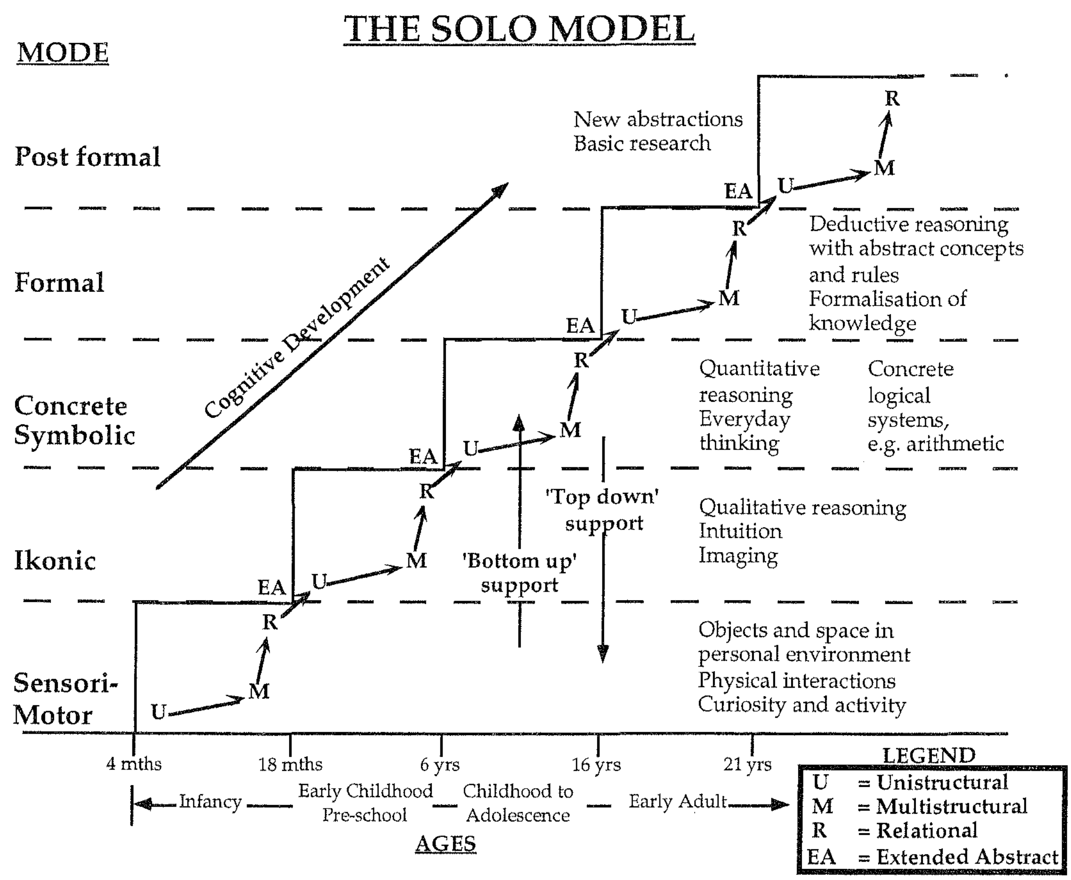


Figure 2.2: The SOLO model (adapted from Biggs & Collis, 1989).

The modes appear in the order shown in Figure 2.2 (from Sensorimotor to Post formal), but, as stated previously, the onset of the ability to function in a higher mode does not mean the disappearance of the previous modes, which will continue to develop. In fact, it is asserted that understandings developed in a previous mode will remain available and may assist (or interfere with) functioning in the higher mode. This is known as *multimodal functioning* (Biggs & Collis, 1991). Watson, Campbell, and Collis (1993) in their study of fractions noted a mutual interaction between Ikonic and Concrete Symbolic development with Ikonic processes appearing to provide support to Concrete Symbolic reasoning. This example of multimodal functioning is shown in Figure 2.2 as 'Bottom up' support. They argued that progress in the Concrete Symbolic mode, without development of complementary Ikonic support, limited both understanding and flexibility when problem solving. In contrast, multimodal interference with performance (new, partially understood Concrete Symbolic knowledge interfering with Ikonic knowledge) has been documented by Jones, Collis, Watson, Foster, and Fraser (1994) in relation to children's understanding of the production of images in mirrors.

Change brought about by cognitive development occurs when the highest mode that a learner can use with any task increases with age; change brought about by learning occurs when the students' responses become more complex within the mode appropriate to the task. The 'target mode' is that level of abstraction that is appropriate to a curriculum unit, and that at which the teacher can expect the student to engage the task (Biggs & Collis, 1989). Biggs and Collis maintain that by carefully defining the appropriate level of abstraction of the target mode, it becomes possible to specify desirable curriculum objectives and performance outcomes throughout school, college, and university according to the desired SOLO level within the appropriate mode. Biggs (1992) maintains that SOLO can be used to provide a profile of student achievement.

The five modes thus progressively open out increasingly abstract possibilities by means of which people may conduct their learning. Whatever the particular mode, a similar learning cycle recurs, from unistructural through multistructural to relational.

The application of the SOLO Taxonomy to a variety of domains has achieved increased interest in the research literature. As a result of the work of a number of researchers, empirical evidence in a variety of subject areas has been gathered that demonstrates more explicitly the modes and levels. Watson and Mulligan (1990) identified two cycles in the conceptual development involved in the solving of mathematical word problems by young children, the first in the Ikonic mode, the second in the Concrete Symbolic mode.

Recent studies have detected two learning cycles within a mode. Levins (1992), in her analysis of data relating to students' descriptions of the process of evaporation, identified two cycles in the Concrete Symbolic mode. She suggested that the early cycle is the one in which students acquire basic concepts. This part of cognitive development is thought to be necessary both in a formative and a supportive role for the growth in concepts that follow. The students then make the transition from the basic understandings that underpin the more demanding abstract ideas in the second cycle; that is, there is a shift from reality-based features in the first cycle to a discussion of processes in the second cycle. Similar findings were observed by Campbell, Watson, and Collis (1992) for calculation of measurement of volume, Levins and Pegg (1993) for plant growth, Levins and Pegg (1994a) for photosynthesis and the geometry of 2-dimensional figures, and Watson, Collis, and Campbell (1995) for decimals and fractions.

Collis and Davey (1986) used the SOLO Taxonomy as an assessment tool for testing a variety of items in secondary school science. The items covered the four areas of Geology, Biology, Chemistry and Physics. Each group of questions was devised so that they formed a hierarchy of difficulty levels and were formulated so that a correct response to a specific question showed an ability to respond at a particular SOLO level. The researchers commented that this study pointed to a need for further investigations in both the curriculum and teaching areas of school science. Further applications of the SOLO Taxonomy to student understanding have been carried out but it has not been extended to the area of curriculum design and classroom teaching.

Such results have important implications for the accurate interpretation of student performance and the planning and sequencing of concepts in instruction (Levins & Pegg, 1994b). The direction that a curriculum designed using a theoretical framework would give to the classroom teacher is most important. If these findings can be effectively translated into classroom strategies for teaching scientific concepts then this will improve not only the way scientific concepts are taught but also the opportunities for students to learn these concepts.

The previous sections discussed theories of learning, the constructivist view of learning and teaching, alternative conceptions, and the SOLO Taxonomy. These aspects of teaching pedagogy and cognitive development will be applied to investigations into the development of an understanding of the physics concepts of 'light' and 'sound'. The following section, therefore, reviews the literature dealing with students' conceptions of light and vision, with reference also to the work of Collis, Jones, Sprod, Watson, and Fraser (1998) in this area. This is followed by a discussion of students' conceptions of 'sound and hearing'.

2.6 Students' conceptions of light and vision

The findings of a number of researchers indicate that students hold a variety of views with respect to light and its role in vision (Stead & Osborne, 1980; Guesne, 1985; Osborne & Freyberg, 1985). Some of the earliest research findings reported that young children made no connection between the eye and the object whereas at a later stage they commonly thought of vision as 'a passage from the eye to the object' (Piaget, 1974).

Guesne (1985) indicated that a number of common views of what light is prevailed amongst students. Some students equated light with its source (as in 'light is in the light bulb'); others equated light with its effect (as in 'light is brightness'). Students holding these conceptions did not regard light as a distinct entity and this made it impossible to interpret a range of light-related phenomena. Considering the case of the transmission of light, Guesne argued that because young students did not see light as an entity, the movement of light was foreign to them and they responded to questions about the transmission of light either by talking about the movement of the source or the effect as in 'it lights up the object'.

Stead and Osborne (1980) reported that some students did not believe that light travelled at all, whereas others saw the distance that light could travel as depending upon factors such as the intensity of the light or whether it was night or day. In addition, Ramadas and Driver (1989) reported that many students did not recognise the necessity of light for seeing and thought that it was possible to see when it was dark. They did not appreciate that light must be present in order for them to see objects, even faintly.

In terms of light and its role in seeing, Eaton, Anderson, and Smith (1983) and Guesne (1985) indicated that students' beliefs could be grouped into four broad notions, illustrated in Figure 2.3 by drawings based on Guesne (1985).

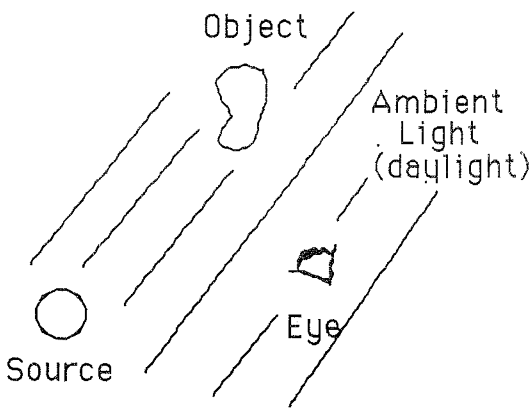
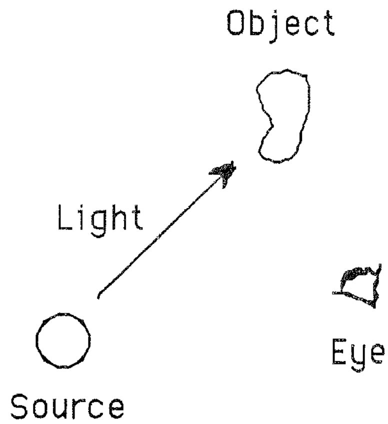
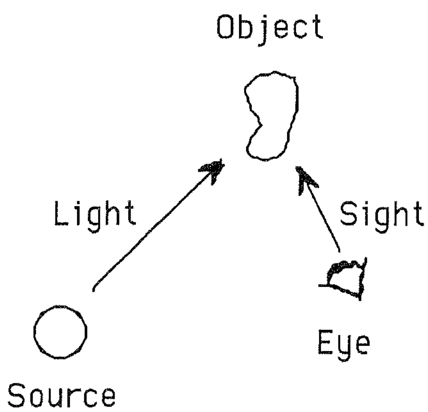
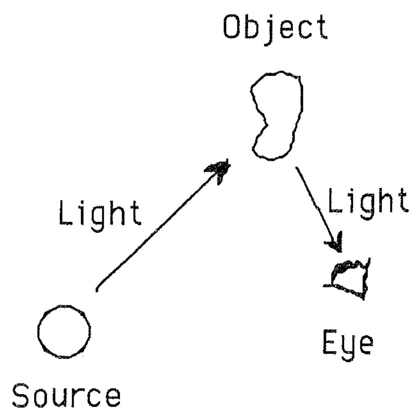
(i) Students believe that they can see objects because there is ambient light; there is no connection between eye, light, and object. 	(ii) Students believe that there is a source of light lighting up the object and making it visible; there is no link between eye and object. 
(iii) Students believe sight is a movement from eye to object that is lit by a light source. 	(iv) Students hold 'the scientific notion' of light reflected off the object into the eye (this notion is reported by Guesne (1985) as being rare in children younger than 14 years). 

Figure 2.3 Student notions of the role of light in seeing

(based on Guesne,1985)

A fifth alternative, referred to by later researchers Jones, Collis, Watson, Sprod, and Fraser (1995) and Jones, Collis, Sprod, and Watson (1996), is shown in Figure 2.4. The five notions shown in Figures 2.3 and 2.4 are referred to throughout Chapter 3 as 'Seeing Conceptions'.

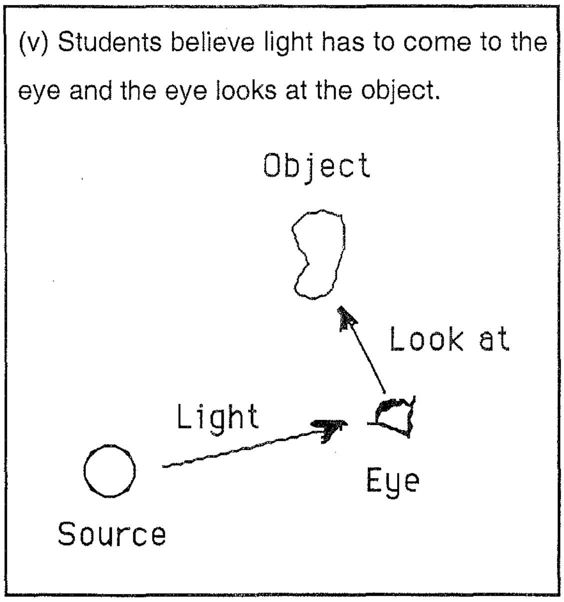


Figure 2.4 A further student notion of the role of light in seeing

According to Osborne and Freyberg (1985), there is a clear indication that what is taught does not always correspond well with what students learn or know. The study of light as a science topic often includes the investigation of its rectilinear nature and, for instance, its relationship to concave mirrors, focal lengths, and focal points. Some of the students' basic ideas about light, how far light travels, and how they actually see objects, may not even be mentioned by the teacher, let alone discussed.

Understanding the nature of light as an entity and the role of reflected light in seeing is of prime importance. A scientific understanding of a number of optical phenomena depends on such concepts. The description of how the eyes see depends upon the understanding that light is reflected off objects to the eyes, rather than that the actual objects themselves are seen.

Eaton et al. (1983) maintain that it takes more than the simple statement of the scientific conception to alter students' 'misconceptions' (Eaton's preferred term). The scientific conception must be carefully explained and contrasted with common misconceptions. Students must understand the differences and be convinced that the scientific conception is better than their misconception - otherwise they will not change their conception.

Teaching largely takes it for granted that the students can immediately understand that light is something that exists and propagates in space. It is probable too that the teacher does not make specific reference to this basic understanding, it being so much a part of the teacher's concept of the world that he/she neither thinks of how fundamental it is nor that it can be a problem for the student (Andersson & Karrqvist, 1983).

According to Andersson and Karrqvist (1983), a good understanding of optical phenomena, such as light, shadow, and colour, must include at least two essential components:

(i) a clear idea that light is something physical that propagates in space; it is invisible and colourless; and

(ii) an understanding that when physical light interacts with the retina the process that leads to the perception of light and colour is initiated.

Although many researchers have investigated students' notions concerning light, few have produced learning materials for use by teachers in improving the understanding of their students with respect to light and the mechanism by which they see. In addition, reported research has rarely evaluated the effectiveness of the teaching sequence in terms of conceptual change. Researchers who have undertaken work in this area are Eaton, Sheldon, and Anderson (1986), Fetherstonhaugh (1990), Fetherstonhaugh and Treagust (1992), and Hubber (1995).

Eaton et al. (1986) investigated the major conceptual problems associated with light and vision. A diagnostic test that could be used as a pre-test, post-test, or both, was designed to reveal important student misconceptions with notes for the teacher to interpret student responses. A set of student handouts and masters for overhead transparencies were included. The instructional strategy was based on the model of conceptual change of Posner et al. (1982) mentioned in Section 2.4 . The principal contribution of Eaton et al. (1986) was in the provision of instructional materials designed to promote conceptual change.

Fetherstonhaugh (1990) designed a series of teaching modules also using the model of Posner et al. (1982). Students' prior conceptions about light were identified using a pre-test. An intervention was designed to teach the topic of light and its properties by initially considering the students' current state of knowledge. The students were involved in activities to enable reflection on their ideas, to allow them to experience dissatisfaction with existing ideas, and to encourage conceptual change. A post-test was then used to determine if the teaching method had resulted in a lower level of misconceptions.

The teaching method of Fetherstonhaugh appears to have been successful and its outcomes were similar to those of the conceptual change teaching described by Eaton, Anderson, and Smith (1983). Research by White and Gunstone (1989) suggested that students' ideas tended to revert to their prior ideas after a period of time. However, Fetherstonhaugh and Treagust (1992) found from a delayed post-test held three years after the intervention that the majority of students did not revert to their prior conceptions, and that the teaching method had a lasting effect.

Hubber (1995) undertook a similar study into students' conceptions of light and its properties. He too used the conceptual change model of Posner et al. (1982) and developed a curriculum model that comprised five phases - orientation, elicitation, restructuring, application, and review - based upon the constructivist teaching sequence of Driver and Oldham (1986).

Each of these researchers addressed students' understanding of a number of concepts associated with light including the nature of light and how light enables an object to be seen. Although some researchers designed teaching materials to improve students' understanding of 'light', and others measured the improvement in student understanding following instruction, none of these related their findings to a hierarchy of cognitive development.

It is important here to mention the work of Collis et al. (1998) as this work deals with students' conceptions of 'light and vision', and plays a vital role in this study. Collis et al. postulated a theoretical model for the development of an understanding of vision, based on the SOLO Taxonomy discussed in Section 2.5. A detailed discussion of this model is included in Chapter 3 where it is applied to the preliminary investigation of 'light and seeing' that formed part of the present research.

The principal focus of the present research is an investigation of 'sound and hearing', and a linking of curriculum design to the cognitive development of an understanding of these concepts. The following section, therefore, reviews the work of other researchers in the area of 'sound and hearing'.

2.7 Students' conceptions of sound and hearing

The topic 'Waves and Optics', which is composed of 'light and seeing' and 'sound and hearing', is often taught to students in the middle years of secondary schooling, around the ages of 13 to 15 years. The concepts of 'light' and 'vision', discussed in Section 2.6, have been the subject of research over a number of years but comparatively little has been done in the area of 'sound and hearing'. This is despite the fact that there are conceptual similarities between light and sound, notably in their mode of propagation.

Among the few researchers working in this area, Boyes and Stanisstreet (1991) investigated the progression of children's thinking about light and sound between the ages of 11 and 16 years. Their study explored the links between the children's understanding of the path of light that enables seeing and the path of sound to enable hearing. Boyes and Stanisstreet observed that, in contrast to their thinking about light, students clearly appreciated more readily the path of sound from a source. They found that, in the youngest age group (11 years), nearly half gave the expected response to a question about the path of sound, a single arrow from the source to the listener, and this increased to nearly 80% in the oldest age group (16 years). No major difficulty concerning the path of sound was observed. However Boyes and Stanisstreet did make the comment that this ease of conceptualisation may have been due to the fact that a cassette radio, the source of sound used in their research, was a part of everyday life for these age groups. They also suggested that students are well aware that they can act as sources of sound that passes from them to the listener, as in normal conversation. In this work the researchers also observed that one student expressed the view that sound travelled from the ear to the object (the source of sound).

From their work with younger pupils, Watt and Russell (1990) maintained that the 'active listening' idea, in which younger children assert that they hear because they are listening, found in approximately 18% of 11-year-olds, was difficult to challenge. These researchers stated that the psychological model of 'active listening' showed an awareness of the effect that concentration and attention play in hearing. They also observed that 'active listening' tended to be given as an explanation for a specific activity or game, such as the 'string telephone' (described in Appendix 1) rather than for listening to everyday sounds. In contrast, Boyes and Stanisstreet (1991), in their study conducted with students ranging from 11 to 16 years old, found the 'active listening' idea was weakly held and quickly discarded.

Linder and Erickson (1989), in their study of tertiary physics students, identified four different ways of conceptualising sound expressed by the students:

- sound is an entity that is carried by individual molecules through a medium (p. 494);
- sound is an entity that is transferred from one molecule to another through a medium (p. 494);
- sound is a travelling bounded substance with impetus, usually in the form of flowing air (p. 496);
- sound is a bounded substance in the form of some travelling pattern (p. 496).

The authors suggested that perhaps the above conceptualizations of sound were all "manifestations of a primitive conceptualization of a travelling medium, that is, conceptualising sound in terms of motion could be viewed as reflecting elements of a natural (before instruction) sense-making of sound phenomena" (p. 499).

Linder (1992a, 1992b) maintained that in advanced secondary and introductory tertiary physics, the topic 'sound' was often treated as a straightforward example of wave physics. His study, undertaken with university students, indicated that sound is a difficult topic. Many of the aspects he discussed, such as the difficulties in representing accurately the difference between a longitudinal and a transverse wave, are beyond the level of understanding expected of 14-year old students. However, Linder's statement that it is not unusual to find students who express a conflict between the way they conceptualise a concept and their 'knowledge' of the concept is thought by this researcher to be applicable to all ages and levels of understanding. Linder gave the example of a student who had the following conflicting ideas: that molecules in air remain stationary and that they are in constant chaotic motion. The student stated that he believed that the air particles move from the sound towards the listener and yet when he explained sound it was as particles remaining stationary and causing a reaction that moves everything towards the listener.

In a later publication, Linder (1993) discussed university physics students' conceptualizations of the factors affecting the speed of sound. Even though these students had completed a physics major in their baccalaureate degree, they still had conceptual difficulties with the topic and these difficulties were not easily exposed in the typical problem-solving-based course evaluation. Linder reiterated that these difficulties arose because sound was one of those introductory physics topics that was glossed over, either because it appeared simple, or because it was assumed that it had been studied at school.

Linder (1993) identified three qualitatively different ways of conceptualizing the factors affecting the speed of sound propagation. The first of these maintained that the molecules of the medium presented an obstruction to sound propagating through the medium. The larger the molecules and the greater the density of molecules, the greater the obstacle they presented to sound travelling through the medium. Although these ideas may be logically linked to intuitive thinking, they are not associated with a scientific understanding of the factors affecting the transmission of sound. The density factor notion led one student to conclude that sound would travel fastest in a vacuum where it would meet the least resistance from the molecules. Maurines (1993) observed this same idea amongst upper secondary students comparing the propagation of sounds, emitted by similar sources, in different media (vacuum, steel, water, air).

The second conceptualization of the speed of sound identified by Linder (1993) held that it was a function of the molecular separation in the medium, that is, the distance a molecule had to travel before being able to interact with a neighbour. This notion too reflected the role of the density of the medium. Both the first and second conceptualizations appear to have been built on sound being conceptualized as an entity in itself.

The third conceptualization stated that the speed of sound was a function of the compressibility of the medium (the more compressible the medium, the faster the propagation). The non-physics term compressibility was used by the students as synonymous with the physics concept of elasticity.

Linder (1993) stated that a common theme could be identified in the students' different conceptualizations of the speed of sound. It would appear that these ideas resulted from students being taught that density, pressure and temperature affect the speed of sound without any explanation of how they do this. Linder's experience was that university physics educators do not take the alternative conceptions research seriously and that many introductory physics textbooks simply give formulae for the speed of sound. Students then make sense of what they are taught in terms of prior understandings that have never been challenged or even considered. The examples the author cited illustrate the kind of sense making that students can make of taught physics by building on preconceived understandings that result in seemingly correct, or partially correct, answers conceptualized in incorrect ways. Linder concluded by saying that the typical method of chalk and talk teaching followed by homework problem solving must be changed as it leaves the majority of students with little true understanding of physics. It is interesting to note that the existence of children's alternative frameworks or conceptions, the impact they have on teaching, and the need to change teaching methods was acknowledged many years earlier in research undertaken with school students in other areas of science (see Section 2.4).

In his investigations of 'sound', Maurines (1986, 1992) focused on concepts that are taught to upper secondary school science students and, therefore, much of his research, such as that on students' conceptions of the propagation of a transverse signal on a string, is not relevant to Year 9 students. However, his investigation of the propagation of sound is relevant (Maurines, 1993). Maurines found that the importance of the medium for the transmission of sound and the relationship between the medium and the sound signal was unclear for many students. Students were also unaware that the speed of sound is a constant that is characteristic of the particular medium. He observed that 40% of students believed that the louder the sound, the greater its velocity. He also found that few students (13%) gave the lack of air as the reason why a disaster happening on the moon could not be heard by an astronaut in orbit around the moon. Of those students who said that the disaster could be heard, the majority said that it was because the astronaut was close enough to the moon. These same students said that the noise would not be heard on the earth because it was too far away.

The findings of the researchers discussed in this section were taken into consideration when planning the curriculum unit to be implemented in the present research, and, in some instances, were included in the questionnaire to determine student understanding. Specific details of these are discussed in the relevant sections. The following section considers briefly aspects of teaching pedagogy not discussed elsewhere in this chapter.

2.8 Other aspects of teaching pedagogy relevant to the present research

The nature of the research investigation and some aspects of the teaching pedagogy to be employed will be discussed briefly in this section. Aspects of pedagogy include the use of 'questioning' as a fundamental component of the Teaching Unit, and the incorporation of analogies into the teaching.

The present research investigation is an action research project. Kemmis and McTaggart (1982) maintain that the linking of the terms 'action' and 'research' highlights the essential feature of the method, that is, trying out ideas in practice as a means of improvement, and as a means of increasing knowledge. Action researchers are intent on describing, interpreting, and explaining events while they seek to change them for the better (McNiff, Lomax, & Whitehead, 1996)

According to McNiff et al. (1996), action research shares the following characteristics with other research: "it leads to knowledge; it provides evidence to support the knowledge; it makes explicit the process of enquiry through which knowledge emerges; and it links new knowledge to existing knowledge" (p. 14). However, it differs from other research in that "it requires action as an integral part of the research process itself; it is focussed by the researcher's own professional values rather than methodological considerations; and it is necessarily insider research in the sense of practitioners researching their own professional actions" (p. 14).

While action research has great strengths, there is some concern that it may not bring about a real change in the classroom, that is, teachers may not change their pedagogy despite claiming to do so. The literature shows that little has been done to investigate whether teachers have changed their classroom pedagogy as a result of involvement in action research. Despite this concern, the many strengths of action research are considered by this researcher to outweigh any disadvantages.

This project is based upon a constructivist view of learning (see Section 2.3.1). Curriculum units are designed to promote science learning. The definition of curriculum appropriate to this research is that of Driver and Oldham (1986) in which curriculum is defined as "a set of learning experiences which enable learners to develop understanding towards a scientific view" (p. 112). Effective curriculum development is seen by Lijnse (1995) and by Driver and Scott (1996) as essentially a research activity. Driver and Scott regard designing teaching schemes to support science learning as inherently problematic in that it requires some appreciation of the prior knowledge of students. In addition, the teacher must recognise that individual learners make sense of learning experiences in a personal way.

In the curriculum units that are part of this research, 'questioning' is an important component of the constructivist teaching sequence. According to Chuska (1995), questions are fundamental to teaching because they provide information; they help students to link prior knowledge to subsequent learning; and they enable students to apply knowledge in various situations. Chuska believes that skilful questioning can lead students to engage in higher level thinking.

Wilson and Jan (1994) maintain that questioning helps to extend thinking skills, to clarify understanding, to gain feedback on teaching/learning, to create links between ideas, and to provide challenges. Among other things, a good question will 'spark' further questions and will stimulate interest in seeking answers.

Teachers must determine the aim of the questions and must design a questioning strategy such that a carefully planned sequence of questions leads to the achievement of the instructional objectives (Chuska, 1995). In addition, teachers must not reply too quickly to a student's answer (Tobin, 1987). The ideal 'wait time' (Rowe, 1973) is at least three seconds, although Rowe observed that the average was less than one second. This delay in replyng allows time for students to consider their answers which, in turn, leads to more informative responses. It also allows time for other, perhaps 'slower', students to contribute.

The ideal situation is to ask fewer questions but more 'open' ones, that is questions that have more than one answer and that will stimulate thinking (Goodrum, 1985). Such questions have the potential to promote discussion and student interaction. They elicit observations, inferences, and hypotheses, and allow students to make judgements.

It is planned also to incorporate analogies into the Teaching Unit where it is felt these will aid in the development of understanding. According to Treagust (1995), analogies are a very effective resource to clarify students' understanding of scientific concepts. When a listener hears an analogy, a mental image is evoked that enables the student to link the knowledge to an already familiar concept. Analogies are believed to enhance students' understanding by providing visualisation of the concept, by helping compare the students' real world with new concepts, and by increasing students' motivation (Duit 1991). According to Duit, the consensus amongst most investigators is that analogies enhance students' learning through a constructivist pathway whereby learners attempt to integrate new ideas into their prior knowledge. However, on a cautionary note, Treagust (1995) points out that analogies are effective "provided that like and unlike characteristics of the analogy and the target concept are understood" (p. 44).

2.9 Conclusion

From the preceding survey of the literature it can be seen that many researchers agree that students come to science classes with a variety of 'alternative conceptions' and that these are often strongly held, resistant to change, and can hinder further learning (White &

Gunstone, 1989). Whereas much of the research has concentrated on identifying these alternative conceptions in a range of topics, little has been done to apply these findings to the design of teaching modules that will promote scientific understanding. Nor have attempts been made to link the investigation of the cognitive development of the student to the design and implementation of appropriate teaching modules.

With the work of previous researchers and the SOLO theory of cognitive development in mind, this research set out to address, in part, the limitations of previous studies with respect to the design of teaching modules closely linked with the cognitive development of students. The way in which students develop an understanding of two physics topics commonly included in a high school curriculum was investigated. The results of this research were applied to the design of constructivist Teaching Units that would establish the nature of alternative conceptions of these physics concepts, where possible eliminate the alternative conceptions, and promote longlasting scientific understanding. The first stage of the research was a preliminary investigation into student understanding of 'light and seeing' (Chapter 3). This pilot study provided valuable experience in analysing students' responses to a questionnaire in terms of a cognitive framework, and in assigning appropriate levels of cognitive functioning to the responses, as well as in designing a curriculum unit closely aligned with the theoretical model for the development of an understanding of the concepts involved. This then set the scene for the major focus of the present research, namely, an investigation into 'sound and hearing'. This investigation postulated a theoretical cognitive model for the development of an understanding of 'sound and hearing'. A constructivist Teaching Unit on 'sound and hearing' that closely followed the pathway proposed in the theoretical model was designed and implemented. Changes in the levels of understanding of the students were monitored by determining the cognitive levels at which they were functioning, over the course of the investigation. Details of the methods used, including the formulation of the theoretical model and the procedure for determining students' observed levels of cognitive functioning, are contained in Chapter 4. The outcomes observed with the target groups of students are discussed in Chapter 5.

Chapter 3

Light and seeing: a preliminary investigation

3.1 Introduction

Prior to addressing the main area of research, a preliminary investigation of students' understanding of 'light and seeing' was undertaken. This was a logical area in which to commence the present research for two reasons. Firstly, there are a number of conceptual similarities that underpin the accepted scientific explanations of 'light' and 'sound' and for this reason the topics are often taught together under the general heading of 'Waves and Optics'. In addition, research was being undertaken at that time by Collis and his co-researchers into students' understanding of vision, which was subsequently published in Collis, Jones, Sprod, Watson, and Fraser (1998). Collis et al. had developed a theoretical model for the cognitive development of an understanding of vision as well as a questionnaire to determine students' understanding and these were available for use in the present research.

In this preliminary study undertaken with Year 9 students, a conventional teaching module on 'light and vision' was restructured using a similar format to that of earlier researchers (see Section 2.6). Knowledge of students' prior conceptions of how people see (see Section 2.6) and patterns of cognitive development observed in a study of school students from Kindergarten to Year 10 by Collis et al. (1998) were used also to inform the design of the Teaching Unit. Changes to student understanding of 'light and seeing' resulting from the implementation of the Teaching Unit were monitored in terms of the theoretical model of Collis et al.

This chapter discusses in detail the preliminary investigation into 'light and seeing'. Section 3.2 outlines the two major components of the investigation, namely the psychological and the practical components, and the four phases involved in the practical component. Section 3.3 discusses the psychological component of the investigation including the questionnaire used to determine students' understanding, the theoretical cognitive model for the development of an understanding of 'light and seeing', and the procedure used to analyse students' responses to the questionnaire and to determine their levels of cognitive functioning. Section 3.4 details the Teaching Unit used in the practical component of this investigation. Section 3.5 discusses the analysis of the responses of the students and the outcomes observed at each phase of the investigation. Finally, Section 3.6 contains a brief conclusion to this preliminary investigation.

3.2 Methodology for the investigation of 'light and seeing'

The investigation had two major components. The first of these was psychological and involved the use of the theoretical cognitive model of Collis et al. (1998) as well as the questionnaire designed by these same researchers to determine student understanding. Responses to the questionnaire were analysed to determine the level of cognitive functioning of students with respect to 'light and seeing'.

The second component of the investigation was practical and consisted of the design and implementation of a Teaching Unit on 'light and seeing' to facilitate the development of an understanding of the topic, together with the monitoring of the level of student understanding over the course of this preliminary investigation. Research had not previously been undertaken to design and implement a curriculum unit in close alliance with a theoretical model for cognitive development, although this had been suggested by Collis and his co-researchers as an extension to their work.

The practical component of the investigation consisted of four phases:

Phase 1: a pre-instruction phase to elicit students' understanding of light and how light reaches the eyes but not including the physiology of eye functioning;

Phase 2: an intervention or instruction phase using the teaching module developed;

Phase 3: an immediate post-instruction phase to determine whether the teaching module had been effective, that is whether the students had a clearer understanding of the concepts taught, and, if conceptual change had taken place, to what extent; and

Phase 4: a delayed post-instruction phase (six months later) to determine how resistant the conceptual change was and whether or not students had reverted to their pre-instruction notions.

Students of mixed ability, aged 14–15 years, from an independent girls' school were used in the investigation, which was carried out with two different Year 9 groups over two consecutive years. In the first year, the unit was taught by the researcher; in the second year, it was taught by a student teacher with the researcher observing. The researcher provided the student teacher with the Teaching Unit to be used, which included notes for her assistance. The two year groups were designated as the Year 9/95 Group and the Year 9/96 Group, respectively, and consisted of twenty-six students in the first group and ten in the second. The students in the Year 9/96 Group were slightly different from those in the previous group as all in the Year 9/96 Group had elected to study additional science, whereas the Year 9/95 Group was composed of students for whom science was compulsory.

3.3 Eliciting student understanding

In the psychological component of the investigation, the questionnaire to determine student understanding of 'light and seeing' and the theoretical cognitive model for the development of an understanding of 'light and seeing' of Collis et al. were together used to determine the level of cognitive functioning of students prior to (pre-instruction) and following the implementation of the Teaching Unit (immediate and delayed post-instruction).

3.3.1 The questionnaire used to determine student understanding

A written questionnaire, developed by Collis et al. (1998), was used to ascertain the understanding of Year 9 students with respect to the mechanism by which they see and the role of light in seeing. Details of the questionnaire are shown in Figures 3.1 and 3.2. Question 1, reproduced in Figure 3.1, was similar to an item used by Adams, Doig, and Rosier (1990) but the mention of light was deleted in order to limit the cuing of responses. Space was provided below the drawing for written responses in which the students could demonstrate their knowledge of 'seeing' in an open-ended context.

<u>**Question One**</u> Explain how is it that we can see a tree or any other object.

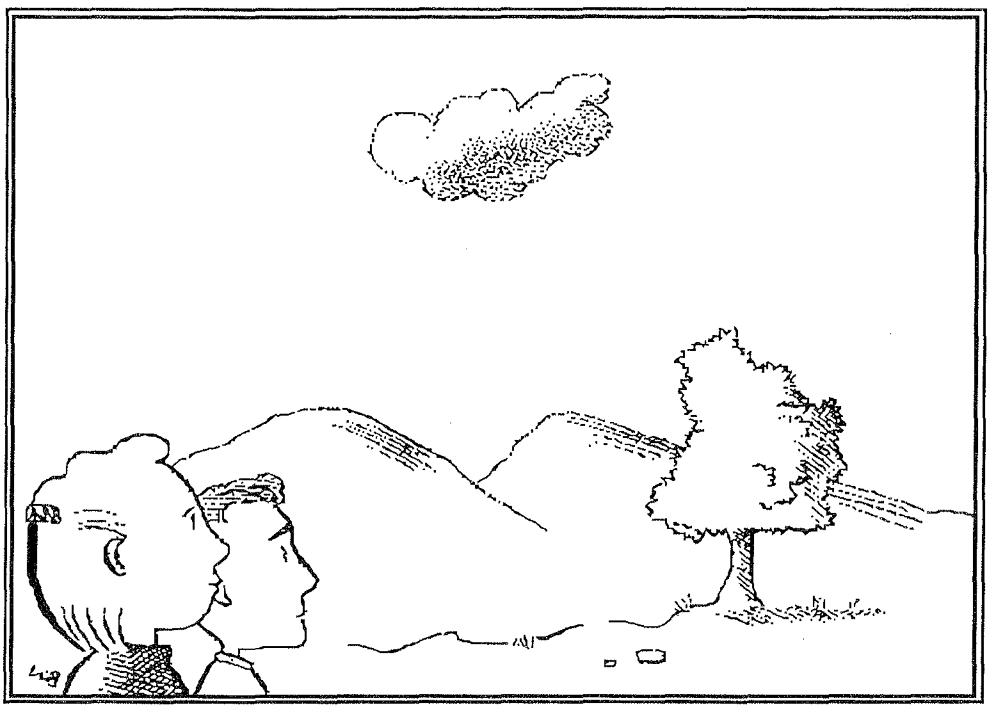
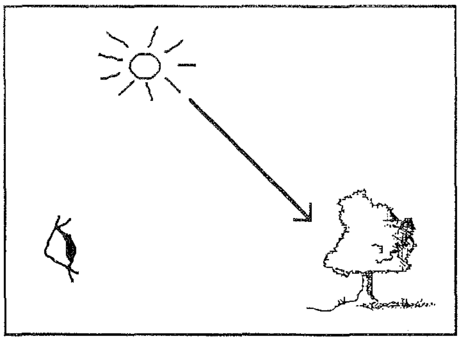


Figure 3.1: Question one of the questionnaire on 'light'
(Collis et al., 1998, p.49)

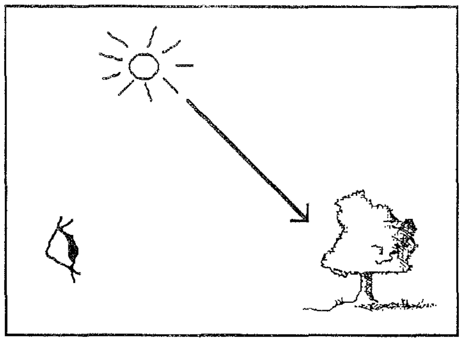
Question Two, shown in Figure 3.2, depicts the five Seeing Conception options referred to in Section 2.6, with a written statement below each one. Students were asked to select and explain the drawing that they thought best represented how an eye would see a tree. Space was provided below each of the drawings for students to say why they had selected a particular Seeing Conception and what was wrong with the other Seeing Conceptions.

Question Two

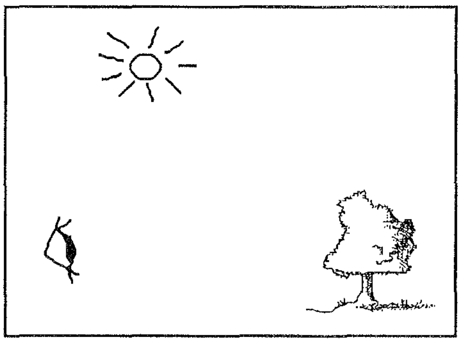
1. (a) **Circle the *one* drawing** that best describes how you believe an eye sees a tree.
   (b) In the space provided, explain why you believe this is how you see the tree.
2. For the other drawings, explain what you think is wrong with the drawing.



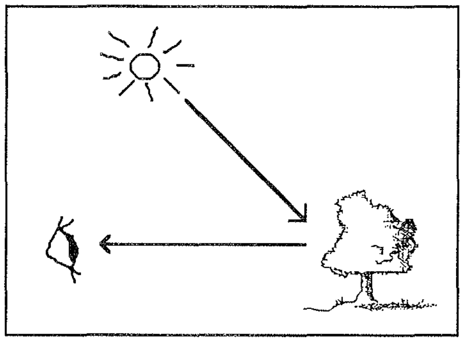
1. Light goes to the tree and we look at the tree.



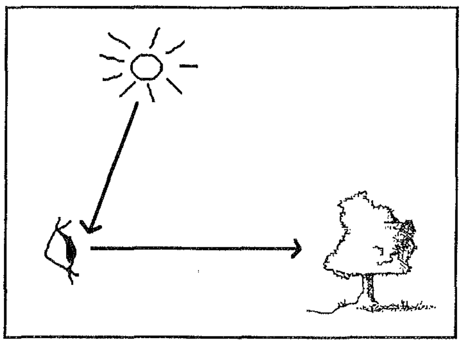
2. Light shines on the tree and we can see it.



3. Light is everywhere in a well lit area and we can see the tree.



4. Light goes to the tree and bounces to our eye.



5. Light comes to the eye and we look at the tree.

Figure 3.2: Question two of the questionnaire on 'light'
(Collis et al., 1998, p.49)

3.3.2 The development map for the standard seeing framework

Collis et al. (1998) described a development map of elements of an understanding of vision. The SOLO Taxonomy of cognitive functioning, described in Section 2.5, was used as the theoretical basis of this developmental model. This is the Development Map for the Standard Seeing Framework, abbreviated hereafter as the Development Map for Seeing, shown in Figure 3.3, and, according to Collis et al., is the pathway most commonly followed in the construction of the standard Concrete Symbolic concept of sight.

The Development Map for Seeing is composed of a sequence of nine major aspects or paired elements, in groups of three, which are related to a scientific explanation of vision but not including the physiology of eye functioning. The construction of the framework of understanding involves building paired connections between the fundamental components, 'light', 'eye', and 'object'. The first three pairs (designated L/E.1, L/O.1, and E/O.1) are elements of perceptual knowledge; the remainder are elements of conceptual knowledge that involve abstractions of concrete referents. The framework proposes a sequential development of paired elements by individuals. The elements of the Development Map for Seeing and the paired combinations are given below. The numbers 1, 2, and 3 represent the increasing level of understanding and the proposed sequential acquisition of paired elements.

L=Light; E=Eye; O=Object

L/E - Light / Eye	L/E.1	Light is necessary for sight
	L/E.2	Eye needs light to see
	L/E.3	Eye needs light entering to see
L/O - Light / Object		
	L/O.1	Light illuminates objects
	L/O.2	Light travels to illuminate objects
	L/O.3	Light reflects off objects
E/O - Eye / Object		
	E/O.1	Look at the object
	E/O.2	Eye / Object involves light
	E/O.3	Light travels object to eye

According to Collis et al. (1998), alternative conceptions of seeing are the result of the combination of incompletely constructed sets of connections or the holding of an incorrectly built connection. In addition, each paired connection may be developed independently of the other two. Collis et al. suggest that if one of the connections becomes "particularly salient" (p. 61) to an individual then that individual may move directly from the Multistructural level in the Ikonic mode (M_{IK}) to the same level in the Concrete Symbolic mode (M_{CS1}) without first integrating the elements to give a Relational response in the Ikonic mode (R_{IK}) (see Figure 3.3).

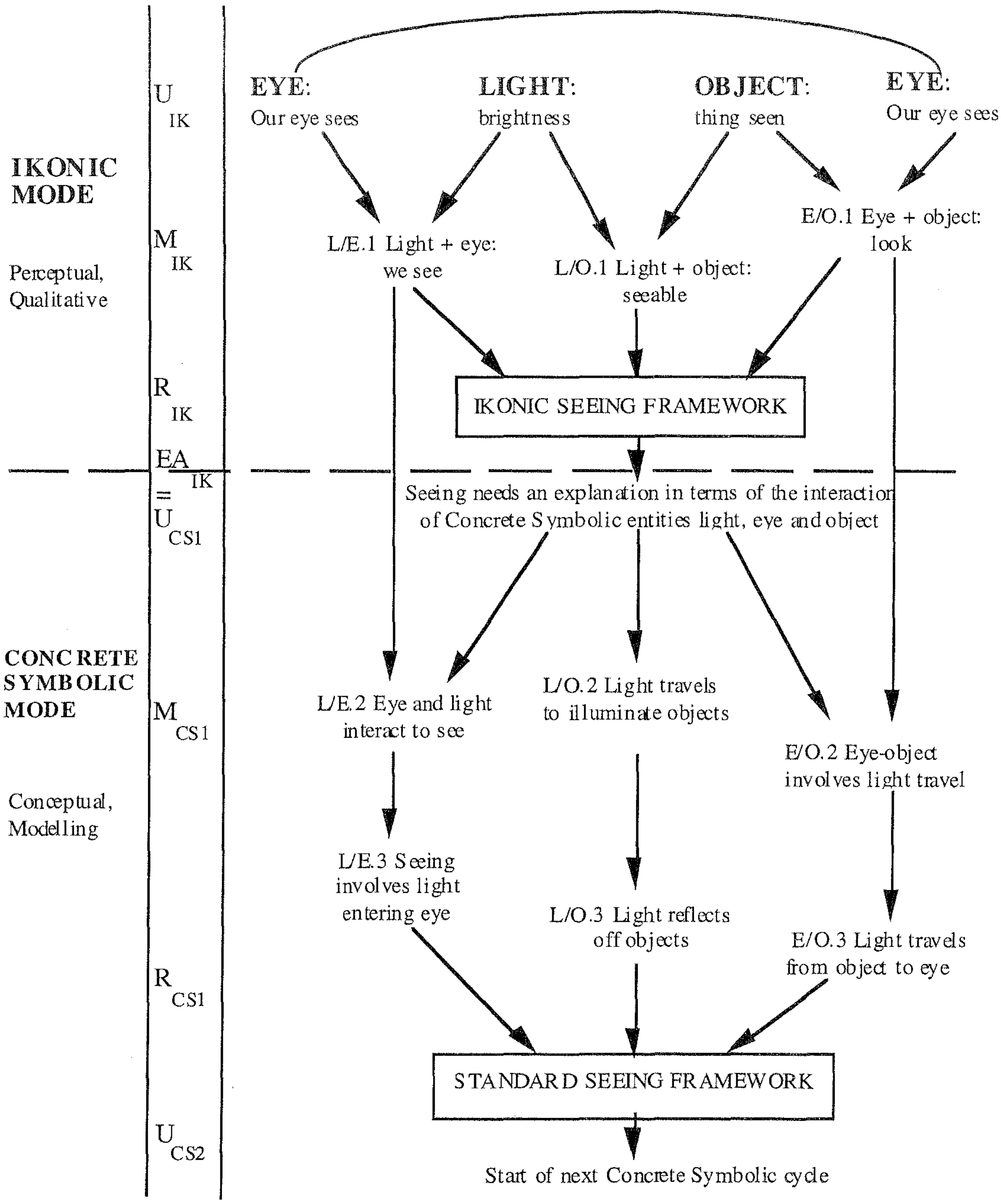


Figure 3.3: Development map for the standard seeing framework
(Collis et al., 1998, p.59)

The Development Map was used to evaluate students' understanding and to interpret their responses to Question One of the questionnaire, and their selection of a 'Seeing Conception' in Question Two, as well as their comments on the other conceptions. Responses to the questionnaire administered to the students were analysed in terms of the number of each type of paired combination present. This in turn was related to the level of cognitive functioning of the student as defined by the Development Map for Seeing.

3.3.3 Assigning the level of cognitive functioning from the responses to question one of the questionnaire

According to Collis et al. (1998), students whose responses to Question One contain the first three pairs of elements are considered to be operating in the Ikonic (IK) mode of the SOLO Taxonomy. When constructing understanding about physical phenomena, individuals operating in the Ikonic mode base their judgements on qualitative perceptual criteria. The Unistructural level in this mode, shown in the Development Map for Seeing as U_{IK}, is represented by an awareness of 'eyes', 'light', or 'object'. Students responding at this level are aware that 'the eye sees'.

At the Multistructural level (M_{IK}) within this mode students link these fundamental elements together in pairs and show a slightly more developed understanding. For example, L/E.1, the linking together of 'light' and 'eye', demonstrates an intuitive understanding that 'we see'; L/O.1, linking 'light' and 'object', means the object is 'seeable'; and E/O.1, linking 'eye' and 'object', is associated with an understanding of the notion of 'looking'. There is no integration or interaction here - "simply the need for one and the other to be available" (Collis et al., 1998, p.58). The next step in this hierarchy occurs as the student begins to construct a Relational framework (R_{IK}) which pulls the individual perceptions together. At this level the student is aware that 'to see something' means 'our eyes are looking at it when it is seeable'.

As the student develops a more sophisticated understanding of 'light and seeing', he/she makes the transition into the Concrete Symbolic mode where seeing needs an explanation in terms of the interaction of Concrete Symbolic entities 'light', 'eye', and 'object' (Collis et al., 1998). The first entity, according to Collis et al., is often 'light' with the other two following as the Concrete Symbolic understanding develops. Light is no longer something that is 'there'. It is now considered as a 'thing', not a condition; light starts at the light source and travels to the object, and somewhere along the way the eye is involved.

At the Multistructural level in the Concrete Symbolic mode (M_{CS1}) the elements are again linked in pairs, for example, L/E.2 where the student understands that 'eye and light interact to see'; L/O.2 where 'light travels to illuminate objects'; and E/O.2 where the student demonstrates an understanding that 'eye-object involves light travel'. As understanding develops, each of the connections in M_{CS1} evolves: 'eye and light interact to see' (L/E.2) becomes 'seeing involves light entering the eye' (L/E.3); 'light travels to illuminate objects' (L/O.2) becomes 'light reflects off objects' (L/O.3); and 'eye-object involves light travel' (E/O.2) becomes 'light travels from object to eye' (E/O.3). However, if integration of the elements does not occur, the understanding remains Multistructural.

At the Relational level (R_{CS1}) the student demonstrates an understanding that light travels from the source to the object and then to the eye. The connections L/E.3, L/O.3, and E/O.3 have been constructed and integrated and the student has acquired what Collis et al. (1998) called the Standard Seeing Framework. Now the implications for the direction of travel of the light from the source to the object and then to the eye are understood.

The reference at the bottom of the Development Map of the start of the next Concrete Symbolic cycle and the use of numbers as in CS**1** and CS**2** acknowledges that a second cycle may occur in this mode, although Collis et al. (1998) did not continue their investigation to this stage. However a second cycle has been identified in other areas of science and mathematics by a number of researchers, for example, Levins (1992) and Levins and Pegg (1994b), and was discussed in Section 2.5. As it was not part of the present investigation, no further discussion is included here.

3.3.4 Assigning the level of cognitive functioning from the responses to question two of the questionnaire

Responses to Question One enabled the level of cognitive functioning of individual students to be determined by looking at which of the paired elements of the Development Map for Seeing were present in their responses. A further indicator of the student's mode of cognitive functioning lay in determining which of the Seeing Conceptions in Question Two (Figure 3.2) she selected. Conception 4 was the scientific notion 'light goes to the tree and bounces to our eye'. The other Seeing Conceptions were: Conception 1, 'light goes to the tree and we look at the tree', Conception 2, 'light shines on the tree and we can see it', Conception 3, 'light is everywhere in a well lit area and we can see the tree', and Conception 5, 'light comes to the eye and we look at the tree'.

Students who chose Conceptions 2 and 3 were designated by Collis et al. (1998) as the 'Seeing Happens' group and were characterised by a low number of paired connections of the Development Map for Seeing. According to Collis et al., this group appeared to accept seeing as a phenomenon needing no further explanation; the majority of these students were found to hold three or fewer connections of the Development Map and to be functioning in the Ikonic mode. Students who chose Conceptions 1 and 5 were designated by Collis et al. as the 'Active Looking' group because they appeared to believe that seeing depended upon a looking process in which 'light' or 'sight' travelled from the object to the eye. According to Collis et al., this notion of light travelling to the eye indicated that this group was more advanced along the path towards a scientific understanding of vision than the 'Seeing Happens' group. Collis et al. observed that the majority of students in the 'Active Looking' group held four or more paired connections of the Development Map for Seeing and were functioning in the Concrete Symbolic mode, although they observed some in this group who still continued to function in the Ikonic mode and held fewer connections. Collis et al. also observed that the majority of students selecting Conception 4, the 'scientific' conception, made eight or nine paired connections (the maximum is nine) of the Development Map.

The level of cognitive functioning of each student in the present research was determined using the questionnaire and relating the student's responses to the Development Map for Seeing. The Development Map was used to inform the design of the Teaching Unit to improve students' understanding of 'light and seeing'. Details of the Teaching Unit are given in Section 3.4.

3.4 The teaching unit

The aim of the Teaching Unit was to create a classroom environment in which students were more likely to understand the currently accepted scientific view of the topic as a result of interactions mediated through discussion with their peers and with the teacher. The teaching strategy involved practical activities and teacher- or student-stimulated discussion. One difference between this and conventional didactic practices was that this strategy took account of students' own ideas and encouraged them to debate their ideas with their peers and with the teacher. However, the major difference between the present research and that of other researchers was the linking of the teaching to a theory of cognitive development.

The Teaching Unit consisted of three main stages - orientation, elicitation and restructuring, and review - based on the constructivist teaching sequence of Driver and Oldham (1986), discussed in Section 2.3. Driver and Oldham used the word 'phase' but the researcher has used 'stage' to avoid confusion with her own use of the word 'phase' to describe the four phases of the present investigation. The time allowed for the unit was approximately four 50-minute lessons. The Teaching Unit trialled in this investigation constituted part only of the whole course of instruction that also included aspects of light other than those specifically dealing with its role in seeing, such as shadows and reflection. The Unit used in the present investigation, which also includes instructions for the teacher, is contained in Appendix 2.

During the implementation of the Teaching Unit, the students were encouraged to express their own ideas on 'light' and to make predictions as to what would happen under various circumstances. The elicitation and restructuring stage was designed around a series of questions that stimulated the students to ask questions of their own, which they then investigated. Their findings were reported to the class. Most of the investigations were carried out in groups of three or four students; reporting back and discussion took place with the whole class. The sequence of questions was designed to follow the pathway of cognitive development proposed in the Development Map for Seeing of Collis et al. (1998). Each question in turn linked together additional elements of the Development Map and represented progress along the pathway towards a scientific understanding of 'light and seeing'. This strategy was modelled on Vygotsky's idea of guidance and assisted discovery to *lead* development (refer to Section 2.2).

The same sequence of questions and activities was used for both the Year 9/95 and the Year 9/96 groups, however, the concept maps and the drawings included in the text have been taken from the Year 9/95 Group.

3.4.1 The orientation stage

The topic 'Light' was introduced by asking students to suggest as many words as possible that came to mind when they thought of 'light' and 'seeing'. All the words were written on a whiteboard. The words suggested included: light, eyes, sun, rays, colour, reflection, dark, image, object, vision, pupil. Working in groups of four, the students then arranged the words into a 'concept map' using sheets of paper provided. As none of the students was familiar with the concept map, this first had to be explained to them. The maps were left on display for review and modification if necessary at the conclusion of the topic. Samples of the students' concept maps are shown in Figures 3.4 and 3.5.

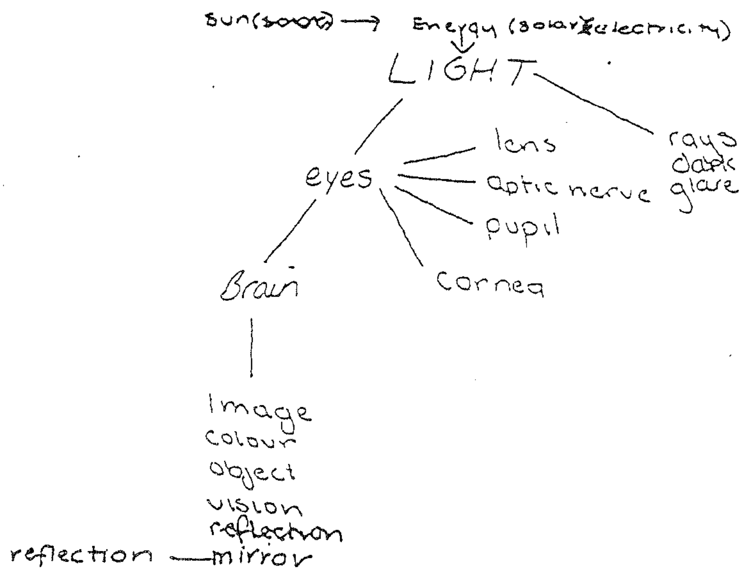


Figure 3.4: Year 9/95 group (i) concept map

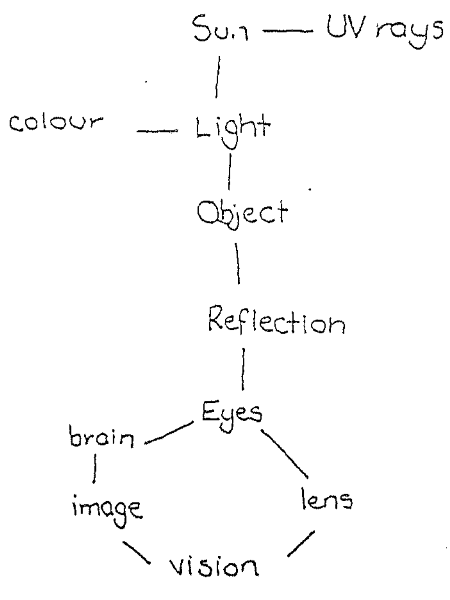


Figure 3.5: Year 9/95 group (ii) concept map

The words 'light', 'sun' (as a source of light), 'eyes', 'pupil' (part of eye), and 'object' are the unistructural elements of the Development Map for Seeing, shown in Figure 3.3. Other words such as 'reflection', 'image', and 'vision' may indicate a linking together of these unistructural elements and an understanding of 'how the eye sees'. Alternatively, they may simply be terms acquired by the student from external sources. The use of these words here has not given any indication of whether the students understand the processes of reflection, vision, and image formation. The word 'rays' implies that light travels but again the level of understanding cannot be determined. In Figure 3.4 (Group (i)), it can be seen that the only mention of 'reflection' by these students was in relation to reflection in a mirror. These students also indicated a direct link between 'light' and 'eyes' rather than 'light' to 'object' to 'eyes'. Figure 3.5 (Group (ii)) appeared to indicate that the students understood the sequence of operations involved in 'seeing' in that they linked together the elements 'light', 'object', 'reflection', and 'eyes', in the correct sequence. Little real inference as to the level of cognitive functioning could be made from the sequence and use of these terms, although, based upon the linking of the elements in the correct sequence, Group (ii) appeared to have a more scientific understanding than Group (i). However, the orientation stage served to bring to the fore the elements involved in 'seeing'. The following stages were designed to assist the students to develop a clear understanding of 'light and seeing' by progressively linking the elements of the Development Map for Seeing together.

3.4.2 The elicitation and restructuring stage

A series of questions was posed that addressed the basic concepts of light and how an eye can see. The aim of this was to enable students to articulate their prior knowledge. The sequence of questions was designed to identify the unistructural elements of the Development Map for Seeing, as the concept map had done, and progressively to link these elements together. The students were asked then to work in groups of three or four to investigate each of these questions and to report back to the class with their findings. They were encouraged to make predictions about specific objects and/or circumstances and to put these to the test.

First of all the students were asked to consider the following questions:

> ***Have you ever been in a place where there is no light at all?***
>
> ***Can you suggest what you would see in the school darkroom?***
>
> ***Do you think that you would be able to see e.g. a diamond ring, a sheet of silver foil, a mirror, a book, or your hand in front of your face?***

A number of the students said that they would be able to see a little bit in the dark once their eyes became accustomed to it. Very few students had experienced total darkness such as in a cave or a photographic darkroom. This activity was designed to make students aware of the importance of light for seeing.

The students then went into the school darkroom in their groups to determine whether or not they could see anything in the dark and whether their observations matched their predictions. The students were instructed to stand for a few moments with their eyes shut and then to open them and to see if they could see the objects that had been placed in the room by the teacher. Each group reported that the room was completely dark and that they could not see the diamond ring, the sheet of silver foil, the book, or their hand in front of their face. As a result of this activity the students concluded that 'light' was necessary for seeing.

The students were asked then to think about how they see and what else they required in order to be able to see. The class all said that 'eyes' were required in order to see. The discussions of the class revolved around the following questions, the first of which was suggested by the teacher:

> ***Why can't you see if you shut your eyes?***
>
> ***What if your eyes are open but you are wearing a blindfold?***
>
> ***Can cats see in the dark?***
>
> ***Does eating carrots help us to see in the dark?***
>
> ***How do bats see in a dark cave?***

As the students discussed the first question, it prompted them to ask the other questions. The first two questions addressed the issue that light must enter the eyes in order to see. The students discussed the idea that if their eyes were closed or, if they were wearing a blindfold, then light could not enter their eyes and, as a result, they could not see. This discussion linked together the elements 'light' and 'eye' as designated in the Development Map by L/E.1 Light + eye: we see. As the students became aware that they are able to see something, that is, an object, they also linked together the notions of 'light' and 'object' as given by L/O.1 Light + object: seeable, and E/O.1 Eye + object: look. The final conclusion was that light was required in order to be able to see an object with the eyes. Even cats, which can see at a lower light intensity than humans, are unable to see in total darkness. The questions about carrots and bats were of general interest to the students and not relevant to an understanding of vision.

The next part of the discussion dealt with the nature of light and was centred around the following questions:

> ***What is light?***
>
> ***Where does it come from?***
>
> ***What are its properties?***

Students were asked for their ideas, which were written on the whiteboard. All the students said that light came from the sun or from a light globe, that is, it travelled from a source to illuminate an object, but they were less clear about what light was. Some students said it was brightness but with no understanding of what this meant; others said it was energy; some even mentioned wavelengths, although they did not appear to understand the significance of this.

The students also did not appear to be able to state the properties of light so this discussion was extended by posing the questions:

> ***What path does the light follow in coming to us - curved, straight, zig-zag?***
>
> ***Can you suggest how you would test this?***
>
> ***Can you shine a torch beam around a corner?***

Students were encouraged to investigate these ideas for themselves and to identify some of the properties of light. The students again worked in small groups. They were provided with three pieces of cardboard with a hole in each and a torch. By shining the torch beam through the holes in the cardboard and showing that the light only shines through all three pieces of cardboard when the holes are aligned, they demonstrated that light travels, and that it travels in straight lines. This was confirmed by running a piece of string through the holes, which showed that the holes were in a straight line. The students also demonstrated this property by trying, unsuccessfully, to shine the torch beam around the corner of the doorway from one room to another.

The students had thus established the Concrete Symbolic notions of the Development Map, L/O.2, 'light travels to illuminate objects', and L/E.2, 'eye and light interact to see', although they had not yet established the nature of this interaction. Also, they had not yet established the notion E/O.2, 'eye-object involves light travel', although they were aware that 'eye-object involved light'.

Once the students had established that seeing an object involved eyes and a source of light, and that light travelled to illuminate an object, the class then moved on to consider what was thought by the researcher to be the most difficult concept to illustrate and the key to many of the students' difficulties with a scientific understanding of 'seeing'. The question was posed:

> ***How do we know whether it is light entering our eyes or our eyes looking at the object?***

The class discussed this question together. This discussion addressed the notion L/E.2, 'eye and light interact to see', and moved further along the pathway of developing understanding to establish the notions L/E.3, 'seeing involves light entering the eye', and E/O.3, 'light travels from object to eye', and the extension of this notion that light is reflected off the object in order to travel to the eye, the notion L/O.3, 'light reflects off objects'. An analogy was suggested by the teacher, and discussed by the students, associating the eye with the other senses of touch, taste, hearing and smell. Each of these senses involved the stimulation of receptors within the organ responsible for that sense - receptors within the skin responded to touch, on the tongue for taste, the nose for smell, and within the ears for hearing. Therefore, by analogy, the receptors for seeing were within the eyes and were activated by the light from the object entering the eye and stimulating the receptors at the back of the eye (the retina) which sent a message to the brain.

A number of students said that it was not necessary to 'look at' the object, the connection E/O.1, that they could see objects out of the corners of their eyes. For these students 'look at' meant turning their head and eyes in the direction of the object. This notion was discussed by the students. It was concluded that the light still had to come to the eye, even if from the side.

Students, working in groups of three or four, were asked then to draw a diagram to illustrate how they believed they could see the book placed on the table in front of them. The groups posted their diagrams on a display board for discussion, with a spokesperson from each group standing by to answer questions or to explain the ideas of the group. Samples of these drawings are shown in Figures 3.6 and 3.7.

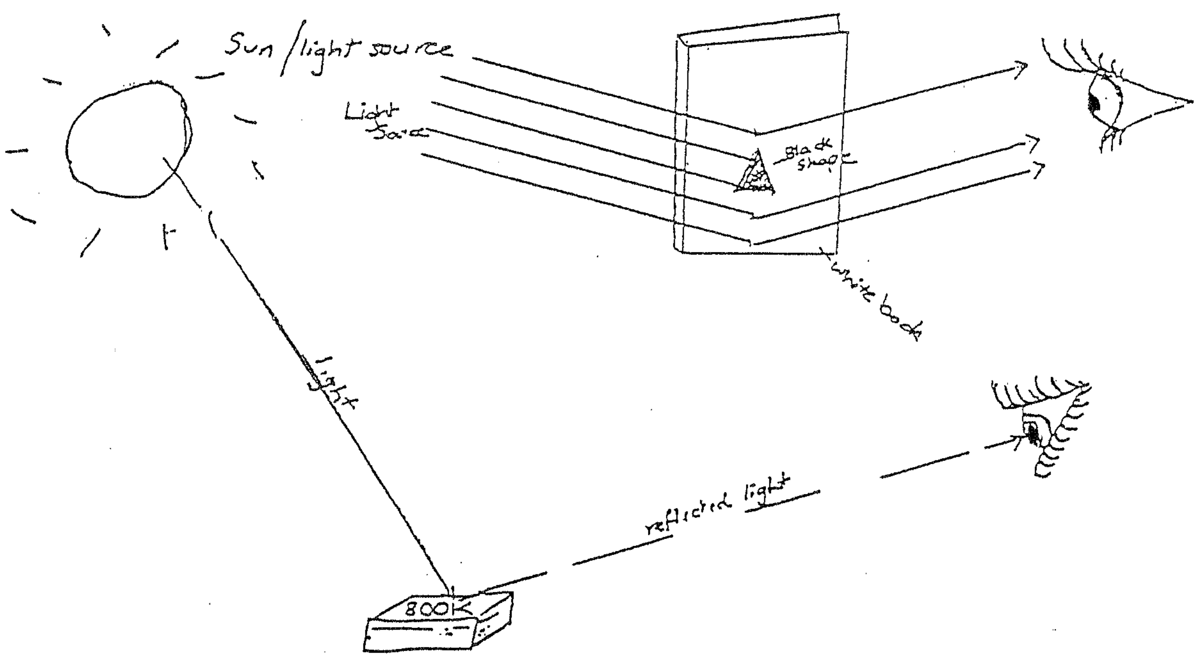


Figure 3.6: Year 9/95 group (i) illustration of 'seeing a book'

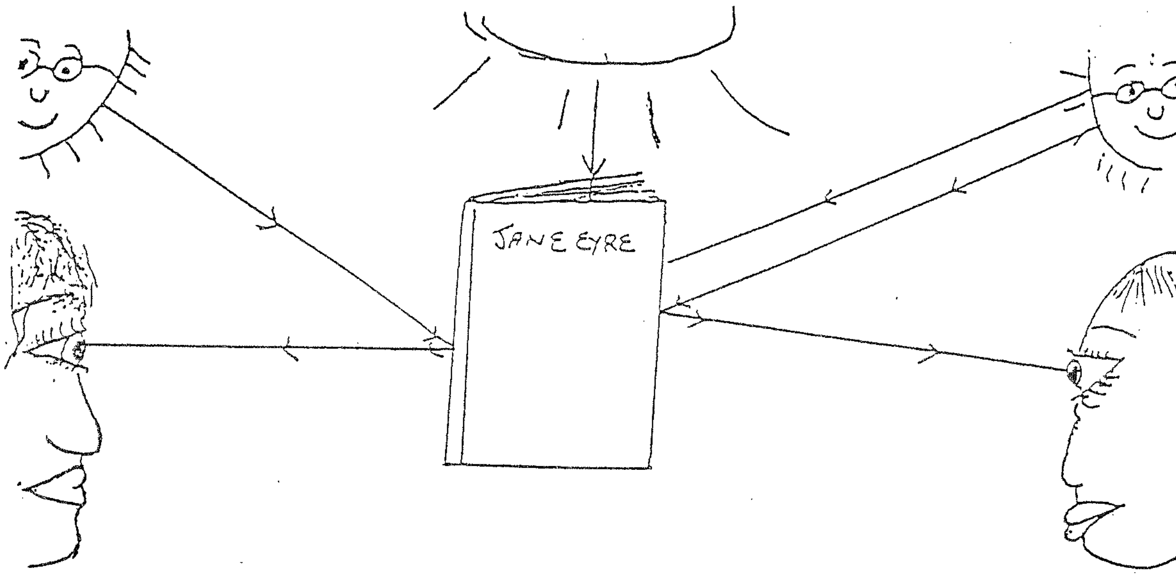


Figure 3.7: Year 9/95 group (ii) illustration of 'seeing a book'

In their diagrams the students demonstrated an understanding that 'light travels to illuminate objects' (L/O.2) and, more importantly, that 'light reflects off objects' (L/O.3), that 'light travels from object to eye' (E/O.3), and that 'seeing involves light entering the eye' (L/E.3). Once each of these three connections, L/E.3, L/O.3, and E/O.3, had been constructed, then students had acquired the Standard Seeing Framework postulated by Collis et al. (1998).

Thus the sequence of questions, activities, and discussions 'led' students along the pathway defined in the Development Map for Seeing according to Vygotsky's notion of 'assisted discovery' (see Section 2.2). The elements involved in developing a scientific understanding of 'light and seeing' were introduced and linked in a hierarchical sequence as the Teaching Unit progressed.

3.4.3 The review stage

At the completion of the Teaching Unit, the students were asked to express their current views on 'light and seeing', whether they believed their notions had changed, and whether they now had a more scientific understanding of light and its role in seeing. Discussion was directed towards the concept maps drawn at the commencement of the unit and the students were asked whether the maps correctly illustrated how they would see an object. It was agreed that the map which illustrated it best was that given in Figure 3.5 that linked together sun, light, object, reflection, and eyes in the correct sequence. It was agreed that, although Figure 3.4 contained the same words as Figure 3.5, the linking of these words was not in the correct sequence. This map gave two incorrect impressions, the first that light from the sun entered the eyes directly, and the second that reflection was associated with a mirror only.

Upon completion of the Teaching Unit, the questionnaire discussed in Section 3.2.1 was administered to ascertain whether conceptual change had taken place and, if so, to what extent. The questionnaire was given again to the students six months after completion of the Teaching Unit to see whether any further change had taken place. The complete responses of the Year 9/95 and Year 9/96 students to the questionnaire, at each phase of the investigation, are contained in Appendices 3 and 4, respectively.

3.5 Determining the change in level of cognitive functioning from the analysis of the responses to the questionnaire

3.5.1 Analysis of the year 9/95 responses

Data were collected by administering the questionnaire discussed in Section 3.3.1 at three of the four phases of the investigation: pre-instruction (Phase 1), immediate post-instruction (Phase 3), and delayed post-instruction (Phase 4). The implementation of the Teaching Unit was Phase 2.

The analysis of the responses to the questionnaire was undertaken by looking at which paired elements of the Development Map for Seeing of Collis et al. (1998) (Figure 3.3) were present in the responses of each student to Question One (Figure 3.1), and which of the Seeing Conceptions given in Question 2 (Figure 3.2) the student selected, at each phase of the investigation. Table 3.1 shows the highest status paired elements of the Development Map in the responses of individual students to Question One, at each phase of the investigation.

As discussed in Section 3.3.2, there is a sequential development of the elements of the Development Map for Seeing, and so the highest of each of the paired elements identified in the students' responses only is shown, as it was assumed, as was done by Collis et al., that students held all elements preceding the highest observed. The only variation to this was, if the student held the alternative notion E/O.1x, 'do not need to 'look at' object', then she was not deemed to hold the element E/O.1, 'look at the object'. Student numbers are not consecutive as some students were not present for all phases of the investigation and were, therefore, excluded from the analysis. Students whose numbers were adjacent and who exhibited identical patterns of elements over the course of the investigation have been grouped together.

Table 3.1: Highest status paired elements of the development map for seeing in the responses of individual year 9/95 students to question one at each phase of the investigation

	Pre-Instruction			Immediate Post-Instruction			Delayed Post-Instruction		
Student Number	L/E	E/O	L/O	L/E	E/O	L/O	L/E	E/O	L/O
2	3/3a	3	3	3/3a	3	3	3/3a	3	3
4	3	3	3	3	3/3b	2	3	3	3
5, 6, 7,11	3	3	3	3	3	3	3	3	3
10	3/3a	3	3	3	3/3b	3	3/3a	3	3
12	3/3a	3	3	3/3a	3	3	3/3a	3	3
13	3	3b	3	2	3/3b	3	3	3	3
14	3b	1	0	3	3/1x	3	3	0	0
15, 16,18	3	3	3	3	3	3	3	3	3
17	3	3/3b	3	3	3	3	3	3	3
19	3b	1	3	3	3	3	3	3	3
20	2/1a/3a	1	1	3	3	3	2	2	1
21	1a/3b	3a	0	3	3	3	3	3a	0
23	3/3b	1	3	3	3/3b	3	2	1x/3b	3
24	3	3/1x	3	3	3	3	3	3/1x	3
25	2/1a/3a	2	3	3	3	3	3	3	3
27	3b	1	0	3	2	3	3	3	3
28	3	3	3	3	3/1x	3	3	3	3
29	2	2	3	3	3	3	3	3	2
30	3/3a	2	3	3	3	3	2/3a	2	2
31	2/3a	1	1	1	0	1	1	3b	0
32	1	1	1	2	2	2	1	2	1

Alternative Notions - defined by Collis et al. (1998):

L/E.1a can see in the dark
L/E.3a light in eye prevents sight
L/E.3b light enters eye from source
L/O.3x light does not reflect off all objects
E/O.1x do not need to 'look at' object
E/O.3a light travels eye to object
E/O.3b image travels object to eye

Two symbols in the above table, e.g. **3/3b**, means student holds two notions, the scientific notion and an alternative notion.

Three symbols, e.g. **2/1a/3a**, means the student holds three notions.

As can be seen in Table 3.1, the majority of students held paired elements of the Development Map for Seeing with the level or status designated by numbers 1, 2, or 3, for example L/E.1, L/E.2, or L/E.3. As discussed in Section 3.3.2, the number 1 indicated that the responses of the student were in the Ikonic mode of the Development Map (see Figure 3.3). If the student integrated all three paired elements, L/E.1, E/O.1, and L/O.1, in the Ikonic mode then she was considered to be operating at the Relational level in that mode. Status numbers 2 and 3 indicated responses in the Concrete Symbolic mode at the Multistructural level. If the paired elements with the status number 3, that is, L/E.3, E/O.3, and L/O.3, were integrated together then the response was considered Relational. A zero in the table means that the student's response contained zero elements of the Development Map for Seeing.

Alternative notions held by the students have been designated by the status number of their response followed by a letter, for example, L/E.1a or L/O.3x. Possible alternative notions, identified by Collis et al., are listed below Table 3.1 and are discussed in the paragraphs following. Where the student held two or more notions at the same time, these have been written as, for example, E/O.3/3b or L/E.2/1a/3a, to cover all the notions held, both scientific and alternative.

From Table 3.1 it can be seen that, immediately following instruction, the responses of the majority of students contained higher status paired connections of the Development Map and fewer alternative notions. The main exceptions were Student 31 who held only two paired elements, L/E.1 and L/O.1, and continued to function in the Ikonic mode, and Student 32 who had made the transition to the Concrete Symbolic mode, but the status of the paired elements observed in her response was lower than those of the majority of other students. The increase in the status of the paired connections and, therefore, in the total number of connections of the majority of students, was taken to indicate an improved understanding of 'light and seeing'.

Six months later it was observed that the status of the paired elements in the responses of seven students had decreased slightly, which was taken as an indication of a regression in their understanding although, with perhaps the exception of Students 31 and 32, they continued to function in the Concrete Symbolic mode. With some students it was difficult to assign a mode of cognitive functioning to their responses as they contained a mix of different status numbers and even in some cases zero elements of a particular pair; see for example, Students 14 and 31.

From the table it can be seen also that, in the pre-instruction phase, five students correctly stated that light enters the eye but they said that this light came from the source rather than reflected off the object, the alternative notion L/E.3b. No students held this alternative notion in either the immediate post-instruction or the delayed post-instruction phase.

Five students, one in the pre-instruction phase, and two in both the immediate and delayed post-instruction phases, stated specifically that they did not need to 'look at' the object in order to see it, the alternative notion E/O.1x. This does not necessarily imply that they held an alternative conception but may instead mean that they believed that they were able to see an object without actually turning their head to look directly at it. They stated correctly in all but one case that light travelled from the object to the eye. One student only (Student 23, delayed post-instruction) said that the image, rather than the light, travelled from the object to the eye, the alternative notion E/O.3b.

In a number of cases the student appeared to hold the scientific notion together with an alternative notion. For example, five students, one in the pre-instruction phase, and four in the immediate post-instruction phase, held the scientific notion E/O.3, 'light travels object to eye', but, at the same time, they also appeared to hold the alternative notion E/O.3b, 'image travels object to eye'. Similarly, in a number of instances in each phase of the investigation, the alternative notion, L/E.3a, was associated with the scientific notion, L/E.3, that is, the student held that 'eye needs light entering to see', but also believed that 'light in eye prevents sight'.

Other alternative notions observed were L/E.1a, 'can see in the dark', which was observed with three students in the pre-instruction phase only, and E/O.3a, 'light travels eye to object', observed with one student only, in the pre-instruction and delayed post-instruction phases. The alternative notion, L/O.3x, 'light does not reflect off all objects', identified by Collis et al., was not observed in any phase of the investigation.

For ease of comparison of the pre-instruction, immediate post-instruction, and delayed post-instruction phases, the data are summarised in Table 3.2, which shows the total number of students holding particular paired elements of the Development Map for Seeing at each phase of the investigation. As stated previously, in each case it was assumed that if a student held high status paired elements then she also held the preceding lower status elements, except in the case of E/O.1. If the student held the alternative notion E/O.1x, then she could not also hold E/O.1, as the two notions are in contradiction.

From the results shown in Table 3.2, it can be seen that there was an increase in the number of students holding the higher status paired elements of the Development Map for Seeing, and operating in the Concrete Symbolic mode, immediately following instruction. However, it can be seen that there was a slight decrease in the percentage of students holding the higher status elements, in particular E/O.3 and L/O.3, six months later, which was an indication that, for these students, the conceptual change was not lasting, although they continued to function in the Concrete Symbolic mode. The apparent increase in the number of students holding E/O.2 compared with the number holding E/O.1, in the immediate post and delayed post-instruction phases, arose because two students held the alternative notion, E/O.1x, instead of the scientific notion, E/O.1.

Table 3.2: Number (percentage) of year 9/95 students holding each of the paired elements of the development map for seeing at each phase of the investigation

	Paired Elements of Development Map (n=26)								
	L/E			E/O			L/O		
Phase	1	2	3	1	2	3	1	2	3
Pre-Instruct.	26 (100)	25 (96)	16 (62)	26 (100)	19 (73)	14 (54)	23 (88)	20 (77)	20 (77)
Immed. Post-Instruct.	26 (100)	25 (96)	23 (88)	23 (88)	25 (96)	23 (88)	26 (100)	25 (96)	23 (88)
Delayed Post-Instruct.	26 (100)	24 (92)	21 (81)	23 (88)	25 (96)	19 (73)	23 (88)	21 (81)	19 (73)

Table 3.3 shows the Seeing Conception selected in Question Two (Figure 3.2) by individual students who selected conceptions other than the scientific notion in one or more phases of the investigation. All other students selected the scientific notion at each phase. Conception 4 was the scientific notion, 'light goes to the tree and bounces to our eye'. The other Seeing Conceptions were: Conception 1, 'light goes to the tree and we look at the tree', Conception 2, 'light shines on the tree and we can see it', Conception 3, 'light is everywhere in a well lit area and we can see the tree', and Conception 5, 'light comes to the eye and we look at the tree'.

From the data given in Table 3.3, it can be seen that, prior to instruction, no students selected Conceptions 1 or 2, two students selected Conception 3 ('light is everywhere'), and four students selected Conception 5 ('light comes to the eye and we look at the tree'). A notion held by the majority of the students selecting Conceptions 3 and 5 in the present research was that light entered the eye but from the source **not** from the object (the alternative notion L/E.3b). These students appeared to be operating predominantly in the Ikonic mode of the Seeing Framework. This was confirmed by the low status of the paired elements of the Development Map for Seeing present in their responses to Question One (see Table 3.1). The responses of these six students contained an average of 4 paired elements of the Development Map compared with an average of 8 paired elements in the responses of those students who selected Conception 4. Collis et al. (1998) had observed that the majority of students functioning in the Ikonic mode held a conception of seeing represented by Conceptions 2 or 3. In the present research, students observed functioning in the Ikonic mode were found to hold Conception 5 and, to a lesser extent, Conception 3, but not Conception 2. Surprisingly, Student 32 correctly selected Conception 4 prior to instruction, and yet her response contained only 3 paired elements and was indicative of the Ikonic mode of functioning. Student 30 was included in Table 3.3 as she selected Conception 1 in the delayed post-instruction phase. However, in the pre-instruction phase, she selected Conception 4 and her response contained 8 paired elements of the Development Map for Seeing.

Table 3.3: Seeing conception selected in question two by individual year 9/95 students who selected conceptions other than the scientific conception at any phase of the investigation

	Seeing Conception Selected at each Phase		
Student Number	**Pre-Instruction**	**Immediate Post-Instruction**	**Delayed Post-Instruction**
14	5	4	5
19	5	4	4
20	3	4	4
21	5	4	5
27	5	4	4
30	4	4	1
31	3	4	4
32	4	3	5

Immediately following instruction, all students, except Student 32 who chose Conception 3, selected the scientific notion of light reflecting off the tree to the eye. The number of paired elements in the response of Student 32 to Question One had increased from 3 to 6 indicating that she appeared to have made the transition from the Ikonic to the Concrete Symbolic mode. It was perhaps surprising that Student 31 selected Conception 4, as her response to Question One contained only two paired elements of the Development Map and was indicative of the Ikonic mode.

Six months after instruction, Students 14 and 21 had reverted to their pre-instruction Conception 5, Student 32 had changed again and selected Conception 5, and Student 30, who had selected Conception 4 both pre- and immediate post-instruction, had now selected Conception 1 ('light goes to the tree and we look at the tree'). The responses of each of these students to Question One now contained fewer paired elements of the Development Map than they had in the immediate post-instruction phase; Students 14 and 21 had decreased from 9 paired elements to 3 and 5, respectively; Student 30 from 9 to 6; and Student 32 from 6 to 5. Student 31 had again selected Conception 4 but her response to Question One contained only 3 paired elements.

These results are summarised in Table 3.4, which gives the total number of students selecting a particular Seeing Conception in Question Two at each phase of the investigation. From Table 3.4 it can be seen that all students, with one exception, chose Conception 4 (the accepted 'scientific' notion) in the immediate post-instruction phase; 77% had chosen it pre-instruction but only 85% chose this option six months after completion of the Teaching Unit, indicating that for a small number of students the conceptual change was not lasting.

Table 3.4: Number (percentage) of year 9/95 students selecting a particular seeing conception in question two at each phase of the investigation

	Phase of the Investigation (n=26)		
Conception Selected	**Pre-Instruction**	**Immediate Post-Instruction**	**Delayed Post-Instruction**
1	0	0	1 (4)
2	0	0	0
3	2 (8)	1 (4)	0
4	20 (77)	25 (96)	22 (85)
5	4 (15)	0	3 (11)

As can be seen in the discussion of the data in Table 3.3, selection of Conception 4 alone was not considered sufficient evidence of a student's understanding. The numbers of paired elements of the Development Map for Seeing held by students, shown in Table 3.1, were also an indicator of understanding, and of their levels of cognitive functioning. Responses to the 'free response' Question One were considered a more accurate indicator of the mode of cognitive functioning than were the responses to the 'multiple choice' Question Two. In some cases, it was observed that, although the student selected the 'scientific' conception in Question Two, her response to Question One did not demonstrate an equivalent scientific understanding. Students appeared to perform better on multiple choice items where one statement 'looked better' than the others.

There are a total of nine paired elements or connections in the Development Map for Seeing (Figure 3.3). As can be seen from Table 3.1, nearly all students tested held at least three paired elements pre-instruction with the greatest number being held by those who selected Conception 4 (the 'scientific notion') in Question Two (see Table 3.3). In addition, the majority of paired elements held by students who selected conceptions other than Conception 4 were of a lower status, indicating a poorer understanding of 'light and seeing'.

A concise way of illustrating any change in student understanding of 'light and seeing', at each phase of the investigation, was to look at the mean number of connections (that is, how many paired elements out of a total of nine) of the Development Map made by the students pre-, immediate post-, and delayed post-instruction. This is shown in Table 3.5.

Table 3.5: Mean number of connections of the development map for seeing in the responses of year 9/95 students pre-, immediate post-, and delayed post-instruction

Mean Number of Connections Made		
Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction
7.3	8.4	7.7

The figure for the mean number of connections was calculated by adding up the number of paired 'scientific' notions held by the student. For example, a student whose response contained the paired elements, L/E.3, E/O.3 and L/O.3, had a maximum number of nine connections as she was credited with holding the lower status elements as well. If a student held an alternative notion, for example, L/E.3b, then she was credited with holding the lower status scientific notions, that is, L/E.1 and L/E.2, in addition to her E/O and L/O combinations. If a student held a scientific notion and an alternative notion of the same status, then she was credited with the scientific notion in her total score. As an example, consider Student 25; pre-instruction, she held the paired elements L/E.2/1a/3a, E/O.2, and L/O.3. Therefore, her total score for paired elements would be 2+2+3=7. Collis et al. calculated the mean number of connections made by students in the same way but related this instead to the percentage of students selecting a particular Seeing Conception. Some discussion of this relationship was included for the present research in the discussion associated with Table 3.3.

As can be seen in Table 3.5, there was a slight increase in the mean number of connections between the pre-instruction and immediate post-instruction phases, and a slight decrease between the immediate post- and delayed post-instruction phases. Despite the small size of the test group, this was taken as indication of an improvement in student understanding as a result of the Teaching Unit, and of a slight regression taking place over the ensuing six months, although the mean number of connections did not return to the pre-instruction level.

The figures for the mean number of connections of the Development Map for Seeing are an indicator of the cognitive level at which the students were functioning at each phase of the investigation. From Figure 3.3, it can be seen that the number of paired elements of the Development Map for Seeing increases as the student progresses along the theoretical pathway for the development of an understanding of vision. The first three paired elements are indicative of a student functioning in the Ikonic mode. The following six pairs are indicative of the Concrete Symbolic mode. The maximum number of paired elements is nine. A student who integrates all nine paired elements is functioning at the Relational level in the Concrete Symbolic mode (R_{CS1}) and has acquired the Standard Seeing Framework. In Table 3.5 it can be seen that, over the course of the investigation, the mean number of connections was between seven and nine. On average, this group of students was functioning in the Concrete Symbolic mode at all times, and between the Multistructural and the Relational levels within this mode.

It was of some concern that, although determining the mean number of connections made by students was a useful technique, it did not take into account the alternative conceptions held by some students. For example, if a student held both the standard conception and an alternative conception, say L/E.3 and L/E.3a (see Table 3.1), then she was credited with holding the standard conception, despite her uncertainty. This gave her a high score for the number of paired connections of the Development Map and gave the appearance of a student who held the Standard Seeing Framework and possessed a scientific understanding of vision and yet, at the same time, she held an alternative notion. For the purposes of the present research, this tool allowed comparisons to be made over the course of the investigation in order to see what impact the Teaching Unit had had on the level of understanding of the students, but it gave no indication of the decreased number of alternative conceptions held by students following the Teaching Unit. As this was considered by the researcher as an indicator of increased understanding, Table 3.6 has been included to show the numbers of students holding each of the observed alternative conceptions, at each phase of the investigation. A small number of students held more than one alternative conception at the same time. This was observed in the pre-instruction phase in which two students held both L/E.1a and L/E.3a at the same time, and one student held both L/E.1a and L/E.3b, and in the delayed post-instruction phase in which one student held both E/O.1x and E/O.3b.

Table 3.6: Number (percentage) of year 9/95 students holding a particular alternative conception at each phase of the investigation

	Phase of the Investigation (n=26)		
Alternative Conception	**Pre-Instruction**	**Immediate Post-Instruction**	**Delayed Post-Instruction**
L/E.1a can see in the dark	3 (12)	0	0
L/E.3a light in eye prevents sight	7 (27)	2 (8)	4 (15)
L/E.3b light enters eye from source	5 (19)	0	0
L/O.3x light does not reflect off all objects	0	0	0
E/O.1x do not need to 'look at' object	1 (4)	2 (8)	2 (8)
E/O.3a light travels eye to object	1 (4)	0	1 (4)
E/O.3b image travels object to eye	2 (8)	4 (15)	2 (8)

From Table 3.6 it can be seen that the number of alternative conceptions held by students decreased following participation in the Teaching Unit. The light/eye (L/E) interaction appeared to be the most difficult concept for the students to understand as shown by the numbers of students holding L/E alternative conceptions prior to instruction. The alternative conception L/E.3a, 'light in eye prevents sight' was still observed in the responses of some students at the conclusion of the Teaching Unit. In contrast, the light/object (L/O) interaction appeared not to cause any major difficulty, and the alternative conception L/O.3x, described by Collis et al., was not observed in the present research. The difficulties with the eye/object (E/O) interaction observed in the responses of a small number of students appeared to remain relatively unchanged over the course of the investigation.

Prior to commencing the investigation into 'sound and hearing', it was decided to repeat the investigation into 'light and seeing' with a second group of Year 9 students in order to confirm the findings.

3.5.2 Analysis of the year 9/96 responses

The same procedure was followed with these students as for the Year 9/95 Group and the data were collected and analysed in the same manner. As stated in Section 3.2, this group was smaller than the previous year group and was composed of students who had elected to study additional science. In addition the Teaching Unit was taught by a student teacher, not by the researcher. Table 3.7 shows the highest status paired elements of the Development Map for Seeing present in the responses of individual students to Question One of the questionnaire, at each phase of the investigation. The student numbers are not consecutive as some students were not present for all phases of the investigation and were, therefore, excluded from the analysis.

From Table 3.7, it can be seen that no students appeared to hold three different notions at the same time as had been observed with the Year 9/95 Group, although a number of students still appeared to hold a scientific notion concurrently with one alternative notion. Possible alternative notions, identified by Collis et al., are listed below Table 3.7, and are discussed in the paragraphs following the table.

The majority of students in this group appeared to hold high status paired elements at each phase of the investigation, including pre-instruction, and to be operating in the Concrete Symbolic mode of the Development Map for Seeing (see Figure 3.3). The meaning of status numbers was discussed in Section 3.5.1. Students 2, 3, and 4 held high status paired elements at each phase of the investigation and appeared to possess a good understanding of 'light and seeing', and yet they continued to hold an alternative notion concurrently with the scientific notions (Student 2 in the delayed post-instruction phase, Student 3 in the immediate post-instruction phase, and Student 4 throughout the investigation).

The responses of Student 7 indicated that she was functioning in the Ikonic mode pre-instruction as she held paired elements of the Development Map designated by the number

1, that is L/E.1, L/O.1, and E/O.1. Following instruction her responses indicated a transition to the Concrete Symbolic mode.

Table 3.7: Highest paired elements of the development map for seeing in the responses of individual year 9/96 students to question one at each phase of the investigation

	Pre-Instruction			Immediate Post-Instruction			Delayed Post-Instruction		
Student Number	L/E	E/O	L/O	L/E	E/O	L/O	L/E	E/O	L/O
2	3	3	3	3	3	3	3	3/1x	3
3	3	3	3	3	3/1x	3	3	3	3
4	3/3a	3	3	3/3a	3	3	3/3a	3	3
5	3	3/1x	3	3	3	3	3	3	3
6	2	2	2/3x	3a/3b	2	1/3x	3b	1	0/3x
7	1	1	1	3	2	2	3	3/1x	2
8	3	3/3b	3	2/3a	2	3	3/3a	3	3
9	3	3	3	3	3	3	3	3	3
11	2	3	1	3	3/3b	3	3	3	3
12	2	3	3	3	3/3b	3	2	3	3

Alternative Notions - defined by Collis et al. (1998):

L/E.1a can see in the dark
L/E.3a light in eye prevents sight
L/E.3b light enters eye from source
L/O.3x light does not reflect off all objects
E/O.1x do not need to 'look at' object
E/O.3a light travels eye to object
E/O.3b image travels object to eye

Two symbols in the above table, e.g. **3/3b**, means student holds two notions, the scientific notion and the alternative notion.

As can be seen in Table 3.7, Student 4 held the scientific notion, L/E.3, as well as the alternative notion, L/E.3a, at each phase of the investigation. This student appeared to understand that seeing involves light entering the eye but at the same time stated that 'light in eye prevents sight'. It may be that what she had in mind was the glare associated with bright sunlight in the eyes rather than an alternative notion as, otherwise, she appeared to have a good understanding of 'light and seeing'.

Fewer students in this group held the alternative notion of light entering the eye from the source instead of reflected off the object, designated as L/E.3b, which had been observed with the previous group in the pre-instruction phase. Student 6 was the only student who appeared to hold this notion; she held it in the immediate post- and delayed post-instruction phases, and not in the pre-instruction phase. It was interesting to note that, over the course of the investigation, this same student held the alternative notion L/O.3x, 'light does not reflect off all objects' which, although identified by Collis et al., had not been observed with the Year 9/95 Group. The alternative notion L/E.1a, 'can see in the dark', observed with the Year 9/95 Group in the pre-instruction phase, was not present in the responses of these students at any stage in the investigation.

Four students stated specifically that they did not need to 'look at' the object in order to see it, the alternative notion E/O.1x. As stated for the Year 9/95 Group, this did not necessarily mean that they held an alternative conception as they had also stated correctly that light travels from the object to the eye. However, they were not deemed to hold E/O.1 if they stated E/O.1x in their response. The alternative notion E/O.3a, 'light travels eye to object', observed with the Year 9/95 Group, was not observed with this group.

Three students, one in the pre-instruction phase and two in the immediate post-instruction phase, stated that 'light travels object to eye' (the scientific notion E/O.3), but they also stated that 'image travels object to eye' (the alternative notion E/O.3b). This is represented by the combination E/O.3/3b. This same combination had been observed with five students in the Year 9/95 Group.

The results contained in Table 3.7 are summarised in Table 3.8 which shows the total number of students holding particular paired elements of the Development Map for Seeing at each phase of the investigation. As stated previously, a student who held the alternative notion E/O.1x was not also credited with holding the scientific notion E/O.1.

As can be seen from Table 3.8, there was little change in the number of students holding the higher status paired elements of the Development Map for Seeing over the course of the investigation. Looking at the data for individual students in Table 3.7, an increase in the status of paired elements can be seen for a small number of students immediately following instruction, and virtually no regression six months later, but looking at the combined data, the numbers are too small to be significant. Of course, as mentioned in Section 3.5.1, the data do not take into account the alternative conceptions held by these students. These data are shown in Table 3.12.

Table 3.8: Number (percentage) of year 9/96 students holding each of the paired elements of the development map for seeing at each phase of the investigation

	Paired Elements of Development Map (n=10)								
	L/E			E/O			L/O		
Phase	1	2	3	1	2	3	1	2	3
Pre-Instruct.	10 (100)	9 (90)	6 (60)	10 (100)	9 (90)	8 (80)	10 (100)	7 (70)	7 (70)
Immed. Post-Instruct.	10 (100)	10 (100)	9 (90)	9 (90)	10 (100)	7 (70)	10 (100)	9 (90)	8 (80)
Delayed Post-Instruct.	10 (100)	10 (100)	9 (90)	8 (80)	9 (90)	9 (90)	9 (90)	9 (90)	8 (80)

Table 3.9 shows the Seeing Conception selected in Question Two (Figure 3.2) by individual students who chose conceptions other than the scientific Conception 4 at any phase of the investigation. From Table 3.9 it can be seen that only Students 6 and 7 chose alternative conceptions. In addition to the fact that the Year 9/96 Group was very small, this also may be a reflection of the fact that they were possibly a more able group and more motivated to study science than the Year 9/95 Group.

Table 3.9: Seeing conception selected in question two by individual year 9/96 students who selected conceptions other than the scientific conception at any phase of the investigation

	Seeing Conception Selected at Each Phase		
Student Number	Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction
6	2	3	5
7	1	2	4

Students 6 and 7 chose a different conception at each phase of the investigation. Conception 2, which was not selected at all by the Year 9/95 Group, was selected by Student 6, pre-instruction, and by Student 7 in the immediate post-instruction phase. As discussed previously, students who chose Conceptions 2 and 3 were identified by Collis et al. as holding three or less paired connections of the Development Map for Seeing and as functioning in the Ikonic mode. This was not observed with these two students. From Table 3.7, it can be seen that Student 6 held 6 paired elements of the Development Map in the pre-instruction phase, which is indicative of the Concrete Symbolic mode. She still held 6 paired elements in the immediate post-instruction phase when she selected Conception 3. Six months later, she held only 3 paired elements, which was an indication of the Ikonic mode of functioning, and yet she selected Conception 5, which Collis et al. had suggested was indicative of the Concrete Symbolic mode.

Although Student 7 selected Conception 2 immediately following the Teaching Unit, the number of paired elements in her response to Question One had increased from 3, pre-instruction, to 7, indicating that she had made the transition from the Ikonic to the Concrete Symbolic mode. So again, in the present research, selection of Conception 2 was not found to correspond with the Ikonic mode, nor was the selection of Conception 1 observed associated with the Concrete Symbolic mode. Six months later, Student 7 selected Conception 4 and her response to Question One contained 8 paired elements indicating that she was functioning in the Concrete Symbolic mode and possessed a fairly good understanding of 'light and seeing', even though she had not developed the Standard Seeing Framework. For this her response would have contained 9 paired elements.

The data from Table 3.9 have been summarised in Table 3.10, which gives the total number of students selecting a particular Seeing Conception in Question Two, at each phase of the investigation. The results shown in Table 3.10 do not show the variation observed with the Year 9/95 Group (see Table 3.4). With the Year 9/96 Group, the number of students selecting Conception 4 remained steady over the course of the investigation.

Table 3.10: Number (percentage) of year 9/96 students selecting a particular seeing conception in question two at each phase of the investigation

	Phase of the Investigation (n=10)		
Conception Selected	Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction
1	1 (10)	0	0
2	1 (10)	1 (10)	0
3	0	1 (10)	0
4	8 (80)	8 (80)	9 (90)
5	0	0	1 (10)

As discussed for the Year 9/95 Group, a concise way of illustrating any change in student understanding over the course of the investigation was to look at the mean number of paired connections of the Development Map for Seeing, out of a possible total of nine, made by students at each phase of the investigation. The data for the Year 9/96 Group are shown in Table 3.11.

Table 3.11: Mean number of connections of the development map for seeing in the responses of year 9/96 students pre-, immediate post-, and delayed post-instruction

Mean Number of Connections Made		
Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction
7.6	8.2	8.1

From Table 3.11, bearing in mind the small number of students involved, it can be seen that there was a slight increase in the number of connections made pre- to immediate post-instruction, but virtually no further change from immediate post- to delayed post-instruction. This shows some contrast with the results obtained with the Year 9/95 Group where a slight decrease in the mean number of connections was observed over the six-month period following the completion of the Teaching Unit. The mean number of connections observed with the Year 9/96 Group was slightly higher prior to instruction than for the Year 9/95 Group, and did not change as much as it had for the previous group following the Teaching Unit. This is possibly not surprising in view of the fact that the Year 9/96 Group was a slightly more able group with a penchant for science.

As the data for the paired connections of the Development Map did not take in account the alternative conceptions held by students over the course of the investigation, Table 3.12 has been included, as was done for the previous group, to show the numbers of students holding each of the alternative conceptions, at each phase of the investigation. In the Year 9/96 Group only one student held two alternative conceptions at the same time (Student 6 in the immediate post-instruction phase).

It was somewhat surprising to observe in Table 3.12 that, in contrast to the outcomes observed with the previous year group, the number of alternative conceptions held by students in the Year 9/96 Group increased following the completion of the Teaching Unit and, six months later, still remained higher than prior to instruction. As this group of students was more motivated towards science than the first group and possibly a more able group, this outcome was a trifle surprising. The only difference between this group and the preceding group, apart from size and perhaps the ability of the students, was that the Teaching Unit was taught by a student teacher with the researcher observing, whereas the Year 9/95 Group was taught by the researcher. In hindsight, perhaps it would have been better for the researcher to have taught the unit herself, but, at the time, it was thought beneficial to have an independent teacher. However, although the researcher provided the teacher with the Teaching Unit and with notes for her assistance, it was observed that the students had some difficulty understanding the teacher as English was not her first language. The researcher did not find the student teacher hard to follow as she was familiar with the content, but, unfortunately, the students did. This may possibly have accounted for the students' uncertainty, and for the increase in alternative conceptions held concurrently with the scientific conception, at the conclusion of the Teaching Unit.

Table 3.12: Number (percentage) of year 9/96 students holding a particular alternative conception at each phase of the investigation

Alternative Conception	Phase of the Investigation (n=10) Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction
L/E.1a can see in the dark	0	0	0
L/E.3a light in eye prevents sight	1 (10)	3 (30)	2 (20)
L/E.3b light enters eye from source	0	1 (10)	1 (10)
L/O.3x light does not reflect off all objects	1 (10)	1 (10)	1 (10)
E/O.1x do not need to 'look at' object	1 (10)	1 (10)	2 (20)
E/O.3a light travels eye to object	0	0	0
E/O.3b image travels object to eye	1 (10)	2 (20)	0

3.6 Conclusion

Despite the small size of the groups and the absence of a wide spectrum of abilities, this preliminary investigation into 'light and seeing' was deemed a useful commencement to the present research. The cognitive model of Collis et al. (1998) proved an invaluable tool for determining the level at which the students were functioning at each phase of the investigation. The development of the Teaching Unit closely linked with the model of cognitive development provided valuable insights into how best to structure lessons so as to promote student understanding. Future applications of the theoretical model and the Teaching Unit are discussed in Chapter 6.

The experience gained with this preliminary investigation into 'light and seeing' was then applied to the main focus of this research, an investigation into the cognitive aspects of 'sound and hearing'. In the following chapters a cognitive model for the development of an understanding of 'sound and hearing' is proposed and linked to the design of a Teaching Unit on 'sound and hearing'. The stages in the development of the theoretical model, the methods used to assess student understanding during the course of the investigation, and the design and implementation of the Teaching Unit are discussed in detail.

Chapter 4

Sound and hearing: methodology, theoretical model, and teaching unit

4.1 Introduction

The intentions of this research were to investigate students' understanding of sound in terms of a theoretical cognitive model and to use the results of this investigation as guidelines for the design of a curriculum module that would facilitate the development of a scientific understanding of 'sound and hearing'. Following the preliminary investigation of 'light and seeing' (Chapter 3) and modelling on previous research into students' understanding of vision published in Collis, Jones, Sprod, Watson, and Fraser (1998), a theoretical model for the cognitive development of an understanding of 'sound and hearing' was proposed, tested by application to responses from students of various ages, and used as the underlying rationale for the design of a Teaching Unit on 'sound and hearing'. Changes to student understanding resulting from the implementation of the Teaching Unit were monitored in terms of the theoretical model.

This chapter discusses in detail the methods used in the investigation of 'sound and hearing'. Section 4.2 outlines the two major components of the investigation, namely the psychological and the practical components, and the five phases involved in the practical component. Section 4.3 discusses the preliminary investigations prior to the design of the questionnaire used to elicit students' understanding of 'sound and hearing', the actual design of the questionnaire, and the final version used in the research. Section 4.4 details the methods used to analyse students' responses to the questionnaire in order to determine the number of key elements of understanding present and the level of cognitive functioning. Section 4.5 discusses the psychological component, the development of the theoretical cognitive model that forms the basis of this research. Sections 4.6 to 4.9, inclusive, discuss testing the theoretical model by applying it to students of a range of different ages and stages of development and determining whether their responses could be analysed in terms of the theoretical model. Section 4.10 discusses the procedure used to compare the levels of cognitive functioning of different groups of students. The teaching module used in the practical component of the investigation is discussed in Section 4.11. Section 4.12 contains a brief conclusion to this developmental chapter. This leads into Chapter 5 in which the results observed with the target groups of students are discussed.

4.2 Methodology for the investigation of 'sound and hearing'

The investigation had two major components. The first of these, and possibly the most important as it underpinned the subsequent research, was theoretical and involved the establishment of the psychological model for the development of an understanding of 'sound and hearing'. Preliminary investigations were carried out from which a questionnaire was devised to determine students' understanding of the topic. From subsequent student responses to the questionnaire, a model for cognitive development based upon the SOLO Taxonomy of cognitive functioning (Biggs & Collis, 1982; updated 1991) was proposed. The theoretical model was then tested by application to students over a range of age groups and stages of development. Some students were interviewed either individually or in class groups and their responses analysed to see whether the level of cognitive functioning could be determined according to the theoretical model. Other students completed the questionnaire either in the draft form or the final version and their responses were analysed also in terms of the theoretical model.

The second component of the investigation was practical and consisted of the implementation of a Teaching Unit on 'sound and hearing' designed to facilitate the development of a scientific understanding of the topic, together with the monitoring of the level of student understanding over the course of the investigation with the target group. The Teaching Unit was structured in such a way as to 'lead' students along the pathway of developing understanding according to the theoretical model; that is, elements of the hierarchical model were introduced in turn and linked in the sequence proposed in the theoretical model for the development of an understanding of 'sound and hearing'. This notion of 'leading' students was based upon the ideas of Vygotsky who emphasised the need for assisted discovery and guidance by teachers to 'lead' development (see Section 2.2).

The sequence for the practical component of the investigation was similar to that used for 'light and seeing' (Chapter 3). The target group for this research was Year 9 students, aged 13–14 years, from an independent girls' school. This component of the investigation was carried out with two different Year 9 groups, over two consecutive years. Both groups were taught by the researcher.

The practical component of the investigation into 'sound and hearing' consisted of five phases, the first four of which were the same as used in the preliminary investigation into 'light and seeing' :

Phase 1: a pre-instruction phase to elicit students' understanding of the topic, in this case sound and how the sound reaches their ears but not including the physiology of ear functioning;

Phase 2: an intervention or instruction phase using the teaching module developed;

Phase 3: an immediate post-instruction phase to determine whether the teaching module had been effective, that is, whether the students had a clearer understanding of the concepts taught, and, if conceptual change had taken place, to what extent;

Phase 4: a delayed post-instruction phase (five months later) to determine how resistant the conceptual change was and whether or not students had reverted to their pre-instruction notions; and

Phase 5: a 12-month delayed post-instruction phase to determine whether any further changes had taken place. This phase was not included in the investigation into 'light and seeing'.

Data for Phases 1, 3, 4 and 5 were collected using a questionnaire the development of which is discussed in Section 4.3. Data from these phases were analysed in terms of the SOLO Taxonomy, which is discussed in detail in Section 2.5. Details of the method of analysis are contained in Section 4.4.

4.3 Eliciting student understanding

4.3.1 Preliminary investigations

Prior to designing a questionnaire to determine the understanding of the target group with respect to the topic 'sound and hearing', Year 4 students (aged 8–9 years) were interviewed in order to obtain their ideas of the topic and what the word 'sound' meant to them. The purpose of these interviews was to obtain appropriate terms to use in the questionnaire, and to gain some insight into how best to structure the questionnaire and what to include so that it would be understood easily by students of different ages and abilities. The interview was conducted with all the students together in the classroom in a relaxed environment and the questions and student responses were audiotaped. The total number of students was eighteen. The class teacher was present during the interview but played no part in the discussions. The complete transcript of this interview is contained in Appendix 5.

The interview commenced with the question, "What do you think of when I mention the word 'sound'?". The wide variety of students' responses to the question reflected their prior experiences but all were examples of sources of sound. Many examples were associated with their homes, for example, 'washing machine', 'coffee grinder', 'CD player'; many with school, for example, 'scraping fingernails on (black)board', 'pencil' (squeaking when you write); with the environment, for example, 'wind', 'waterfall', 'bird sounds', 'duck quacking'; and some with themselves, for example, 'laughing', 'tummy rumbling'.

Further questioning indicated that the students understood that sound travelled from the source to the ear but, even though one student suggested that sound waves travelled through the air, the majority did not appear to understand what sound waves were nor how they travelled through the air.

One student had completed a project on 'the ear and hearing' in Year 3 and, consequently, appeared to have a good understanding of sound. However, even though this student used the terms 'vibration' and 'sound wave', her responses did not appear to influence the responses of the other students, possibly due to the fact that the other students were unfamiliar with these terms.

At the end of the discussions, the students were asked if they would draw a picture showing how a person could hear a sound, for example, a clock ticking or a bell ringing. Their drawings were subsequently divided into groups on the basis of the links (if any) between the ear and the source of the sound, how those links were represented, and whether or not they indicated a direction of transmission. Samples of these drawings are contained in Appendix 6.

Year 7 students (aged 11–12 years) were interviewed in a similar manner to Year 4 students. The interviews were carried out in two separate class groups in the school science laboratory. The teacher was not present during the interviews as, with these older students, it was thought her presence might inhibit their responses. The total number of students was forty-one. The interviews were audiotaped and transcripts of these are contained in Appendix 7.

The Year 7 students gave responses to the first question similar to those of the Year 4 students but indicative of slightly greater maturity and wider experience. One student gave an example for sound of 'gas' (out of a tap) which she may have encountered at home or in the school science laboratory; another mentioned 'waves at the beach'. Again these responses reflected the students' prior experiences in the home, at school, and in the surrounding environment.

When the class was asked, "How does the sound of my voice get to your ears?", the initial responses 'by listening', and 'by concentrating', were given. This is the notion of 'active listening' observed by Watt and Russell (1990) and by Boyes and Stanisstreet (1991) (see Section 2.7). This had not been mentioned by the Year 4 students. Some of the Year 7 students mentioned 'vibrations in the air' and 'ear drum vibrating when sound wave hits it'. However, when asked how the vibrations get to the ear, they did not appear to know, other than by 'movement of the air' in 'air waves' or 'currents'. Some students stated that they would not be able to hear if there were no air present as "there would be nothing to carry it (the sound)".

These class interviews were useful in eliciting ideas from students of different ages, but they gave no indication of the level of functioning of individual students. Individual interviews or a questionnaire of the type subsequently developed would be required for this. In the class situation some students only will respond and so care must be taken in drawing conclusions from these responses as to the level of functioning of individual students or even of the class group as a whole.

As with the Year 4 students, at the end of the discussions, the Year 7 students were asked to draw a picture showing how a person could hear a sound. These drawings were divided into groups similar to those used for Year 4. Table 4.1 shows the groups into which the drawings of the Year 4 and Year 7 students were divided and the number (percentage) of students in each group. Samples of the Year 7 drawings are contained in Appendix 8.

Table 4.1: Nature of the links between the source of the sound and the ear shown in the drawings of year 4 and year 7 students

Group	Nature of Link between Source and Ear	Number (Percentage) of Year 4 Students (n=18)	Number (Percentage) of Year 7 Students (n=41)
1	single-headed arrows from source to ear	5 (28)	0
2	double-headed arrows linking source to ear	2 (11)	0
3	curved lines radiating out from source, some going to ear	2 (11)	9 (22)
4	link (for example, wavy lines) between source and ear	5 (28)	24 (59)
5	words used to indicate sound travel	0	3 (7)
6	no link drawn between source and ear	4 (22)	5 (12)

The drawings in Group 1, showing single-headed arrows marking the path of the sound to the ear, indicated the notion that sound travels from the source to the ear. The students in Group 2 who used double-headed arrows to link the source of the sound and the ear indicated a link between the source and the ear but did not indicate a direction of travel of the sound.

Students in Group 3 depicted sound with curved lines going from the source to the listener's ear with the curve towards the ear [source))))) ear]. Two students in Group 3 showed the curved lines radiating out in all directions with one set of curves reaching the listener's ear. These students demonstrated their understanding that sound goes out in all directions from the source but that only some of the sound reaches the ear. One student in Group 3 showed the curves facing towards the source, which could be taken to indicate the alternative notion of sound travelling from the ear to the source. Another student drew curves facing in both directions and meeting at a vertical line midway between source and ear, which again illustrated a link between the source and the ear but without showing a direction of travel of the sound.

Students in Group 4 used wavy lines to link the source and the ear. Arrows were not used to indicate the direction of movement or the transmission of the sound but, as the students had been asked to show how they would hear a sound, that is, how the sound would reach their ears, they may have considered the direction of transmission implicit in their drawings. Two students in Year 7 used words accompanying the drawing to demonstrate their understanding.

Group 5 was composed of students who used words only to indicate sound travel from the source to the ear. Students in Group 6 did not show any link between the source of the sound and the ear and four of the five Year 7 students in Group 6 drew the source of the sound only.

Six students (15%) in Year 7 mentioned air. One of these students wrote on her drawing "sound waves carried on the air". This student had indicated an understanding that air was involved in the transmission of sound and that air carried the sound even if she did not understand the mechanism by which this occurred. Three Year 7 students used the term 'vibration' and one of these students wrote "the vibration from the bell travels thought [sic] the air and into the person's ear". Three students in Year 7 used the term 'sound waves' and three also depicted sound bouncing off walls or furniture prior to reaching the ear. Words were not used by the Year 4 students although this may have been due partly to their lack of proficiency in writing rather than to their lack of understanding.

Overall the drawings of the Year 7 students demonstrated that they had a better understanding of how a sound reaches the ear of the listener than did the Year 4 students. As far as can be ascertained none of the Year 7 students had received formal tuition on 'sound'. It is possible that they had gleaned the knowledge demonstrated in their drawings from external sources such as books, television, science club activities (such as involvement in the Double Helix Science Club) or discussions with older students.

The responses and drawings of the Year 4 and Year 7 students were useful in deciding what aspects of 'sound and hearing' should be included and how to phrase the questions that would make up the questionnaire to determine the understanding of the target group. These students were not part of the target group and clarification of the understanding depicted in their drawings was not sought nor was the level of understanding of individual students determined.

4.3.2 Designing the questionnaire

The responses of the students discussed in the previous section, together with situations that demonstrated students' lack of understanding identified in the literature, were used to design a questionnaire similar to that used to determine student understanding of 'light and seeing' (Section 3.2).

One situation, mentioned in the literature and observed by the researcher prior to undertaking this research, was that some students thought that sound could be transmitted in a vacuum. When the students could no longer hear an alarm ringing in a bell jar from which the air had been evacuated, a small number said that it was because the alarm was no longer ringing, even though they could hear it again once the air was let back into the bell jar. They had been told what a vacuum was but they still did not make the connection between the presence of the air and hearing the sound of the alarm. It appeared that they had no notion of the vital role played by the air in the transmission of the sound. An item containing the notion of sound in a vacuum was, therefore, incorporated into the questionnaire. The transmission of sound in different media was also included.

It was of interest to determine how many students adhered to the 'active listening' notion (see Section 2.7), discussed by Watt and Russell (1990) and Boyes and Stanisstreet (1991). Thus this notion was given as one of the options for selection in the questionnaire.

Boyes and Stanisstreet (1991) had observed also in their research that one student thought that sound travelled from the ear to the source of the sound. This reverse notion had been identified too in the drawing of a Year 7 student included in the preliminary investigations of the present research. As a result, this reverse notion was included as an option for selection in the questionnaire.

The draft questionnaire was shown to a senior secondary school Physics teacher and to a University Physics lecturer for their comments and to determine whether they thought the language used was appropriate for middle secondary school students. The questionnaire was given then to 26 Year 10 students (aged 14–15 years) and to 38 first year University Physics students in order to ascertain their responses and to identify any ambiguities in the questions that might confuse the students for whom it was designed. The complete responses of these students are contained in Appendices 9 and 10, respectively.

Some slight modifications were made to the wording of Question Two of the questionnaire as a result of the input from the teachers and students consulted. The modified questionnaire was given then to 24 Year 6 students (aged 10–11 years) to complete prior to giving it to the Year 9 students. The Year 6 students were the youngest group with whom the questionnaire was used. The complete responses of these students are contained in Appendix 11. Each of the three questions comprising the questionnaire used in the investigation of students' understanding of 'sound and hearing' is discussed in Section 4.3.3.

4.3.3 The final questionnaire

Question One (Figure 4.1) of the questionnaire was similar in design to that used by Collis et al. (1998) in their research into 'light and seeing' but, based on the preliminary investigations with Year 4 and Year 7 students discussed in Section 4.3.1, was modified for use in determining student understanding of 'sound and hearing'. This was an open-ended question and showed a drawing of a child and, nearby, a bird in a tree. Students were asked to explain how the child can hear the sound of the bird singing in the tree. Space was given below the drawing for the student's response. This question allowed students to respond in their own words instead of having to choose one of a range of options presented to them.

Question 1 Explain how the child can **hear** the sound of the **bird** singing in the tree.

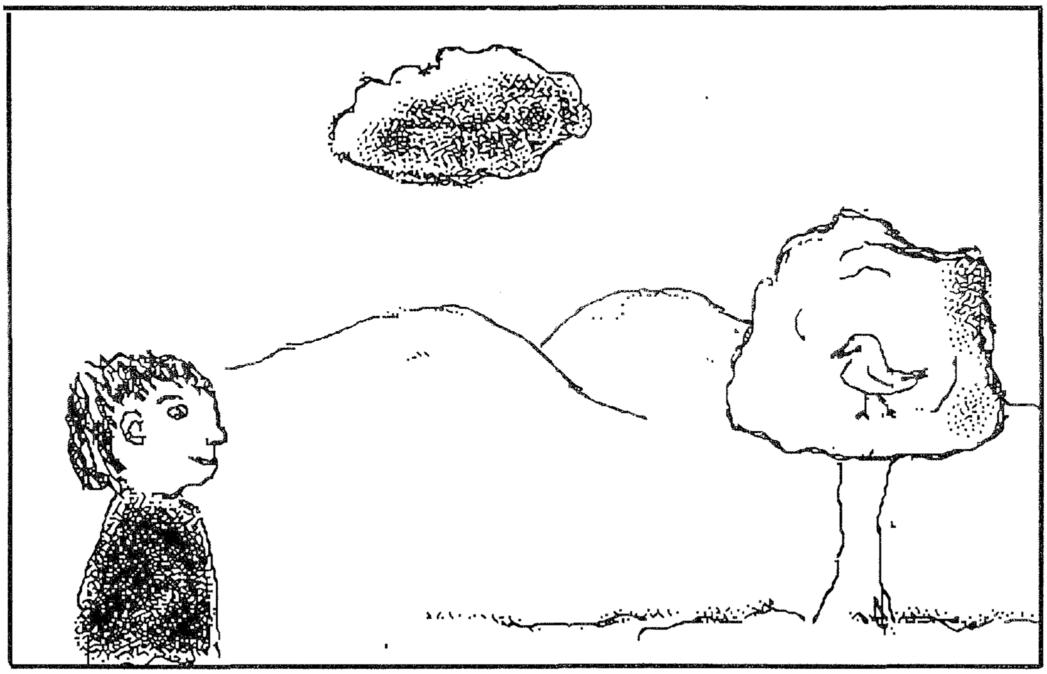


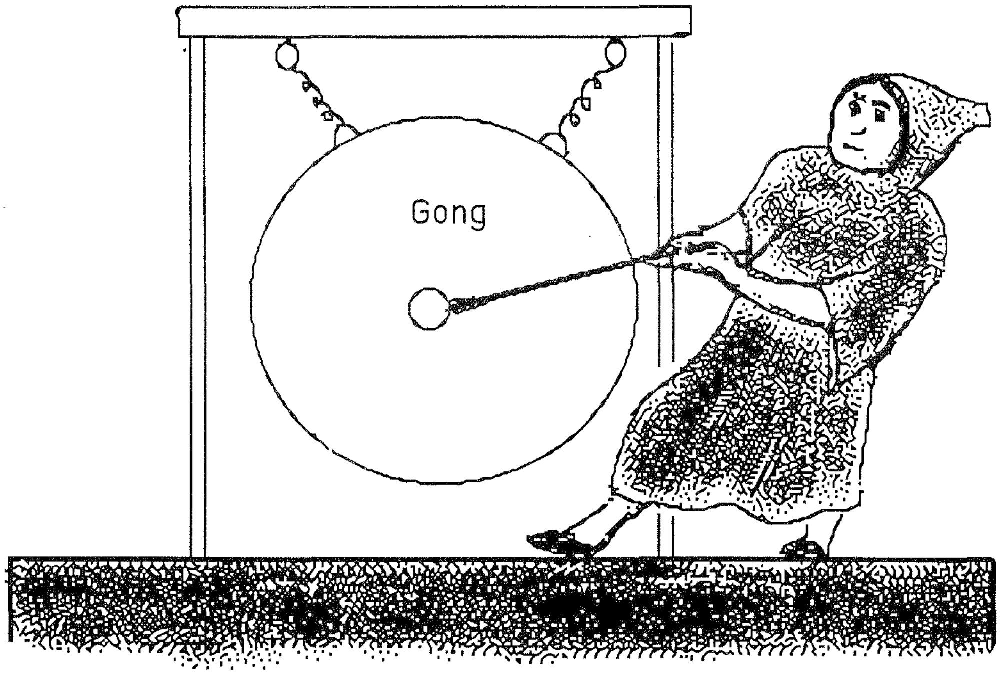
Figure 4.1: Question one of the questionnaire on 'sound'

Question Two (Figure 4.2) consisted of a picture and six suggested notions as to how the student might hear the sound of the gong shown in the picture when it is struck. Students were asked to circle the one sentence that **best** described this. They were asked to say what they thought was wrong with the other sentences. Three lines were given below each statement for the student's response. It was in this question that the notion of 'active listening' as well as that of sound travelling from the ear to the source were given as options for selection.

The combination of the 'free response' question (Question One) and the 'limited selection' question (Question Two) was thought to be effective in determining students' understanding of how sound reaches their ears. Students' responses as to what was wrong in each statement in Question Two were helpful in clarifying their meaning in their responses to Question One and also their reasons for selecting a particular option in Question Two.

Question 2

1. Circle the **one** sentence that **best** describes how **you** hear the sound of the gong when it is struck.
2. For the other sentences, explain what you think is **wrong** with them.



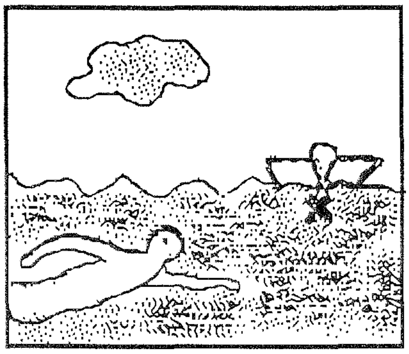
1. The gong makes a sound when it is struck and the sound echoes around the room.
2. The clapper strikes the gong and you concentrate and listen to the sound.
3. The sound waves travel through the air from your ear to the gong when it is struck.
4. The gong sets the air vibrating and the vibrations travel to your ears.
5. The clapper strikes the gong and you hear it with your ears.
6. The gong vibrates when it is struck and you hear the sound.

Figure 4.2: Question two of the questionnaire on 'sound'

Question Three (Figure 4.3) was similar in its format to that used for 'light and seeing' by Collis et al. (1998) in that pictures were used to present various situations for consideration by the students. The question consisted of six drawings.

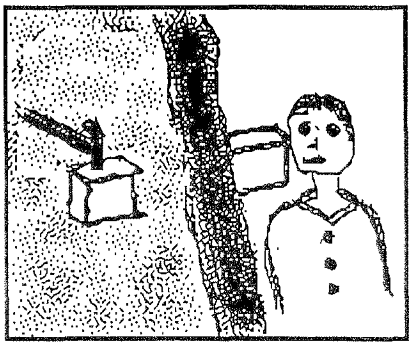
Students were asked to indicate for each drawing whether or not they would be able to hear the sound and to explain how or why not in each case. Three lines were given below each picture for the student's response. The pictures depicted the transmission of sound in a variety of different media: water, steel, string, and air. The situation of the alarm clock ringing in a vacuum (that is, in the absence of the medium) in a bell jar was also included.

Question 3 In **each** of the drawings below, indicate **whether or not** you would be able to hear the sound.
Explain **how** or **why not** in each case.



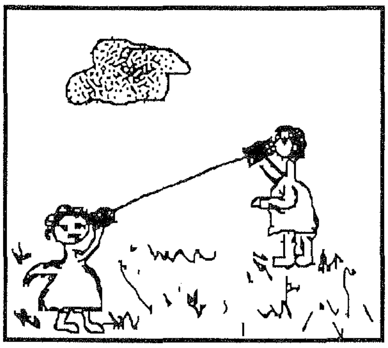
The sound of the boat engine if you were swimming under the water.

Yes/No



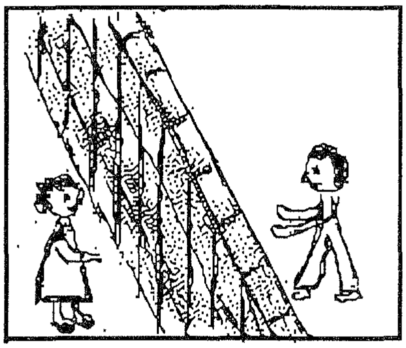
The sound of a hammer being struck on the end of a steel girder protruding through a solid brick wall.

Yes/No



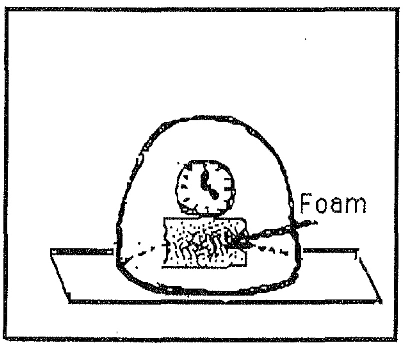
Your friend talking quietly to you on a tight string between two tins.

Yes/No



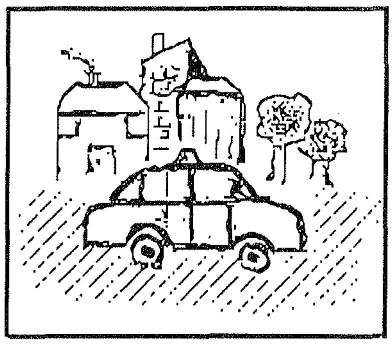
Your friend talking quietly on the other side of a high wall.

Yes/No



The sound of an alarm clock ringing in a vacuum in a bell jar.

Yes/No



The sound of a police siren just after the car has passed by you.

Yes/No

Figure 4.3: Question three of the questionnaire on 'sound'

This questionnaire was used then to determine the level of cognitive functioning of the target group of students at each phase of the practical component of the investigation mentioned in Section 4.2. The methods used to analyse students' responses to the questionnaire and to determine their levels of cognitive functioning are discussed in Section 4.4.

4.4 Procedure for the analysis of the responses to question one of the questionnaire

4.4.1 Identifying the key elements in the responses to question one

Question One was an open-ended question in which students were asked to explain, in their own words, how the child shown in the picture could hear the sound of the bird singing in the tree. The responses were analysed by looking for certain key words or elements in the response that indicated an understanding of how sound is heard, that is, how sound reaches the ear of the listener. The presence of these elements and the building of links between them, leading, finally, to an acknowledgement of the role played by the medium, was postulated to follow a pathway of developing understanding. This developing understanding could be related to the changing level of cognitive functioning given in the SOLO Taxonomy of Biggs and Collis (1991). The theoretical model proposed for the development of an understanding of 'sound and hearing' is discussed in Section 4.5. This will illustrate how the elements discussed here are linked to form a framework of cognitive development.

The elements contained in the responses to Question One were identified and a hierarchy of responses was formulated. The most basic responses to Question One contained mention of the source of the sound (the element 'sound') and/or the ear (the element 'ear') only, for example, 'the bird sings' or 'we hear because we have ears'. More informed responses arose when the student linked these elements together, for example, 'we hear the sound of the bird with our ears' (linking 'sound' and 'ear') or 'the sound travels to our ears' which linked the two elements 'sound' and 'ear' with a third element 'travel'. If the student mentioned the elements 'air' (the medium) or 'vibration' then this was taken to show a greater understanding, for example, 'the sound or sound wave travels through the air to our ears' or 'the vibrations travel through the air'. The most complex responses were found to contain four Key Elements: 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear'. The Key Elements were derived from linking together the elements 'sound' and 'vibration', hence 'vibration of the source'; 'vibration' and 'medium', hence 'vibration of the medium'; 'travel' and 'medium', hence 'travel through the medium'; and 'vibration' and 'ear', hence 'vibration of the ear'. Thus the single elements represented part of the Key Elements of understanding. If the four Key Elements were present in the student's response, and related together in a meaningful way, then the student was considered to have a scientific understanding of 'sound and hearing'.

4.4.2 Determining the level of cognitive functioning

The elements contained in students' responses to the questionnaire were related to the increase in level of cognitive functioning given in the SOLO Taxonomy. The SOLO Taxonomy is discussed in detail in Section 2.5. In this section it will be discussed in relation to the developing understanding of students with respect to 'sound and hearing'. In this research, reference will be made principally to the Ikonic and Concrete Symbolic modes as these are the modes most commonly observed in students in primary and lower to middle secondary school. Within each mode, students' responses become more complex as change is brought about by learning. Only the middle three levels of responses, Unistructural, Multistructural and Relational, postulated by Biggs and Collis (1989), fall within the target modes.

The most basic response to Question One, as mentioned in Section 4.4.1, that is 'the bird sings', was considered Unistructural in the Ikonic mode. This response was intuitive and contained only one element, in this case 'sound', concerned with how a sound reaches the ears. The response 'we hear the sound of the bird with our ears' was considered Multistructural in the Ikonic mode as it contained two elements, 'sound' and 'ear'. Although the element 'sound' was contained in the statement accompanying Question One and was not generated by the students, it was still considered as a unistructural element in the Ikonic mode. The students were aware that there must be a sound for them to hear; in this situation it was created by the bird singing. They then linked this element with the second element 'ear'. A student who linked together the notions of 'sound' and 'ear' with the connecting element 'travel' was considered to be operating at the Relational level in the Ikonic mode. Thus three elements were involved in the development of understanding in the Ikonic mode, 'sound', 'travel' and 'ear'. In some instances it was observed that students used 'sound wave' instead of 'sound', without demonstrating an understanding of the difference, so this was taken still as the element 'sound'.

If the student mentioned 'air' or 'vibration', then this was taken to represent a transition from the Ikonic to the Concrete Symbolic mode as the medium and its role in the transmission of sound, and the notion of 'vibrations', are not intuitive notions but demonstrate a scientific understanding of how sound is propagated. A Unistructural response in the Concrete Symbolic mode would contain the single element 'air' or 'vibration'. Generally, few students were found to be operating at the Unistructural level in the Concrete Symbolic mode. If they acknowledged the medium, then, in most cases, they also mentioned other elements. A response that contained two sequential elements, for example, 'air' and 'vibration', or 'vibration' and 'ear', or 'sound wave' and 'air', was considered Multistructural in the Concrete Symbolic mode. Students who mentioned 'vibrations' were considered to have a slightly better understanding than those who mentioned 'sound waves', even though both were operating at the same level in the mode, as the mention of vibrations indicated a clearer understanding of the nature of the sound wave. Thus, in the Concrete Symbolic mode, two additional elements, 'air' and 'vibration', were involved in the development of understanding. As these were not intuitive notions they were, therefore, not considered elements of the Ikonic mode. Students who included 'vibration' as part of their response no longer included the simpler element 'sound' but demonstrated a more scientific understanding of the nature of the sound. Similarly 'travel' was replaced by 'travel through air' as the student demonstrated an understanding of how sound is transmitted.

If the four Key Elements mentioned in Section 4.4.1, 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear', were present in the response and, more importantly, as also mentioned in the previous section, were linked together in a meaningful way, then the student was considered to be operating at the highest level, the Relational level, within the Concrete Symbolic mode.

Two sub-levels were observed in the Relational level of the Concrete Symbolic mode. These have been designated as R_a and R_b. A student who acknowledged that the sound vibration travelled through the air to the ear was designated as R_a. A student who stated that the air vibrated was designated as R_b as she demonstrated an understanding of how the vibration was transmitted. It appeared that, to the first student, air was merely space, whereas, to the second student, air was an interactive medium, even though both students were operating in the Concrete Symbolic mode and both at the Relational level.

Each student's response to the questionnaire was analysed by identifying the Key Elements, or parts thereof, present. Identification of the Key Elements made it possible to determine the level of understanding of the student with respect to 'sound and hearing', and in which mode of cognitive functioning the student was operating.

4.4.3 Assigning a score for the number of key elements present in the responses to question one

In order to facilitate the analysis of each response, a scoring system was devised that allowed a total score for each response to be assigned on the basis of the number of Key Elements present. Thus students received a score of one for each of the four Key Elements present in their response, giving a maximum total score of four. Some elements, however, constituted part only of the Key Element and were counted as 0.5. For example, if the students used the term 'sound wave' but did not specifically mention 'vibration', or if they stated that the sound 'travelled to the ear' but did not say 'through the air', it was considered that they did not show a full understanding of the nature of sound waves and how they are transmitted. In both cases these examples represented the difference between a student functioning in the Ikonic mode and one functioning in the Concrete Symbolic mode. Thus it was not only the presence of the Key Elements but the nature of those elements and the context in which they were mentioned that indicated the level of understanding. Key Elements present in the students' responses and the score associated with these are shown in Table 4.2.

Table 4.2: Scoring key elements in the responses to question one of the questionnaire

Student Response	Score for Key Element Present
Source produces sound **or** sound wave or Source produces vibrations (vibration of source)	0.5 or 1
Hear with ears **or** sound enters ear (no mention of how ear receives signal) or Vibration of ear	0.5 or 1
Sound, sound wave **or** vibration travels to ear (no mention of medium) or Sound, sound wave **or** vibration travels through air (mention of medium)	0.5 or 1
Mention of air (air as space) or Vibration of air (air as interactive medium)	0.5 or 1

In three of the four boxes shown in Table 4.2, a score of 0.5 is associated with the Ikonic mode. However, in the last box, a score of either 0.5 or 1 is indicative of the Concrete Symbolic mode and represents, instead, the different notions of 'air', either as space or as an interactive medium.

Each response was, therefore, assigned a score for the total number of Key Elements present. This scoring system thus provided a useful tool for analysing the responses of each student and determining the SOLO level at which she was functioning.

Some examples of student responses to the questionnaire with the Key Elements highlighted, the total score assigned, and the corresponding SOLO level, are shown in Table 4.3. The score for each individual element has been included in brackets within the student's response. The examples have been taken from the responses of Year 6 or Year 10 students who completed the questionnaire prior to its implementation with the target group.

Table 4.3: Selected student responses to question one with the number of key elements and SOLO level assigned

Response	Total Number of Key Elements Present	SOLO Level
The boy can hear from his **ears** [0.5].	0.5	IK U
The child can pick up the **sound** [0.5] the bird is making by **sound waves being carried** [0.5] by the wind.	1	IK M
The bird makes a chirping **sound** [0.5] which **travels** [0.5] in sound waves and the child picks up those sound waves and the sound **hits the ear drum** [0.5].	1.5	IK R
The **sound waves** [0.5] **travel** [0.5] from the bird to the child and the sound waves **vibrate through the ear** [1].	2	CS U
The bird sings and **sound waves** [0.5] **travel through the air** [1] [0.5] to the child's **ear** [0.5].	2.5	CS M
The child can hear the bird because when it opens its beak and lets out the **sound** what is actually happening is there are **vibrations** [1] that **travel through the air** [1] [0.5] and end up in the childs **ear** [0.5].	3	CS M
When the bird sings, **sound waves** in the form of **vibrations** [1] **travel through the air** [1] [0.5] and down the ear canal of the child. The **ear drum vibrates** [1].	3.5	CS R_a
The bird uses its voice to create **vibrations of the air** [1] [1] These **vibrations travel** [1] in waves in all directions. Some of these waves travel to the person's ear. The sound enters the ear and sets the **eardrum vibrating** [1].	4	CS R_b

The elements for which a score was assigned are highlighted in each response in Table 4.3. Therefore, taking the response, "The bird makes a chirping **sound** which **travels** in sound waves and the child picks up those sound waves and the sound **hits the ear drum**", as an example, and using Table 4.2 as reference, it can be seen how the score for the Key Elements was assigned. The word 'sound' received a score of 0.5, that is 'source produces sound', part of the Key Element 'vibration of the source'. 'Travels' also received a score of

0.5 for the notion 'sound travels to ear', part of the Key Element 'travel through the medium'. Similarly 'sound hits the ear drum' indicated a partial understanding of 'vibration of the ear' and received a score of 0.5. It could be seen from this response that this student was functioning in the Ikonic mode as there was no mention of 'vibration' or 'air' in her response. She linked together the three Ikonic elements 'sound', 'travel', and 'ear'. This response was, therefore, indicative of the Relational level in the Ikonic mode, and the total score assigned was 1.5.

In the same way, the score was assigned for the response, "When the bird sings, **sound waves** in the form of **vibrations travel through the air** and down the ear canal of the child. The **ear drum vibrates**". 'Sound waves in the form of vibrations' received a score of 1 as this was the Key Element 'vibration of the source'. 'Travel through the air' received a score of 1 for the Key Element 'travel through the medium', in this case 'air', and 0.5 for the mention of 'air' which was part of the Key Element 'vibration of the medium', but did not say that the air itself vibrated. Similarly, 'ear drum vibrates' received a score of 1 as this was the Key Element 'vibration of the ear'. This response was indicative of the Concrete Symbolic mode, R_a level, and the total score received was 3.5.

The response in Table 4.3, designated as CS U level of cognitive functioning, received a score of 2 for the Key Elements present in the response. This response contained only one element 'vibration', indicative of the Concrete Symbolic mode. The remainder of the response was composed of ikonic elements (parts of the Key Elements). This student would have been considered to be functioning in the Ikonic mode if she had not mentioned 'vibration'. She was on the border of the transition from the Ikonic to the Concrete Symbolic mode. As this model is a developmental model encompassing this transition then it would be expected that some students would be observed at this level.

For ease of relating the score received to the level of cognitive functioning, a summary of the relationship between the number of Key Elements and the SOLO level is shown in Table 4.4.

Table 4.4: Relationship between the number of key elements and the SOLO level in the responses to question one of the questionnaire

SOLO Level	Total Number of Key Elements Present
IK U	0.5
IK M	1
IK R	1.5
CS U	2
CS M	2.5 - sound waves 3 - vibrations
CS R_a	3.5
CS R_b	4

Modes: IK = Ikonic CS = Concrete Symbolic

Levels within the mode: U = Unistructural M = Multistructural R = Relational

The Key Elements contained in students' responses to Question One of the questionnaire and the cognitive level determined as a result of those Key Elements were together used to formulate a pathway or map for the development of an understanding of 'sound and hearing' which is discussed in Section 4.5. This network of hierarchical responses involves the building of an understanding of the connection between the source of sound and the ear in terms of vibrations, in the Ikonic and Concrete Symbolic modes of cognitive functioning.

4.5 The development map for hearing

A pathway representing the building of an understanding of 'sound and hearing' was postulated. This pathway is called the Development Map for the Standard Hearing Framework, referred to throughout as the Development Map for Hearing. Initially this has been divided into two sections for ease of presentation.

The theoretical model proposed for 'sound and hearing' is similar to the model of Collis et al. (1998) for 'light and seeing' in that it is built up of individual elements considered elements of understanding. Collis' model is composed of paired combinations of three elements. These paired combinations increase in level of sophistication as understanding develops within the Ikonic and Concrete Symbolic modes. The Development Map for Hearing consists of five individual elements, similar to Collis' 'key' elements, only three of which are involved in the Ikonic mode. The fourth and fifth elements are not introduced until the Concrete Symbolic mode as they are not considered as ikonic or intuitive notions. The elements are linked in pairs at the Multistructural level and in triples at the Relational level. The term Key Element has been reserved in this research for the linked elements 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear', discussed in Section 4.4.

The first section of the Development Map presented is in the Ikonic mode (Figure 4.4), the mode associated with intuitive knowledge, and shows the development of understanding as the student becomes aware of the relationship between the source of the sound and the ear. In this mode students understand that they can hear because they have ears and that the sound travels to their ears. These are intuitive notions and do not indicate a scientific understanding of the nature of sound nor how that sound gets to the ears. From the time when they are very young, students are aware that they hear with their ears and they are used to the idea of talking to someone and knowing that the sound of their voice goes to the ear of the other person.

The links that each student makes between the elements in this Development Map determine the cognitive level at which that student is functioning. As discussed in Section 4.4.2, a student who mentions only one element, either 'sound' as in 'the bird sings', or 'ear' as in 'we hear because we have ears', is operating at the Unistructural (U) level within this mode. If the student links the two elements 'sound' and 'ear' together as in 'we listen, we hear' then that student is functioning at the Multistructural (M) level. A student who states that the source produces a sound that travels to the ear is integrating the three elements, 'sound', 'ear' and 'travel' and is, therefore, operating at the Relational (R) level in the Ikonic mode. The term 'sound wave' has been included in this pathway as it was mentioned by some students although, as mentioned in Section 4.4.2, it appeared that these students did not differentiate between 'sound' and 'sound wave' and this was merely a term that they had encountered in books or on the television and as such was considered an intuitive notion. This is represented in the Ikonic Framework as sound [wave]. In the Concrete Symbolic Framework the bracket is not included as it is anticipated that students will understand the difference between 'sound' and 'sound wave'. The arrows represent the pathway followed by the students as their understanding develops and they link the elements together. Finally they are said to possess the Ikonic Hearing Framework.

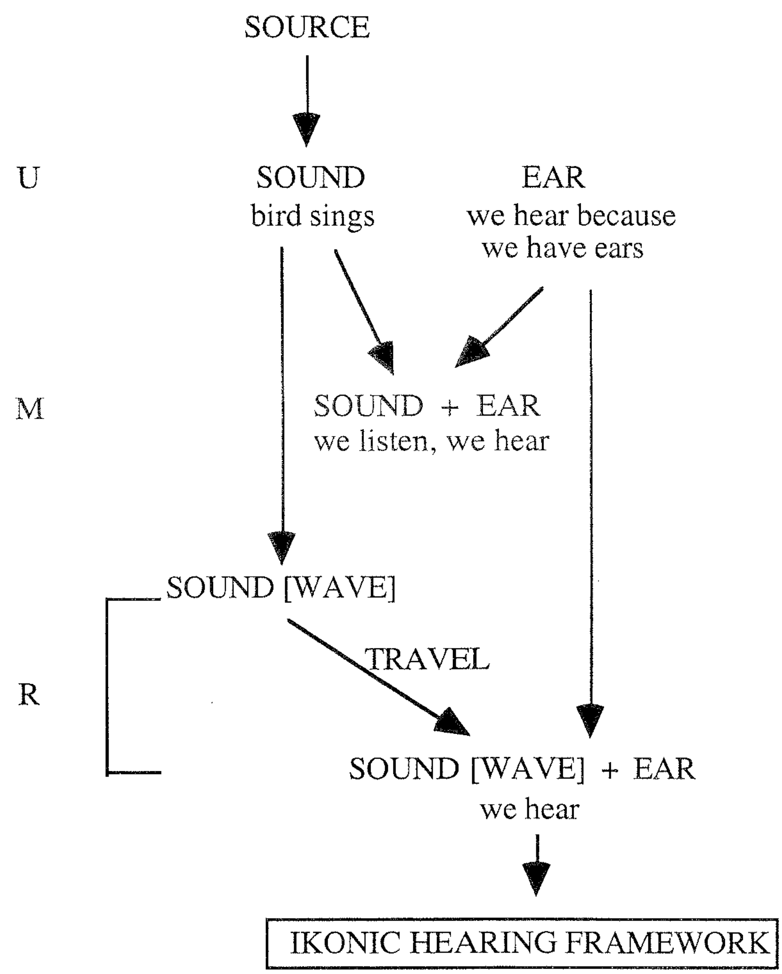


Figure 4.4: Development map for hearing in the ikonic mode

The second section of the pathway refers to the Concrete Symbolic mode of cognitive functioning (Figure 4.5), the mode most commonly associated with upper primary and lower secondary schooling. In this mode, students acknowledge the presence of the medium, in this case 'air'. A student who mentions the single elements 'air' or 'vibration' would be considered Unistructural in the Concrete Symbolic mode. As stated in Section 4.4.3, students observed functioning at this level are on the border of the transition from the Ikonic to the Concrete Symbolic mode. A student operating at the Multistructural level within the Concrete Symbolic mode would link the notions of 'sound wave' and 'air', 'vibration' and 'ear', or 'vibration' and 'air' but would not integrate these paired notions together. The use of the term 'vibration' implies some understanding of the nature of a sound wave. Therefore, although the linking of either 'sound wave' or 'vibration' with 'air' is considered to be Multistructural in the Concrete Symbolic mode, the use of 'vibration' demonstrates a slightly more scientific understanding.

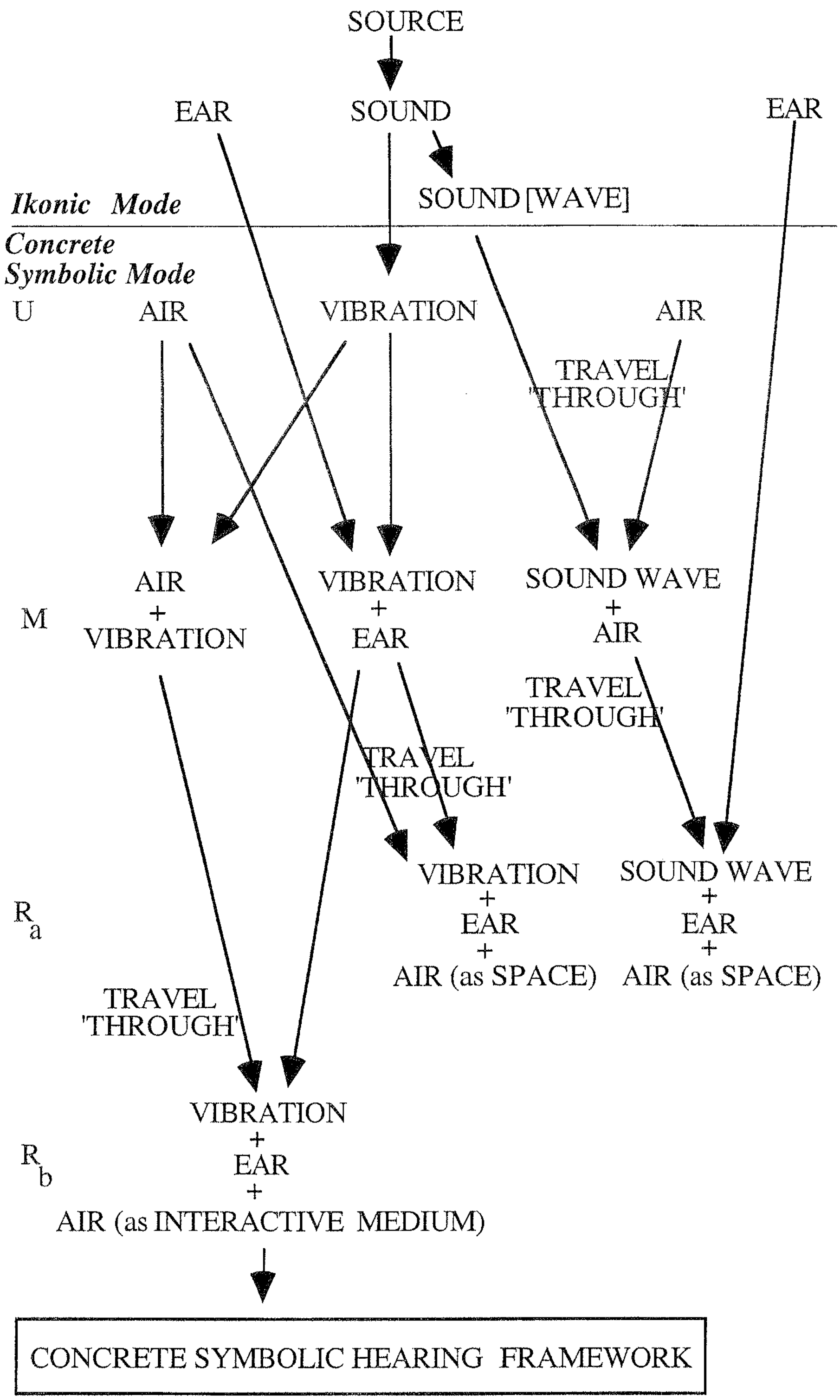


Figure 4.5: Development map for hearing in the concrete symbolic mode

In the Concrete Symbolic mode it was observed that some students stated that sound waves or vibrations travelled through the air, thus recognising the presence of the medium, but they did not appear to understand the role played by the air. For them air was merely space and not an interactive medium the vibration of which is necessary for the transmission of sound. Therefore, as discussed in Section 4.4.2, two Relational (R) levels were postulated for the Concrete Symbolic Mode, R_a in which air is space, as in 'vibrations travel through the air', and R_b in which air is an interactive medium, as in 'vibration of the air'. Once the student integrated the notions of 'vibration of the source', 'travel through the air' (but not necessarily vibration of the air), and 'vibration of the ear' then that student was said to be operating at the R_a level. The student had recognised the importance of the medium but had not yet understood the vital role it plays. When the student included the notion of 'vibration of the medium', then she demonstrated a scientific understanding of how sound travels to the ear and was said to be operating at the R_b level in the Concrete Symbolic mode.

Again the arrows shown in the Development Map represent the pathway followed by the students as they develop an understanding of 'sound and hearing' in the Concrete Symbolic mode. Students may 'travel' one of a number of different paths until the point at which they have linked together the elements 'vibration', 'ear', 'air', and 'travel through the air'.

From the theoretical model it can be seen that it would be possible for a student to relate together the elements 'sound wave', 'ear', and 'air' to produce a Relational response. This was, however, not observed in the responses of the students involved in this investigation and has only been included in the Development Map for completeness and to show that such a response is theoretically possible.

Since the theoretical pathway for the development of an understanding of 'sound and hearing' is a developmental pathway that encompasses the transition from the Ikonic to the Concrete Symbolic mode of cognitive functioning, the two sections have been integrated and are presented in Figure 4.6. Students whose responses to the questionnaire demonstrate that they are functioning at the top level in the Concrete Symbolic mode and possess a scientific understanding of 'sound and hearing' are said to have acquired the Standard Hearing Framework.

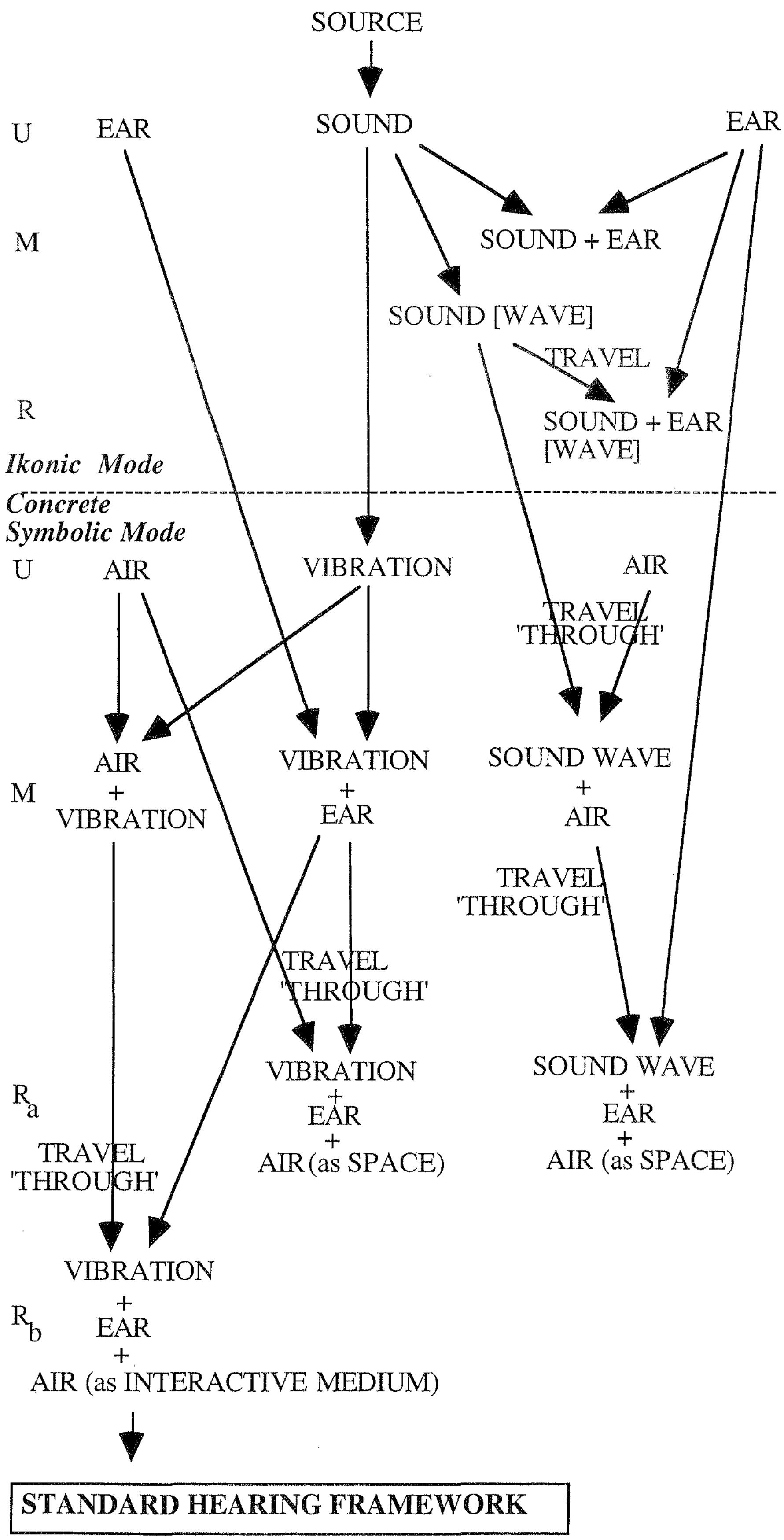


Figure 4.6: Development map for the standard hearing framework

Although identifying the Key Elements in a response, assigning the cognitive level according to the SOLO model, and postulating a Development Map for Hearing to illustrate the developing understanding of the student have been presented in separate sections within this chapter, these have all run concurrently throughout the research. One did not precede the other. Appropriate modifications were made as the model was tested, and the refined model was applied to the responses of the target group of Year 9 students (Chapter 5).

Prior to undertaking the research with the target group of Year 9 students, the model of the Development Map for Hearing was tested by application to the responses of students of a range of ages and stages of development in order to see whether the students' levels of cognitive functioning could be determined using the theoretical model. The findings of this testing are discussed in Sections 4.6 to 4.9, inclusive. Individual Year 1 and Year 3 students were interviewed and the analysis and discussion of these interviews are contained in Section 4.6.1. The responses obtained in the class interviews with Year 4 and Year 7 students (see Section 4.3.1) are re-analysed and discussed in Section 4.6.2. As mentioned in Section 4.3.2, the questionnaire developed for this research was administered to Year 6, Year 10, and Physics 1 students. Analyses of the responses of these students to Question One of the questionnaire are contained in Sections 4.6.3 (Year 6) and 4.6.4 (Year 10 and Physics 1). Section 4.7 discusses the responses of Year 6, Year 10, and Physics 1 students to Question Two of the questionnaire. In Section 4.8, the development of the procedure used for the analysis of responses to Question Three of the questionnaire is discussed and, in Section 4.9, the application of this procedure to testing the model of the Development Map for Hearing with the responses of Year 6, Year 10, and Physics 1 students to Question Three is discussed.

4.6 Testing the model of the development map for hearing from responses to interviews and from the responses to question one of the questionnaire

4.6.1 Interviewing year 1 and year 3 students

Six students from both Year 1 and Year 3 were interviewed. The students were selected by the class teacher on the basis of perceived academic ability as well as willingness to talk to the interviewer and to have their interviews audiotaped. Two students from each class were considered above average ability, two average, and two below average. Each interview lasted about ten minutes. Complete transcripts of the interviews are contained in Appendices 12 (Year 1) and 14 (Year 3). Each student was assigned a number according to the order of the interviews. One of the problems associated with interviewing such young students was getting them to respond to the interviewer. Although the students might talk willingly to the teacher whom they knew, they took some encouragement and gentle prodding to respond to the interviewer. Thus special care had to be taken to avoid cuing the responses.

The interview commenced with the question, "How do you hear a sound?" or "How do you hear the sound of my voice?". All students stated that they heard with their ears. The students were then asked if they would be able to hear underwater or out in space. They were also asked what was between the interviewer and themselves and, when they responded 'air', they were asked if they thought air would be necessary in order to hear and would they still be able to hear if there was no air present.

At the completion of the interviews, the students were asked to draw a picture showing themselves and how they might hear a sound, for example, the interviewer's voice, a dog barking, or a bell ringing. The students' drawings are contained in Appendices 13 (Year 1) and 15 (Year 3).

4.6.1.1 Year 1 students

All the drawings of the Year 1 students showed the listener and the source of the sound but only two of the six students drew a representation of the sound travelling out from the source towards the listener. Student 3 drew lines radiating out from the source, in this case a dog barking, and Student 4 used the word 'meouw' to illustrate the cat mewing. The four students who had not shown a representation of the sound travelling from the source were considered to be operating at the Multistructural level in the Ikonic mode since they indicated the two sequential elements 'sound' and 'ear' as in 'we listen, we hear'. Although only Students 4 and 5 had specifically drawn the ear, all had said in their interviews that they heard with their ears. Students 3 and 4 who represented sound coming out from the source, the notion of sound travelling, were considered to be operating at the Relational level in the Ikonic mode since they had linked the three elements 'sound', 'ear', and 'travel'. They had indicated a relationship between 'sound' and 'ear' in terms of the sound 'travelling' from the source towards the ear, even though they had not drawn the connection completely.

For the Year 1 students, the interviews were thought to be more useful in determining the cognitive level of the individual students than were the drawings. However this young group sometimes required prompting to respond so it is possible that cuing may have occurred inadvertently. It was interesting that three students said quite definitely that they could hear underwater. This appeared to have been an activity that they had experienced. They were more certain about sound travelling underwater than whether they would be able to hear in the absence of air. Two students thought that without air they would not be able to hear because "I think the air would send the sound of my voice to your ears" (Student 3) or because the sound "floats in the air" (Student 2). This acknowledgement of the need for air to be present could be taken to indicate that these students were operating in the Concrete Symbolic mode, possibly at the Multistructural level. They appeared to link the three elements of 'sound', 'ear', and 'air' (medium) together. However, too great an emphasis should not be placed on the students' understanding of the involvement of air as this may have been prompted by the interviewer mentioning 'air' in the question. It was likely that the student who said that the sound "floats in the air" was probably still operating in the Ikonic mode, Relational level, as this appeared to be an intuitive notion. The other four students did not know whether the air was required or not. Even though one said it might be required "because it helps you hear" (Student 6), this appeared to be an intuitive response and, as a result, it was felt that these four students were Multistructural in the Ikonic mode. Table 4.5 shows the SOLO level of each of the students determined from the drawings and from the interviews.

Table 4.5: SOLO level of year 1 students determined from the drawings and from the interviews

	SOLO Level	
Student Number	**From Drawing**	**From Interview**
1	IK M	IK M
2	IK M	IK R
3	IK R	CS M
4	IK R	IK M
5	IK M	IK M
6	IK M	IK M

Modes: IK = Ikonic CS = Concrete Symbolic

Levels within the mode: U = Unistructural M = Multistructural R = Relational

The results obtained with this group of Year 1 students indicated that it was possible to classify the responses and the drawings of the students according to the theoretical model. With one exception in the interviews, all the students were observed to be functioning in the Ikonic mode, the majority at the Multistructural level. The SOLO levels observed with the drawings and the interviews corresponded quite well although it was felt that individual interviews were possibly more reliable with very young students once they had overcome their shyness with the interviewer. The transition from the Ikonic to the Concrete Symbolic mode is postulated by Biggs and Collis (1991) to begin at around six years (refer to Section 4.4 for a detailed discussion of modes and levels of cognitive functioning with respect to 'sound and hearing'). These students were aged 6–7 years and were thus at the stage at which this transition is postulated to begin to occur. Therefore, these results that showed the students to be functioning in the middle and towards the highest level of the Ikonic mode were in good agreement with Biggs and Collis.

4.6.1.2 Year 3 students

The drawings of the Year 3 students differed from those of the Year 1 students in that all except one drew a representation of the sound produced by the source. Student 2 used curved lines, Student 3 straight lines, and Student 6 music notes, to illustrate the sound travelling from the source towards the listener although these 'sounds' did not actually reach the listener. Students 1 and 4 represented the sound produced by the source also but did not show that sound travelling towards the listener. Only one student (Student 5) drew the source and the listener only and did not include any representation of the sound travelling. It appeared then that the three students who represented 'sound' coming from the source towards the listener were operating at the Relational level in the Ikonic mode as they demonstrated a connection or relationship between the two elements 'sound' and 'ear' by illustrating the third element 'travel' in their drawings. Those students who showed only two sequential elements, 'source' or 'sound' and 'ear', without a connecting element, were considered to be operating at the Multistructural level in the same mode.

As with the Year 1 students, the individual interviews appeared to provide a clearer picture of the cognitive level at which the students were operating. Student 3 said that the sound of the interviewer's voice reached her ears by vibration of the air and that out in space you would not hear "without a microphone, because there is no air to vibrate out in space". On the basis of her response, this student was considered to be operating at the Multistructural level in the Concrete Symbolic mode. It was possible that the student had obtained the information about the transmission of sound from sources outside the classroom, such as books, television, or from older family members. The other students interviewed thought air may be important but were not really sure. Student 1 knew that there was no air present in space "because there's no air and you can't breathe unless you have a back thing and there's no water" and, although she thought that air may be required in order to hear, she did not know why. These responses were, therefore, thought to be in the Ikonic mode. Student 2 said that sound reached the ears "by sound waves" and was considered to be operating at the Relational level in the Ikonic mode. The remaining students appeared to be operating at the Multistructural level in this mode. Table 4.6 shows the SOLO level of each of the students determined from the drawings and from the interviews.

Table 4.6: SOLO level of year 3 students determined from the drawings and from the interviews

	SOLO Level	
Student Number	**From Drawing**	**From Interview**
1	IK M	IK M
2	IK R	IK R
3	IK R	CS M
4	IK M	IK M
5	IK M	IK M
6	IK R	IK M

Modes: IK = Ikonic CS = Concrete Symbolic

Levels within the mode: U = Unistructural M = Multistructural R = Relational

The results obtained with the Year 3 students indicated that, as was found with the Year 1 students, it was possible to determine the level at which the students were functioning from both the responses to the interviews as well from the drawings. Again there was fairly good agreement between the levels assigned for both drawings and interviews. The results obtained with the two groups of students were very similar; with the drawings the results were identical. It is difficult to say which medium gave a more accurate picture of the levels of cognitive functioning of the Year 3 students (aged 8–9 years) as they were slightly older than the Year 1 students. It is possible that, as no cuing would have occurred with the drawings and their drawing skills may have been slightly better than the Year 1 students, that the observed outcomes of the drawings may have been more accurate.

4.6.2 Re-analysis of interviews with year 4 and year 7 students

In the preliminary investigations carried out prior to designing the questionnaire, Year 4 and Year 7 students were interviewed in class groups as a starting point for designing the questionnaire. These interviews are discussed in Section 4.3.1. However, once the Development Map for Hearing had been formulated, it was decided to re-analyse the transcripts of the interviews with these students to see if their group responses and their individual drawings supported the proposed model and were indicative of particular cognitive levels.

From the transcript of the taped class interview with Year 4 students (Appendix 5) it appeared that, as a group, the students were operating at the Relational level in the Concrete Symbolic mode of cognitive functioning. This level was determined on the basis of the responses to the question, "How does the sound get to your ears?". The class responded that the sound travelled from the source to the ears in sound waves through the air. Thus they acknowledged the involvement of the medium (air) and linked together the elements 'sound' or 'sound wave', 'ear', and 'travel through the medium'. This observed level was possibly higher than expected for students aged approximately 9 years, since, as mentioned in Section 4.6.1.1, the transition from Ikonic to Concrete Symbolic mode of cognitive functioning is postulated to begin to occur around 6 years. However, as this was an interview with the whole class, this may represent the cognitive level of some of the students only, those who gave the responses. If interviewed individually, the cognitive level at which each student was operating may have appeared to be quite different.

The drawings of each Year 4 student gave a good indication of the level at which that student was operating. Samples of drawings representative of each of the groups into which the drawings were divided are given in Appendix 6. For details of these groups refer to Section 4.3.1. From the drawings it could be seen that the majority of the students were operating in the Ikonic mode at either the Multistructural or Relational level. None of these students specifically indicated 'air' or 'travel through the air' in their drawings although these had been mentioned in the class interview. However, they did illustrate a link between the source of the sound and the ear that implied a movement of the sound (travel) to the ear.

The responses of the Year 7 students (Appendix 7) indicated that, as a group, the class was operating in the Concrete Symbolic mode. According to the theoretical SOLO model this is the cognitive mode expected for students in lower secondary school. These students responded readily to the interviewer and a range of responses was obtained. These included mention of sound waves and of vibrations. Some students appeared aware that sound waves travelled by vibration of the air. This indicated that the class was operating at the Relational level in the Concrete Symbolic mode and that some were functioning at the R_a level, and some even at the R_b level, the highest level according to the theoretical model.

The drawings of the individual Year 7 students indicated that the majority were functioning in the Ikonic rather than the Concrete Symbolic mode. This was a slightly lower level than expected and was possibly due to the students' inability to represent 'air' in their drawings, other than by the use of words. Within the Ikonic mode, students were observed at the Multistructural and Relational levels. Those who drew the source and the ear were considered Multistructural, and those who indicated in their drawings that sound travelled from the source to the ear were considered to be operating at the Relational level. The three students who wrote on their drawings that vibrations travelled through the air were considered to be operating at the R_a level in the Concrete Symbolic mode. None of the students demonstrated in their drawings an understanding of air as an interactive medium but merely of air as space. Samples of drawings representative of each of the groups into which the drawings were divided are given in Appendix 8. For details of these groups refer to Section 4.3.1.

The foregoing discussion indicated that it was possible to classify the class responses and the drawings of the Year 4 and Year 7 students according to the theoretical model of cognitive development. With both groups of students, the outcome observed with the 'class' interview was different from that observed in the drawings of individual students. As 'the class' does not mean 'all students in the class', the interview was not a reliable source of data. More reliable data were obtained from the individual drawings. Individual interviews, or completion of the questionnaire in the case of the Year 7 students, would have been more definitive in determining the cognitive level at which each student was functioning but, as these were not the target group, further investigation was not carried out with these students.

As was observed in Section 4.6.1, with Year 1 students the interviews appeared to provide more reliable data than the drawings possibly due to the lack of skill in drawing of these young students compared with the probing nature of individual interviews. With the Year 3 students the individual interviews and the drawings yielded similar outcomes. Now in this section, it was observed that individual drawings were more reliable than group interviews. This latter observation is not surprising since, as mentioned previously, in a group situation only some students will respond. Thus it can be seen that the most appropriate tool for determining the level of cognitive functioning depends to some extent on the maturity of the students concerned but to be reliable the assessment must be carried out individually.

4.6.3 Year 6 responses to question one of the questionnaire

Prior to giving the final draft of the questionnaire to the target group of Year 9 students, it was given to Year 6 students (aged 10–11 years) in order to determine whether their responses could be classified according to the theoretical model of the Development Map for Hearing. The twenty-four students in this group had not studied 'sound' prior to completing the questionnaire. A complete set of responses is included in Appendix 11.

This young group of students had some difficulty understanding what was required of them, particularly in Question One, so a little more explanation was required prior to commencing the questionnaire, but it was possible to do this without cuing the responses. The responses of the students to Question One (Figure 4.1) were analysed by determining the number of Key Elements present and the cognitive level at which each student was operating. These responses, the number of Key Elements present, and the SOLO level are shown in Table 4.7. Key words or phrases considered as Key Elements of the Development Map and used to determine the SOLO level of the student are highlighted. The score for each individual element has been included in brackets within the student's response. A summary of the class results is given in Table 4.8.

Table 4.7: Number of key elements and SOLO level in the responses of year 6 students to question one of the questionnaire

Student Number	Response	Number of Key Elements Present	SOLO Level
1	Through his **ear** [0.5]. The **vibration** [1] from the bird **travelled** [0.5] to the boys ear.	2	CS U
2	The bird makes a **sound** [0.5] and invisible **sound waves travel through the air** [1] [0.5] and reach his **ear** [0.5].	2.5	CS M
3	The boy's **ears** [0.5] are very sensitive to **noise** [0.5] and can hear the birds sharp chirping.	1	IK M
4	The **ears** [0.5] hear a bird. **Sound travels** [0.5] very fast so almost as soon as the **bird sings** [0.5] the boy hears it even from a great distance the sound reaches him almost immediately.	1.5	IK R
5	He can **hear the bird** [0.5] in the tree because he has **ears** [0.5] and he isn't deaf. He can also hear the bird because he is **listening** [notion of 'active listening']	1	IK M
6	When the bird sings the **sound** [0.5] rings around it when you go so close the **sound waves travel** [0.5] to you and you listen. [notion of 'active listening']	1	IK M
7	With his **ears** [0.5] and his brain and picturing and concentrating on the bird.	0.5	IK U
8	The boy can hear from his **ears** [0.5].	0.5	IK U
9	No response.	–	–
10	The bird would sing and the **sound** [0.5] would **vibrate** [1] **through the air** [1] and reach the child's **ear** [0.5]. Also birds don't sing they whistle.	3	CS M

11	The child can hear the bird because it makes a **sound** [0.5] that can **travel** [0.5] a long distance and so the child can hear it.	1	IK M
12	The child can **hear** [0.5] the bird because he is **listening** [notion of 'active listening'] hard. The bird is using its vocal cords to let the boy hear its beautiful **music** [0.5].	1	IK M
13	The **sound** is a **vibration** [1] and can **travel on air** [1] [0.5] The air carries the vibration to your **ear** [0.5].	3	CS M
14	The boy can hear the bird because the bird **sends out** [0.5] **sound waves** [0.5] which the boy can hear.	1	IK M
15	The bird is making a **sound** [0.5] so the boy can hear it through **sound waves** [0.5].	1	IK M
16	The child can hear the bird singing because the **noise** [0.5] **carries** [0.5] from the bird's mouth into the person's **ear** [0.5] because of the vibration. I don't really know much about it.	1.5	IK R
17	He can hear the bird because he can see it and he **listened** [0.5] [notion of 'active listening'] closely and he can hear the bird. He isn't very far away so the **singing** [0.5] of the bird could be quite loud.	1	IK M
18	The child hears the bird through his **ear** [0.5] after the **sound** [0.5] **has travelled** [0.5].	1.5	IK R
19	The **sound** [0.5] of the bird would **travel** [0.5] from the bird to his **ear** [0.5].	1.5	IK R
20	With its **ears** [0.5].	0.5	IK U
21	The bird sings a tune and the **noise** [0.5] gets **carried** [0.5] into the boy's **ear** [0.5].	1.5	IK R
22	Well the birds pretty close to him. The bird seems to have a higher voice than other creatures so usually you could pick a bird from a dog for example. Also the **sound** [0.5] is coming from a tree so you could figure it out like that.	0.5	IK U
23	Well the birds chirp is loud and the nerves in the boys **ears** [0.5] can sense that it is the birds voice **singing** [0.5] out loud.	1	IK M

24	The bird sings and the **sound waves** [0.5] **travel through the air** [1] [0.5] and the boy picks up the sound with his **ear** [0.5]. He can now hear the bird singing.	2.5	CS M

Table 4.8: Number (percentage) of year 6 students operating at each SOLO level with corresponding number of key elements determined from the responses to question one

SOLO Level [Number of Key Elements] (n=23)								
[0]	**IK U** [0.5]	**IK M** [1]	**IK R** [1.5]	**CS U** [2]	**CS M** [2.5]	**CS M** [3]	**CS R_a** [3.5]	**CS R_b** [4]
0	4 (17)	9 (39)	5 (22)	1 (4)	2 (9)	2 (9)	0	0

From Table 4.8, it can be seen that, of the 23 students who completed the questionnaire, 18 were operating in the Ikonic mode, that is, had between 0.5 and 1.5 Key Elements of the Development Map for Hearing in their responses, and 4 were operating in the Concrete Symbolic mode, holding 2.5 or 3 elements. One student was functioning at the Unistructural level in the Concrete Symbolic mode, that is, she was on the border of the transition from the Ikonic to the Concrete Symbolic mode and her response contained 2 elements of the Development Map. There were no students whose responses contained zero elements of the Development Map, and no students who were operating at the Relational level in the Concrete Symbolic mode. The greatest number of the students (39%) were operating at the Multistructural level in the Ikonic mode. These results were perhaps slightly lower than one would expect for a class at the upper level of primary school even though, as far as could be ascertained, they had not undergone instruction in the topic of 'sound and hearing'. The Concrete Symbolic mode is the mode associated with upper primary and lower secondary schooling (Biggs & Collis, 1991). However not all students will be operating in this mode, a number may still be operating in the Ikonic mode as was observed in this instance. It would be expected that the level at which the students were operating would improve with tuition on 'sound'. The results, however, have demonstrated that the responses of the students to the questionnaire can be classified according to the theoretical model of the Development Map for Hearing.

4.6.4 Year 10 and physics 1 responses to question one of the questionnaire

The responses of the Year 10 and Physics 1 students to Question One of the questionnaire were examined in order to determine whether they too fitted the theoretical model for the development of an understanding of 'sound and hearing'. The complete responses of these students to the questionnaire were not included in the body of the thesis but are contained in Appendix 9 (Year 10) and Appendix 10 (Physics 1). Summaries of the SOLO levels observed with both groups of students are given in Tables 4.9 and 4.10, respectively.

Table 4.9: Number (percentage) of year 10 students operating at each SOLO level with corresponding number of key elements determined from the responses to question one

SOLO Level [Number of Key Elements] (n=26)								
[0]	IK U [0.5]	IK M [1]	IK R [1.5]	CS U [2]	CS M [2.5]	CS M [3]	CS R_a [3.5]	CS R_b [4]
0	0	1 (4)	3 (11.5)	0	4 (15)	5 (19)	10 (39)	3 (11.5)

Table 4.10: Number (percentage) of physics 1 students operating at each SOLO level with corresponding number of key elements determined from the responses to question one

SOLO Level [Number of Key Elements] (n=38)								
[0]	IK U [0.5]	IK M [1]	IK R [1.5]	CS U [2]	CS M [2.5]	CS M [3]	CS R_a [3.5]	CS R_b [4]
0	0	0	1 (3)	1 (3)	9 (24)	4 (10)	16 (42)	7 (18)

From Tables 4.9 and 4.10, it can be seen that the majority of students were operating in the Concrete Symbolic mode and, in the case of the Physics 1 students, most were functioning at the higher levels within that mode. Four students were functioning in the Ikonic mode in Year 10 and only one student was observed in this mode amongst the Physics 1 students.

According to Biggs and Collis (1991), transition from the Concrete Symbolic mode to the next highest mode, the Formal mode, begins to occur around the age of 14 years (Year 10 students are aged around 14–15 years) and the Formal mode is the mode commonly expected for University entrance. Therefore, although the highest mode considered in the present research was the Concrete Symbolic mode, it was expected that all the Physics 1 students would be functioning at or near the top of the Concrete Symbolic mode, whereas nearly one third were observed functioning at the Multistructural level and below. It was also perhaps a little surprising to observe a University Physics student functioning in the Ikonic mode.

These results have demonstrated that the responses of the students to the questionnaire can be classified according to the theoretical model of the Development Map for Hearing, and that the range of cognitive levels at which the students are functioning can be determined.

4.7 Testing the model of the development map for hearing from the responses to question two of the questionnaire

Each of the sentences in Question Two (Figure 4.2), in which students had to select the sentence which 'best' described how they could hear the sound of a gong, reflected elements of the Development Map that were indicative of a particular cognitive level (see Section 4.4 for a discussion of Key Elements and cognitive levels). The sentences were arranged randomly rather than in order of increasing level of understanding. Option 1 ('the gong makes a sound when it is struck and the sound echoes around the room') was indicative of a student functioning at the Unistructural level in the Ikonic mode. Option 2 ('the clapper strikes the gong and you concentrate and listen to the sound') contained the notion of 'active listening' and was indicative of the Ikonic mode, Multistructural level. Option 3 ('the sound waves travel through the air from your ear to the gong when it is struck') was the reverse notion and as such was incorrect, however, it was taken to be indicative of the Concrete Symbolic mode as it mentioned the medium. As there was no recognition of the contradiction by students who selected this option, it was indicative of the Unistructural level in this mode, that is, at the point of transition from the Ikonic to the Concrete Symbolic mode. As discussed in Section 2.5, according to the SOLO Taxonomy, as the level shifts from Unistructural to Relational there is an increased ability to recognise and resolve conflict. Students who do not recognise the conflict in Option 3 are, therefore, considered to be functioning at the Unistructural level. This was also the appropriate level for a response that contained only the single Concrete Symbolic element 'air'. Option 4 ('the gong sets the air vibrating and the vibrations travel to your ears') was the 'best' description and was indicative of a student functioning at the CS R_b level in the Development Map for Hearing. Option 5 ('the clapper strikes the gong and you hear it with your ears') was indicative of the Ikonic mode, Relational level. The final option, Option 6 ('the gong vibrates when it is struck and you hear the sound'), was similar to Option 5 although more 'scientific' in that it mentioned 'vibrations' and, as such, was indicative of the Concrete Symbolic mode, Multistructural level. Thus each statement in Question Two was indicative of a different level of cognitive functioning according to the theoretical model.

The responses to Question Two were not used in the formulation of the Development Map for Hearing nor in assigning each student's level of cognitive functioning but were used as further evidence of the level of students' understanding of 'sound and hearing'. It was observed that Question Two did not discriminate between the cognitive levels at which the students were functioning as well as did Question One. This is illustrated by the data presented in Table 4.11 and discussed below.

The responses of Year 6, Year 10, and Physics 1 students to Question Two were examined to see what percentage of students selected the various options. The results are shown in Table 4.11. In Year 6 the total number of students was 24 but, as one student selected two options, the total percentage was greater than 100%. In Year 10 the total number of students was 26, and for the Physics 1 class, 38. The total percentage for Physics 1 was also greater than 100% as one student selected four of the six options.

The 'best' description was contained in Option 4 ('the gong sets the air vibrating and the vibrations travel to your ears') and, with all three groups, the majority of students selected this option. On the basis of this selection, these students were considered to be operating at the Relational (R_b) level in the Concrete Symbolic mode. A greater percentage of students selected options other than Option 4 in Year 6 than in Year 10, which is not surprising in view of the difference in their stages of development. Three students in Year 6 selected Option 3, the reverse notion, but only one student in Year 10 and none in Physics 1.

As mentioned in Section 4.3.2, it was of interest to determine how many students adhered to the 'active listening' notion, which was Option 2. Students who held this notion linked together the two elements 'sound' and 'ear': 'we listen, we hear' and were considered to be operating at the Multistructural level in the Ikonic mode of the Development Map for Hearing. In contrast to the observations of the earlier researchers (Watt & Russell, 1990; Boyes & Stanisstreet, 1991), there was almost no indication from the responses to Question Two of the questionnaire used in the present research of students holding the 'active listening' notion. It is possible that this may have been more evident in an interview, the mode of investigation used by the other researchers, but in the questionnaire no students selected the 'active listening' notion in either Year 6 or Year 10, and only one student in Physics 1. However, although no students selected the 'active listening' option in Question Two, four students (17%) in Year 6 included this notion in their written responses to Question One (see Table 4.7). This does agree with Watt and Russell (1990) who found the 'active listening' idea present in 18% of 11-year olds, the age of the Year 6 students used in the current research.

Table 4.11: Number (percentage) of year 6, year 10, and physics 1 students selecting a particular option in question two of the questionnaire

	Year Group of Students		
Option Selected	**Year 6** (n=24)	**Year 10** (n=26)	**Physics 1** (n=38)
1	6 (25)	1 (4)	2 (5)
2	0	0	1 (3)
3	3 (12.5)	1 (4)	0
4	12 (50)	23 (88)	34 (89.5)
5	2 (8)	0	1 (3)
6	2 (8)	1 (4)	3 (8)

A discrepancy was observed between the percentage of students operating at each SOLO level determined from the responses to Question One and from the responses to Question Two of the questionnaire. The level of cognitive functioning determined from selecting the 'best' option in Question Two was considerably higher than from the 'free response' Question One. For example, the results for Question Two indicated that 50% of Year 6 students were functioning at CSR_b, the highest level in the Development Map for Hearing, compared with no students functioning at this level determined from Question One (see Table 4.8). From their responses to Question One, nearly all Year 6 students were functioning in the Ikonic mode, the majority at the Multistructural level. This discrepancy was most probably due to the difference between 'creating a response' as in Question One and the easier task of selecting the 'best' item from a list of multiple choice items as in Question Two. A similar, though slightly less marked, discrepancy was observed in the responses of Year 10 (Table 4.9) and Physics 1 (Table 4.10) students to Question One compared with their responses to Question Two, shown in Table 4.11. Again the students performed better on the multiple choice item.

4.8 Procedure for the analysis of the responses to question three of the questionnaire

The Key Elements contained in students' responses and the corresponding cognitive level were determined for Question Three of the questionnaire as had been done for Question One. However, since Question Three (Figure 4.3) involved the transmission of sound in a variety of different media and in the absence of a medium, these responses were not used to formulate the Development Map for Hearing. Instead they were used as further evidence of students' levels of understanding.

4.8.1 Identifying the key elements in the responses to question three

Four Key Elements that demonstrated the level of understanding of the students were identified, but these Key Elements were slightly different from those identified in Question One. Each of the six pictures in Question Three depicted a situation with which students may have been familiar, but the medium involved in the transmission of the sound was not always air. These situations were used to determine whether students understood fully the importance of the medium and, more particularly, the ability of different media to transmit sound vibrations. For this reason, 'identification of the principal medium' was considered a Key Element of understanding as, in some of the pictures in Question Three, there was more than one medium capable of transmitting the vibrations, but only one principal medium.

In this question the Key Element of Question One, 'vibration of the medium', still applied but the medium was not just air as was the case in Question One. It was the demonstration of the understanding of the role of the medium that was the important factor here. The Key Element 'travel through the medium' was also the same as for Question One. The difference between the Key Elements identified in Question One and those identified in Question Three was that 'vibration of the ear' was not considered a Key Element of students' understanding. The 'ear' was considered implicit in the students' responses. 'Vibration of the source' was also not considered a Key Element. With these modifications, the levels of cognitive functioning could be determined from responses to Question Three in the same manner as for Question One.

The fourth Key Element for Question Three was 'correct answer plus correct explanation', that is, 'correct answer as to whether they would hear the sound plus correct explanation of how sound will travel'. Question Three asked students to indicate whether or not they would be able to hear the sound in the situations depicted in each of the pictures, and to explain how or why not in each case. Therefore, their correct answer 'Yes' or 'No' as to whether they would hear the sound, together with their explanation, was considered a Key Element of their understanding. A simple 'Yes' or 'No' would not suffice. To some extent this last Key Element is a combination of the other three, but the complete Key Element does not have to be present for the response to be considered correct. The response may, however, contain parts of the other three Key Elements. As an example, consider the response to Picture (i), "Yes, vibrations are converted into sound waves and can still pass through water due to the oxygen content." The answer is correct, the student will be able to hear the sound, but the mechanism by which the vibrations pass through the water is not correct. A second example, taken from the response of a Year 10 student to Picture (v), is, "No, because the air is compact in the bell jar and is very dense". The student is correct in that the sound would not be heard but the reason is incorrect as there is no air present in the bell jar. Thus both responses contain part only of the Key Element of understanding 'correct answer plus correct explanation'.

Thus the four Key Elements for Question Three were 'vibration of the medium', 'identification of the principal medium', 'travel through the medium', and 'correct answer plus correct explanation'. If, as stated in Section 4.4.1 for Question One, the four Key Elements were present in the student's response and related together in a meaningful way then the student was considered to have a scientific understanding of 'sound and hearing'. The allocation of the score for the Key Elements, or parts thereof, present in the students' responses is discussed in Section 4.8.3.

4.8.2 Determining the level of cognitive functioning

The elements contained in students' responses to Question Three of the questionnaire were related to the increase in level of cognitive functioning given in the SOLO Taxonomy (see Section 2.5), in the same way as for Question One. Each student's response to the questionnaire was analysed by identifying the Key Elements, or parts thereof, present. Thus the level of understanding of the student with respect to 'sound and hearing' could be determined. The relationship between the number of Key Elements and the SOLO level observed in the responses to Question Three was the same as that used for Question One (see Table 4.4).

As Question Three dealt with the transmission of sound in different media, responses acknowledging the role of the medium were indicative of a student functioning in the Concrete Symbolic mode of the Development Map for Hearing since it was in this mode, rather than in the Ikonic mode, that the medium was an element of understanding. The notion of 'vibrations' was, similarly, indicative of a student functioning in the Concrete Symbolic mode.

Since responses containing the four Key Elements discussed in Section 4.8.1 are indicative of students functioning in the Concrete Symbolic mode rather than the Ikonic mode, then the most basic response in this mode would contain mention of one element only of the Development Map for Hearing, either 'medium' or 'vibration'. For example, the response, "No because there is no air in the bell jar" (Picture (v)) contained the single Concrete Symbolic element 'air' which, in Question Three, was the Key Element 'identification of principal medium', and was indicative of a student functioning at the Unistructural level in that mode. If the student mentioned two elements of the Development Map, 'medium', the Key Element for Question Three of 'identification of principal medium', and 'vibration', part of the Key Element 'vibration of medium', then her response would be considered Multistructural in the Concrete Symbolic mode.

Key Elements for Question Three are extensions of the elements of the Development Map for Hearing in the Concrete Symbolic mode, 'medium', 'vibration', and 'travel through medium'. 'Medium' gives rise to 'identification of the principal medium'; 'vibration' gives rise to 'vibration of the medium'; and 'travel through the medium' is the same for both Questions One and Three. Recognition of the principal medium is a key indicator of understanding as it acknowledges both the necessity for a medium and the fact that other materials besides air can function as media for the transmission of sound. The increasing structural complexity of responses to Question Three is similar to Question One but the emphasis is more on the application of the medium and less on the origin and destination of the sound.

As the 'ear' was not considered a Key Element of understanding in Question Three, then it can be seen that it was the left hand side of the Development Map for Hearing (Figure 4.6) only that was involved in this context. As was discussed in Section 4.5 in relation to responses used in the formulation of the Development Map, in the theoretical model it would be possible for a student to relate the element 'sound wave', rather than 'vibration', together with the elements 'air' ('medium') and 'travel through medium' to produce a Relational response, as illustrated by the right hand side of the Development Map. This too would be possible theoretically in responses to Question Three but again, as mentioned for Question One, this was not observed. It was observed instead that when students were functioning at the Relational level of the Concrete Symbolic mode, they appeared to have developed beyond the notion of 'sound wave' to a scientific understanding of 'vibration'.

If the four Key Elements for Question Three mentioned in Section 4.8.1, 'vibration of the medium', 'identification of the principal medium', 'travel through the medium', and 'correct answer plus correct explanation', were present in the response and, as mentioned previously, were linked together in a meaningful way, then the student was considered to be operating at the Relational level in the Concrete Symbolic mode. In Question Three, responses indicative of the Ikonic mode arose when students omitted mention of 'vibration' or 'medium' or their responses contained part only of the Key Elements of understanding identified for Question Three. An example of an Ikonic response is given by, "Yes because the sound waves travel over the wall". There is no mention of the medium nor of vibrations and the response contains part only of the Key Elements 'travel through the medium' and 'correct answer plus correct explanation'. If this response is matched to the Development Map for Hearing, it can be seen that this response is at the Relational level in the Ikonic mode. Other examples of Ikonic responses are given in Table 4.13.

4.8.3 Assigning a score for the number of key elements present in the responses to question three

As had been done for the responses to Question One, a scoring system was devised that allowed a score for each response to be assigned on the basis of the number of Key Elements present. Students received a score of one for each of the four Key Elements present in their responses, giving a maximum total score of four. Some elements, however, constituted part only of the Key Element, and received a score of 0.5, for example, if a student stated that the swimmer shown in Picture (i) (see Figure 4.3) would hear the sound because of the air in the water transmitting the vibrations rather than the water itself doing so. The student has identified the need for a medium and has understood the role of air as a medium and that vibrations travel through the medium, but has not understood that water too can act as a medium for the transmission of sound and is the principal medium in this situation. Therefore, she would receive a score of 0.5 for part of the Key Element 'identification of the principal medium'. She would receive a score of 0.5 also for part of the Key Element 'correct answer plus correct explanation'. For this latter Key Element, the response 'Yes' or 'No' as to whether the student would hear the sound in the picture would receive a score of 0.5 if the answer was correct, but, either there was no explanation as to 'how' or 'why', or the explanation was incorrect.

Similarly, in Picture (ii), the principal medium for the transmission of the sound was the steel girder. The hammer strikes the steel and the listener has her ear close to the end of the girder. If the student said that the vibrations travelled through the air then she has demonstrated an understanding of air only as a medium and would receive a score of 0.5 for identifying one possible medium.

Similar situations arose with Picture (iii), in which the principal medium was string, and Picture (iv) in which the medium was air. In each situation, it was the nature of the explanation rather than merely the correct 'Yes' or 'No' that allowed the level of understanding of the student to be determined. The key factor here was whether the students understood, not only the role of the medium, but also that other media besides air can transmit sound vibrations. For example, in the case of the 'string telephone' (Picture (iii)), a Year 6 student stated correctly, "Yes", she would hear the sound, but her explanation was, "I've tried it before and I can hear whoever is whispering". She received a score of 0.5 only as, although her answer was correct, her explanation was intuitive, based on experience, and did not demonstrate an understanding of how the sound was transmitted. This last example is discussed in greater detail following Table 4.13.

The situation of the alarm clock in the bell jar (Picture (v)) was used to determine whether the students understood that in a vacuum there are no air particles present to vibrate and, therefore, transmission of the sound cannot occur. In the final picture (Picture (vi)), in which the medium was air, students showed whether they understood that sound vibrations travel outwards in all directions from the source through the air. Key Elements present in students' responses and the score associated with these are shown in Table 4.12.

Table 4.12: Scoring key elements in the responses to question three of the questionnaire

Student Response	Score for Key Element Present
Mention of vibrations or Vibration of the medium	0.5 or 1
Identification of other possible media or Identification of principal medium	0.5 or 1
Sound, sound wave **or** vibration travels or Sound, sound wave **or** vibration travels through the medium	0.5 or 1
Correct answer 'Yes' or 'No' or Correct answer 'Yes' or 'No' with correct explanation	0.5 or 1

As previously stated, the same relationship between the total number of Key Elements present in the response and the SOLO level applied as for Question One (see Table 4.4).

Some examples of student responses to Question Three with the Key Elements highlighted, the total score assigned, and the corresponding SOLO level, are shown in Table 4.13. As there were six different pictures for the students to examine, the examples have been selected from different pictures. The picture from which the response has been taken is noted in the table. As before, the examples have been taken from the responses of Year 6 or Year 10 students.

Table 4.13: Selected student responses to question three with the number of key elements and SOLO level assigned

Response	Total Number of Key Elements Present	SOLO Level
No, because your ears would be **blocked** [0.5, sound travels] from the water . [Year 6, Picture (i)]	0.5	IK U
Yes [0.5], I've tried it before and I can **hear** whoever it is **whispering** [0.5, sound travels]. [Year 6, Picture (iii)]	1	IK M
Yes [0.5] because the **sound waves travel** [0.5]**over the wall** [0.5, other medium]. [Year 6, Picture (iv)]	1.5	IK R
No [1] because there is no **air** [1] in the bell jar. [Year 6, Picture(v)]	2	CS U
Yes [0.5], **vibrations** [0.5] are converted into sound waves and can still **pass through water** [1] **due to the oxygen content** [0.5]. [Year 10, Picture (i)]	2.5	CS M
Yes [1], the **sound** would **vibrate** [0.5] **along** [0.5] the **girder** [1]. [Year 6, Picture (ii)]	3	CS M
Yes [1], because the **vibrations** [0.5] **travel through** [1] **the string** [1]. [Year 6, Picture (iii)]	3.5	CS R_a
No [1], because **sound waves cannot travel** [1] through a vacuum - there's **no air** [1] **to set vibrating** [1]. [Year 10, Picture (v)]	4	CS R_b

The selected responses given in Table 4.13 illustrate the gradual increase in the complexity of responses as the level of understanding of students increases. Students whose responses make no mention of the medium are considered to be operating in the Ikonic mode, and the number of Key Elements present in their responses varies from 0.5 to 1.5 as the level increases from Unistructural to Relational. The student in Table 4.13 whose response received a score of 2 was considered to be Unistructural in the Concrete Symbolic mode. She had correctly identified the medium in Picture (v) but her response contained only one element of the Development Map for Hearing.

The elements for which a score was assigned are highlighted in each response in Table 4.13. Therefore, taking the response, "**Yes**, I've tried it before and I can **hear** whoever it is **whispering**", as an example, and using Table 4.12 as reference, it can be seen how the score for the Key Elements was assigned. The response 'Yes' received a score of 0.5 only as, although the answer was correct, the student had not explained 'how' the sound was transmitted. Based on her prior experience, she gave the intuitive (Ikonic) response, "I've tried it before". 'Hear' and 'whispering' together illustrated the student's understanding that sound travelled to her from the person making the sound, which was part of the Key Element 'travel through the medium' and as such received a score of 0.5. Thus the total score for this response was 1 and was indicative of a student functioning at the Multistructural level in the Ikonic mode.

Similarly, the score for the response, "**No**, because there is no **air** in the bell jar" was assigned. The response 'No, because ----' received a score of 1 as this was the Key Element 'correct answer plus correct explanation'. 'Air' received a score of 1 also as this was the Key Element 'identification of principal medium'. The total score assigned was 2. The student had understood that the medium 'air' had been removed from the bell jar, but she had not stated the significance of this. She had mentioned only one element of the theoretical pathway. This was an example of a Unistructural response in the Concrete Symbolic mode.

In the same way the score was assigned for the response, "**Yes, vibrations** are converted into sound waves and can still **pass through water due to the oxygen content**". The response 'Yes' received a score of 0.5 for the correct answer but an incorrect explanation as to how the sound was transmitted. The word 'vibrations' received a score of 0.5 also as this was part of the Key Element 'vibration of the medium'. 'Pass through water' received a score of 1 for the Key Element 'travel through the medium', and 'due to the oxygen content' received a score of 0.5 for identification of the involvement of a medium, although not the principal one. Thus the total score assigned to this response was 2.5, which was indicative of the Multistructural level in the Concrete Symbolic mode.

Terms such as 'sound wave', 'vibration', and 'travel through the medium', appeared in the responses as the level within the Concrete Symbolic mode increased and, most importantly, as there was recognition of the role of the medium and that other media besides air can transmit sound vibrations. The increasing hierarchy of responses corresponded to the increase in level of cognitive functioning postulated in the Development Map for Hearing (see Figure 4.6).

Once the increasing structural complexity of responses to Question Three and the relationship of these responses to the theoretical Development Map for Hearing had been defined, it was decided to look at the responses of students who completed the questionnaire prior to its implementation with the target group, in order to see whether their responses 'fitted' the theoretical model.

4.9 Testing the model of the development map for hearing from the responses to question three of the questionnaire

The responses of Year 6, Year 10, and Physics 1 students to Question Three of the questionnaire were analysed to ascertain whether the cognitive levels at which these students were functioning could be determined according to the theoretical model. As only the data obtained from the questionnaire were available to test the theoretical model, this section is smaller than the equivalent section (Section 4.6) for the analysis of Question One in which data obtained from interviews and from drawings were available also. The complete responses of the students are contained in Appendices 9 (Year 10), 10 (Physics 1), and 11 (Year 6). With the Year 6 students, the words 'vacuum' and 'girder' in Question Three had to be explained to the students prior to commencing the questionnaire, but it was thought possible to do this without cuing the responses. The number (percentage) of students functioning at each SOLO level, with corresponding number of Key Elements, for each picture in Question Three, is given in Tables 4.14 (Year 6), 4.15 (Year 10) and 4.16 (Physics 1).

Table 4.14 Number (percentage) of year 6 students operating at each SOLO level with corresponding number of key elements determined from the responses to question three

	SOLO Level [Number of Key Elements] (n=24)								
Picture	[0]	IK U [0.5]	IK M [1]	IK R [1.5]	CS U [2]	CS M [2.5]	CS M [3]	CS R_a [3.5]	CS R_b [4]
(i)	1 (4)	4 (17)	8 (33)	2 (8)	2 (8)	1 (4)	4 (17)	2 (8)	0
(ii)	1 (4)	5 (21)	5 (21)	5 (21)	1 (4)	3 (12.5)	2 (8)	1 (4)	0
(iii)	4 (17)	4 (17)	3 (12.5)	1 (4)	1 (4)	3 (12.5)	3 (12.5)	5 (21)	0
(iv)	3 (12.5)	5 (21)	10 (42)	4 (17)	1 (4)	0	0	0	0
(v)	12 (50)	2 (8)	1 (4)	0	3 (12.5)	0	3 (12.5)	0	0
(vi)	0	13 (54)	6 (25)	3 (12.5)	0	1 (4)	1 (4)	0	0

[1 student did not respond to Picture (ii), 1 to Picture (iv), and 3 to Picture (v)]

Those students in the above table whose responses were found to contain zero Key Elements either wrote a response that showed no understanding of the transmission of sound in the situation depicted, or the response was irrelevant. This was more evident with the Year 6 students than with the older Year 10 or Physics 1 students. Some examples of such responses, taken from the responses of Year 6 students, were given by: "No, I don't know why because I think it depens [sic] on personality. Some people talk loud and others think they are shouting" (Student 9, Picture (iv)); "No, but nearly" (Student 19, Picture (iii)); "No, because alarm clocks wake me up" (Student 20, Picture (v))

Table 4.15 Number (percentage) of year 10 students operating at each SOLO level with corresponding number of key elements determined from the responses to question three

	SOLO Level [Number of Key Elements] (n=26)								
Picture	[0]	IK U [0.5]	IK M [1]	IK R [1.5]	CS U [2]	CS M [2.5]	CS M [3]	CS R_a [3.5]	CS R_b [4]
(i)	2 (8)	0	2 (8)	1 (4)	0	2 (8)	8 (31)	11 (42)	0
(ii)	0	1 (4)	3 (11.5)	5 (19)	2 (8)	5 (19)	3 (11.5)	6 (23)	1 (4)
(iii)	0	3 (11.5)	0	0	1 (4)	3 (11.5)	8 (31)	7 (27)	3 (11.5)
(iv)	1 (4)	2 (8)	12 (46)	6 (23)	0	3 (11.5)	1 (4)	1 (4)	0
(v)	1 (4)	1 (4)	4 (15)	3 (11.5)	0	3 (11.5)	6 (23)	3 (11.5)	3 (11.5)
(vi)	1 (4)	3 (11.5)	5 (19)	8 (31)	3 (11.5)	0	4 (15)	1 (4)	1 (4)

[1 student did not respond to Picture (iii), and 2 to Picture (v)]

Table 4.16 Number (percentage) of physics 1 students operating at each SOLO level with corresponding number of key elements determined from the responses to question three

	SOLO Level [Number of Key Elements] (n=38)								
Picture	[0]	IK U [0.5]	IK M [1]	IK R [1.5]	CS U [2]	CS M [2.5]	CS M [3]	CS R_a [3.5]	CS R_b [4]
(i)	0	2 (5)	3 (8)	0	0	2 (5)	19 (50)	2 (5)	10 (26)
(ii)	0	3 (8)	0	1 (3)	2 (5)	0	14 (37)	3 (8)	14 (37)
(iii)	0	2 (5)	0	0	0	0	17 (45)	6 (16)	11 (29)
(iv)	0	2 (5)	0	18 (47)	3 (8)	1 (3)	2 (5)	1 (3)	10 (26)
(v)	2 (5)	0	1 (3)	0	2 (5)	1 (3)	18 (47)	5 (13)	7 (18)
(vi)	0	4 (11)	1 (3)	16 (42)	5 (13)	0	7 (18)	0	3 (8)

[1 student did not respond to Picture (ii), 1 to Picture (iv), and 2 to each of Pictures (iii), (v) and (vi)]

From Table 4.14, it can be seen that the majority of Year 6 responses are indicative of students functioning in the Ikonic mode and from Table 4.16 that the majority of Physics 1 responses are indicative of students fuctioning at the higher levels within the Concrete Symbolic mode. The Year 10 students (Table 4.15) occupy a position between the two, but not greatly different from the Physics 1 students. In some instances, particularly with Year 6 students, it can be seen that, as expected in a developmental model, students function better if the situation is one with which they are familiar, for example, Picture (iii), the string telephone. Similarly, they function poorly if they are unfamiliar with the situation, for example, Picture (v), transmission in a vacuum.

These results have demonstrated that students' responses to Question Three can be analysed in terms of the theoretical Development Map for Hearing. The observed outcomes are in accordance with the theoretical SOLO model of Biggs and Collis (1991), which states that transition from the Ikonic to the Concrete Symbolic mode begins to occur around 6 years (Year 6 students are aged 11 years), and from the Concrete Symbolic to the Formal mode around 14 years, the age of the Year 10 students. Although this research did not include data on the Formal mode of Biggs and Collis, mention has been made of this to draw attention to the ceiling effect for formal thinkers on the questions used to determine levels of understanding with respect to 'sound and hearing'. It is perhaps surprising that a number of Physics 1 students were observed functioning in the Ikonic mode. It would be expected that, since these students are studying University Physics, they would all be functioning at the highest levels in the Concrete Symbolic mode.

4.10 Comparing the overall performances of students using the combined total scores for question one and question three

As the the levels of cognitive functioning of students had been determined from the responses to Question One (Section 4.6), and from the responses to the six pictures of Question Three (Section 4.9), the scores allocated for responses to these two questions were combined in order to facilitate the task of comparing the overall performance of different groups of students. Question Two was not included as it had been observed that students performed better on this multiple choice question than on Questions One and Three in which they had to write their own explanations (see Section 4.7) and, as a result, there was less discrimination between students' cognitive levels observed with Question Two. Question One examined students' understanding of the transmission of sound in a single context only, in which the medium involved was 'air'. Question Three, on the other hand, involved the transmission of sound in a variety of different media and in the absence of a medium. Thus Question Three determined whether students were able to apply their knowledge of the relatively simple situation of Question One to other settings. Those students who were able to do this successfully thus demonstrated a more complete understanding of 'sound and hearing' and of the role of the medium. By combining the scores for the two questions, it was possible to discriminate more effectively between the performance across tasks of different groups of students. The number (percentage) of Year 6, Year 10, and Physics 1 students in each designated range of combined total score from Question One and Question Three is given in Table 4.17.

Table 4.17 Number (percentage) of year 6, year 10, and physics 1 students in each range of combined total score for question one and question three

	Number (Percentage) of Students in each Year Group		
Combined Total Score	**Year 6** (n=24)	**Year 10** (n=26)	**Physics 1** (n=38)
0–5	6 (25)	0	0
5.1–10	9 (38)	2 (8)	2 (5)
10.1–15	7 (29)	6 (23)	4 (11)
15.1–20	2 (8)	13 (50)	16 (42)
20.1–25	0	5 (19)	13 (34)
25.1–30	0	0	3 (8)

From the data presented in Table 4.17, graphs, showing the percentage of students in each range of combined total score, were drawn to enable comparison of the three groups of students to be made more readily, rather than comparing columns of figures. These are shown in Figure 4.7. The graphs are aligned one above the other to facilitate the comparison.

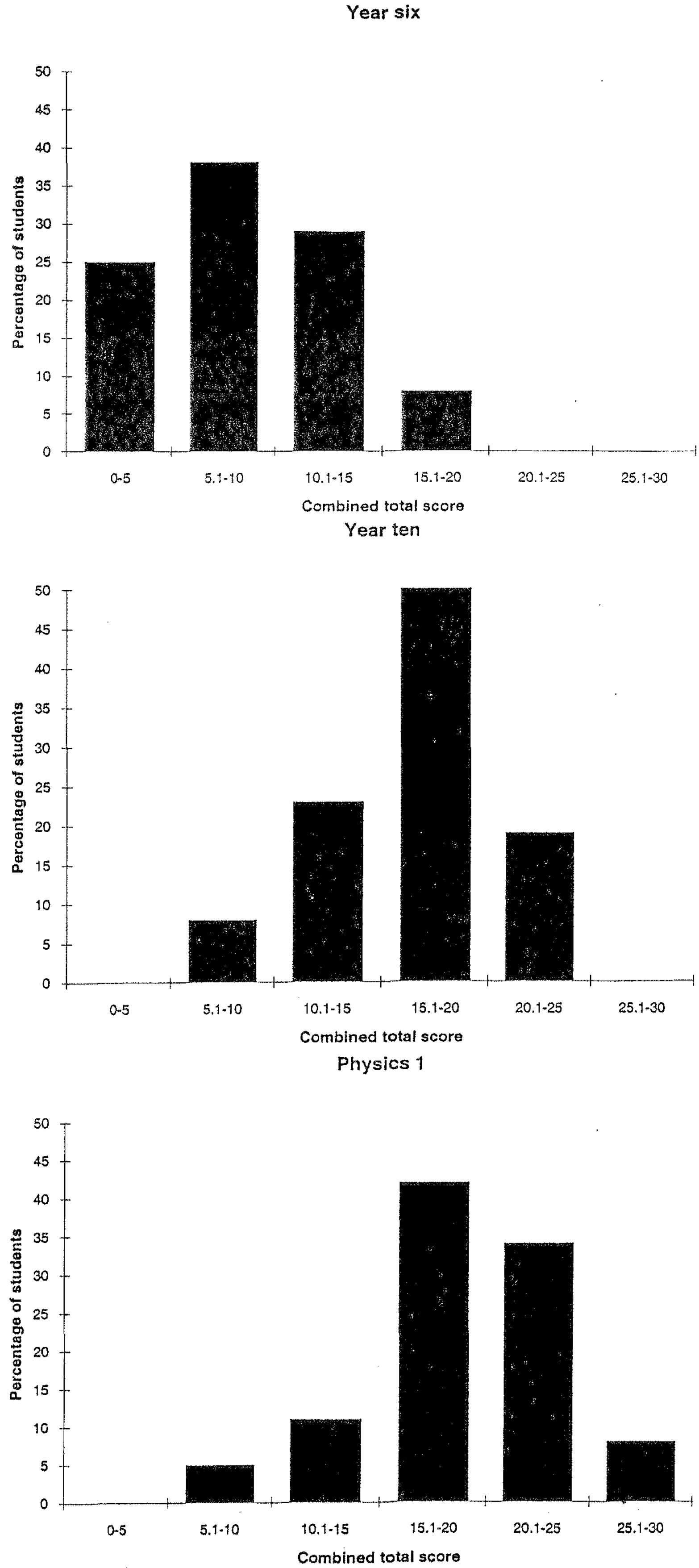


Figure 4.7 **Graphs showing the percentage of year 6, year 10, and physics 1 students in each range of combined total score for question one and question three**

From the graphs shown in Figure 4.7, it can be seen that there was a shift towards the higher range of combined total scores for Questions One and Three from Year 6 to Year 10, and from Year 10 to Physics 1 students. The improvement was most marked between Year 6 and Year 10, which was to be expected as the theoretical model is a developmental model and cognitive development occurs as the students mature. The trend was less marked from Year 10 to Physics 1 but this too was as expected since, according to the SOLO model, these students would be functioning at the highest levels in the Concrete Symbolic mode. However, as not all students conform in a developmental model, some students are observed in lower ranges than hypothesised.

The trends shown in the graphs illustrated the usefulness of the theoretical model for determining the cognitive levels at which students were functioning with respect to 'sound and hearing', as well as for predicting the cognitive levels at which other groups of students would be expected to function. The data also indicated that the model will serve as a useful tool for monitoring changes brought about by teaching. The success of the developmental model with Year 6, Year 10, and Physics 1 students thus augured well for its use with Year 9 students.

This chapter has discussed the development of the questionnaire designed to elicit student understanding of 'sound and hearing', the formulation of the theoretical model for the development of an understanding of 'sound and hearing', and the testing of the theoretical model by application to the responses of students of a range of ages and stages of development. The trends observed indicate that the model should work well with the Year 9 target group of students, and that it should be possible to monitor changes in the level of understanding following the implementation of the Teaching Unit.

Once these preliminary investigations had been completed, a Teaching Unit was developed closely linked with the theoretical model for the development of an understanding of 'sound and hearing'. This is discussed in Section 4.11.

4.11 Design of the teaching unit

Linder (1992b) stated that physics should be taught in an environment that encouraged students to explore their understandings, an environment that acknowledged, respected and encouraged students' sense-making abilities. As discussed in Section 2.7, he maintained that sound was often thought of as a relatively straightforward topic, yet his study indicated that sound is a difficult topic. Although much of what Linder wrote is beyond the level of scientific understanding appropriate for the Year 9 students participating in the current research, his statement of the importance of taking into account students' prior understanding, and teaching in an environment that allows for discussion, analysis, and thinking about the concepts being taught, is appropriate for all ages and levels of understanding.

Watt and Russell (1990) had observed that young children envisaged sound as an invisible object whose passage from source to listener needed space. For these children air was simply space. This same observation was made in the current research undertaken with slightly older students where there was a distinction between those students for whom air was 'space' and those for whom air was an 'interactive medium' (see Section 4.5). Watt and Russell also observed that children were more aware of the medium in the case of a 'string telephone' (mentioned in Section 2.7 and described in detail in Appendix 1) as they could see it. In addition, as discussed in Section 4.3.2, some students also believed that sound could be transmitted in a vacuum. It appeared that they had no understanding of the vital role played by the air in the transmission of the sound.

As a result of the above observations as well as the responses obtained in the interviews with younger students, it was felt that the role played by the medium in the transmission of sound was the key to student understanding. All students were aware that they heard sounds with their ears and that something produced the sound, but many students were not aware **how** that sound was produced nor **how** it reached their ears. Nor did they indicate an understanding of the transmission of sound in different media. This was further confirmed by the responses given to the questionnaire discussed earlier in this chapter.

The Teaching Unit, which constituted the Instruction Phase of the investigation, was therefore structured in such a way as to probe the students' understanding of the nature of sound and how it is transmitted. A series of questions were posed for discussion by the whole class. This included discussion of sound waves and vibrations and what these terms actually meant. The sequence of questions was designed to follow the pathway of cognitive development postulated in the Development Map for Hearing discussed in Section 4.5. Each question in turn linked together additional elements of the Development Map and represented progress along the pathway towards a scientific understanding of 'sound and hearing'. The class responses to the series of questions were audiotaped and retained for reference, but transcripts of the tapes were not included in the thesis. The total time taken by the Teaching Unit was approximately four 50-minute lessons.

The Teaching Unit was given to two different groups of Year 9 students over two consecutive years, with slight modification prior to the second group. The 1997 Teaching Unit is discussed in Section 4.11.1, and the 1998 Unit in Section 4.11.2.

4.11.1 The 1997 teaching unit

The design of this Teaching Unit was similar to that for 'light and seeing'. The main difference between this and conventional teaching is that students' own ideas were sought and were taken into account. As Lemke (1990) had stated that learning is essentially a social process, students were encouraged to express their ideas on 'sound' and, in discussions with their peers and with the teacher, to make predictions as to what would happen under various circumstances.

The Teaching Unit was based upon the constructivist teaching sequence of Driver and Oldham (1986) discussed in Section 2.3 and consisted of two main stages, orientation, and elicitation and restructuring. The sequence of discussions and activities was structured in such a way as to successively introduce and link together elements of the theoretical pathway proposed for the development of an understanding of 'sound and hearing' (refer to Section 4.5), with the desired outcome being that all students would demonstrate a scientific understanding of 'sound and hearing' and possess the Standard Hearing Framework (see Figure 4.6) at the completion of Teaching Unit. Thus the Teaching Unit also mirrored Vygotsky's notion of constructivism which advocates guidance by teachers and peers, and assisted discovery, to 'lead' development.

The orientation stage

At the commencement of the Teaching Unit, the investigator gave a brief introduction to inform the students that the course was about 'sound' and how they hear a sound. This was designed to encourage the students to think about sound and how they could hear. The Teaching Unit trialled in this investigation constituted part only of the whole course which also included aspects of 'sound' other than those specifically dealing with the transmission of sound through a medium.

The elicitation and restructuring stage

On the first occasion that the Teaching Unit was introduced to the students the complete series of questions was addressed prior to any activities. The questions were written on the whiteboard and discussed by the entire group. Demonstrations and activities followed this. In the following discussion the questions are accompanied by the class responses and an assessment of the level of understanding indicated by these responses.

The first lesson commenced with the question, '*What do we need to hear?*' The students' responses, 'ears' and 'a sound', introduced two elements of the intuitive or Ikonic notion '*we hear because we have ears'*. Responses that contained either of these elements were considered to be Unistructural in the Ikonic mode of the Development Map for Hearing. As discussed in Section 4.5, all children are aware from an early age that, when something makes a sound, they hear it with their ears, '*we listen, we hear*' (the 'active listening' idea of

Watt and Russell, 1990). This is intuitive and does not indicate a scientific understanding. However, if the students linked the two unistructural elements together then they were considered to be operating at the Multistructural level in the Ikonic mode.

The question, *'How does the sound get from the source to the ear?'*, produced the Ikonic response 'travels'. The linking together of the elements 'ear' and 'sound' by the connecting element 'travel' indicated a student operating at the Relational level in the Ikonic mode of the Development Map. Those students who responded 'travels through the air' had acknowledged the presence of the medium even if they were not yet aware of its role. These students were considered to be operating in the Concrete Symbolic mode, since the element 'medium' is not considered an intuitive (Ikonic) element.

The remaining questions dealt in turn with the nature of sound and sound waves, vibration of the source, vibration of the air, and, finally, vibration of the ear drum. These elements are not considered intuitive elements. They are all elements of the Concrete Symbolic mode of functioning and, as they made appropriate links between these elements, students demonstrated a developing scientific understanding of how a sound gets to their ears.

The questions, *'How does sound get through the air?'* and *'What are sound waves?'* produced Multistructural responses in the Concrete Symbolic mode. These responses linked together the notions of 'sound waves' and 'travel through the air' or 'vibrations' and 'travel through the air'. Although both of these responses were considered Multistructural, the mention of 'vibrations' indicated a slightly better understanding than 'sound waves'.

The questions, *'Where do these vibrations come from?'*, *'How do the vibrations of the source get to the ear?'* and, finally, *'What happens when the vibrations reach the ear?'*, were designed to stimulate discussion and to elicit responses which linked together the notions of 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear'. Such responses indicated a transition from the Multistructural to the Relational level in the Concrete Symbolic mode of the postulated Development Map for Hearing. If a response contained all of these four Key Elements, then it was indicative of a student with a scientific understanding of 'sound and hearing' whose level of cognitive functioning was at the top of the hierarchical Development Map for Hearing. This student had thus acquired the Standard Hearing Framework. The aim of the Teaching Unit was to have all students functioning at this level at the completion of the Unit.

Considerable discussion centred on the nature of sound. Students were shown the prongs of a tuning fork, the diaphragm of a loudspeaker, and the strings of a guitar, all of which vibrated when they made a sound. These demonstrations assisted students to conclude that sounds are made by something vibrating.

The vibration of the air was the most difficult concept for the students to appreciate as they could not see it. They could see and feel a tuning fork vibrating at the same time as they heard it making a sound. They could also feel the bench the tuning fork was touching vibrating as well. This made them aware that the vibrations of a sound source can be transmitted to other objects; that is, a vibrating object can set a second object vibrating. A discussion of the nature of 'air' assisted the students to understand how vibrations might be passed to the air. The students were told that air is an elastic, springy material made up of lots of particles. When an object starts vibrating in the air, it sets the air particles vibrating as well.

The demonstration of vibrations was followed by a demonstration of the movement of a sound wave through the air using a stretched spring called a 'slinky'. Students held each end of the spring and extended it slightly. One student then moved her hand to and fro slowly, into the spring and out again. The resultant pushes and pulls could be seen moving along the spring just like the squashes and stretches in a sound wave.

Linder (1992b) is critical of the use of the 'slinky' to introduce students to travelling longitudinal waves. However the reasons he gives are based on the theory of wave motion. This theory is relevant for tertiary physics students but is beyond the scope of Year 9 students. Linder claims that students should be taught the real thing (physics) and not about analogies, pictures, and schematic representations, that may not only be misleading but also false. However the researcher believes that, although it is important to teach the 'real thing', it is often appropriate to simplify that scientific view for younger students, and the use of analogies may facilitate student understanding. The 'slinky' is ideal for demonstrating the compressions and rarefactions that occur as the wave moves through the medium, and also that the wave travels in a straight line parallel to the direction in which the particles are vibrating.

As discussed in Section 2.8, the use of analogies is often recommended as a method of making difficult abstract concepts accessible to students (Duit, 1991; Thiele & Treagust, 1992). They have the power to evoke rich, almost instantaneous, mental pictures that enhance student learning. However care must be taken to ensure that an impression is not conveyed that the analogy is a true description of the target concept (Harrison & Treagust, 1993). In addition, the use of analogies encourages Ikonic functioning (Watson et al., 1993) which was discussed in Section 2.5 as being necessary support for development in the Concrete Symbolic mode.

The students were given a series of diagrams, shown in Figure 4.8, illustrating how the vibration of a tuning fork sets up regions of compression and rarefaction that are transmitted through the surrounding air.

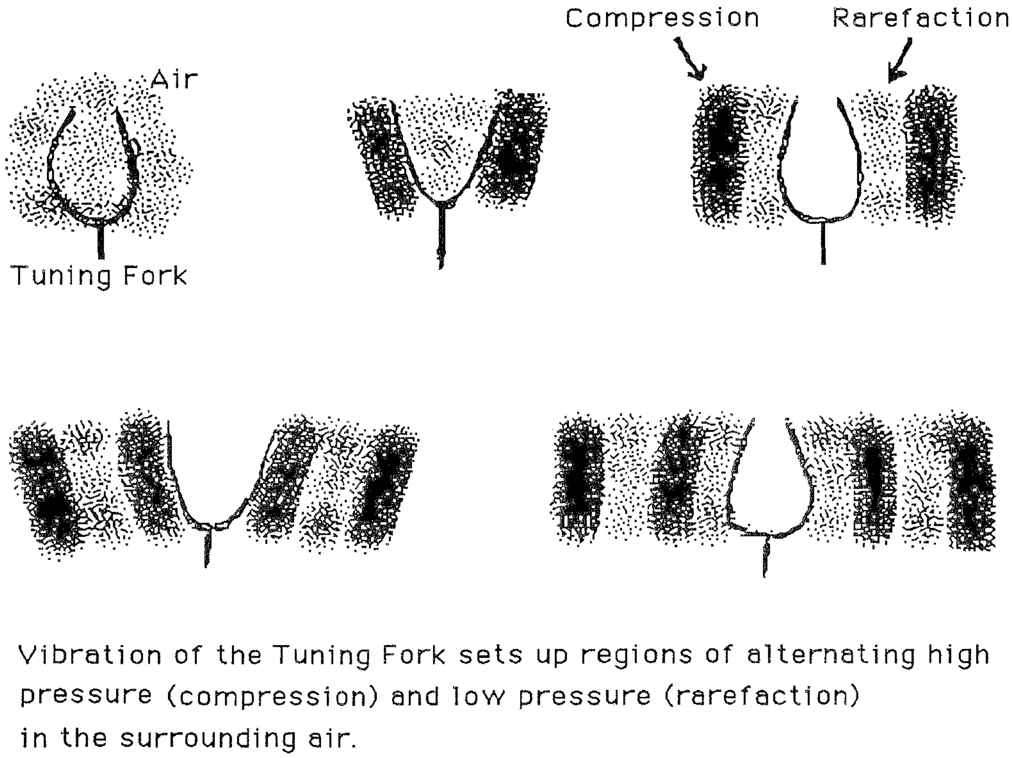


Figure 4.8: Vibration of a tuning fork

These variations in pressure were also represented by a wave diagram (Figure 4.8) where the region above the base line represented high pressure and the region below the base line, low pressure. Linder (1992b) discussed the difficulty in representing accurately the difference between a longitudinal and a transverse wave. Although an understanding of the difference is vital at the tertiary level, it is beyond what is required for Year 9 students. For the latter the simple wave diagram, shown in Figure 4.9, and commonly found in textbooks written for students of this age, for example, Pople (1989), is very useful for illustrating changes in frequency and loudness of a sound. The text also recommends the use of the 'slinky' to illustrate the difference between transverse and longitudinal waves.

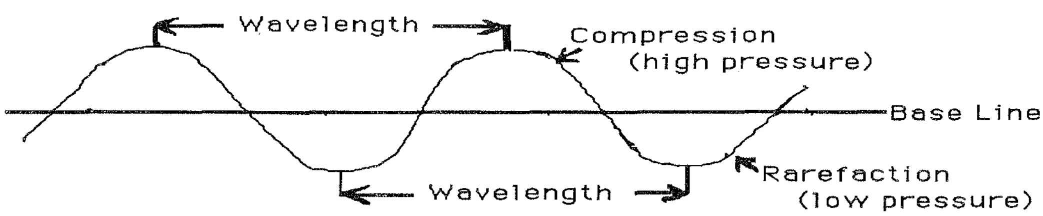


Figure 4.9: A typical wave diagram

It was explained to the students that the height of the peaks shown in Figure 4.9, indicating the maximum pressure, gives a measure of the intensity of the sound, and this is related to the loudness of the sound. The distance between the peaks, the wavelength, is a measure of the pitch or frequency of the sound, which is the number of vibrations made each second by the body disturbing the air molecules. The students were asked how they would represent a sound of higher frequency than the one shown in the diagram. As the object producing the sound vibrates faster, the frequency increases and, therefore, the distance between the peaks in the pressure wave decreases. Figure 4.10, in which the peaks are closer together, illustrates a wave at a higher frequency than the one in Figure 4.9.

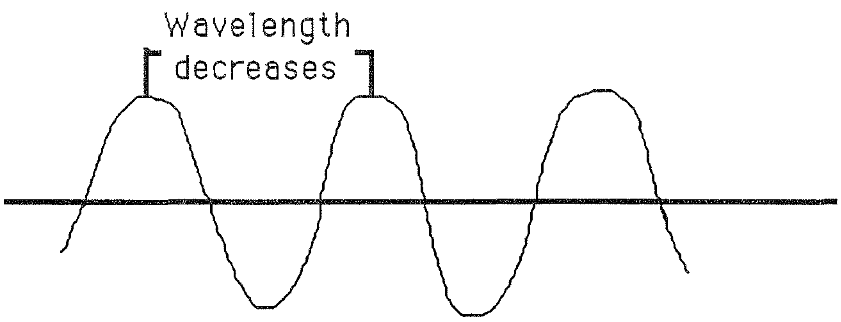


Figure 4.10: A typical high frequency wave diagram

The students were also asked to draw a diagram representing a louder sound than that shown in Figure 4.9. Discussion then followed on the range of frequencies heard by humans and other animals.

An experiment, shown in Figure 4.11, was set up to determine the hearing range of each of the students and the teacher. A high frequency signal generator was attached to an amplifier and to a speaker, with the front cover removed, so that the students could see the vibrations of the membrane of the speaker, and how this changed as the frequency of the sound changed. A cathode ray oscilloscope was also attached so that the students could see the changes in the shape of the wave pattern as the frequency and loudness of the sound changed. Students were thus able to see the wave patterns illustrated in the diagrams at the same time as they heard the changes in frequency. Students listened to the frequency range from 2000 to 20,000 cycles per second to determine the range of frequencies they could hear.

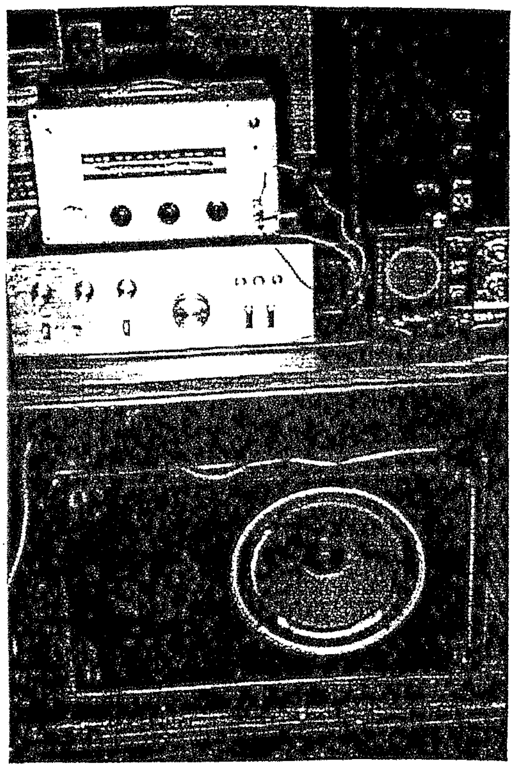


Figure 4.11 Apparatus used to determine hearing range

If sound is due to the vibration of a source and these vibrations can be tranferred to other objects, then students should draw the conclusion that any object capable of vibrating should be able to conduct sound. The transmission of sound in different media and the factors affecting transmission, such as the density of the medium, were then discussed. The 'string telephone' was discussed but was not made and tested with this group. What happened to the sound of an alarm clock ringing in a bell jar when all the air was removed from the jar, and what they observed as the air was let back in, was discussed and investigated by means of a demonstration by the teacher.

The discussion of the vibration of the medium and the transmission of sound in different media was designed to lead the students to conclude that media other than air can transmit sound, and that the more dense a substance is, that is, the closer together its particles, the more quickly it will conduct sound. Therefore, solids will conduct sound more quickly than liquids which, in turn, will conduct sound more quickly than gases. In the experiment with the alarm clock in a bell jar, students should observe that no sound will be transmitted in the absence of a medium.

From the discussion of the movement of the particles of the air and of other media, students may also conclude that the speed of sound will be affected by the temperature of the medium that transmits it. In a cold medium, particles move slowly and reduce the speed at which sound is transmitted. When the same medium is heated, its particles jostle one another more rapidly and speed up the transmission of sound. However, although this was discussed, it was not investigated by the students.

It was anticipated that all students would now have a clear understanding of the nature of sound and of the vital role played by the medium in the transmission of that sound. The Key Elements of 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear', were addressed in turn during the course of the Teaching Unit and finally linked together. The questionnaire was then used to determine how effective the Teaching Unit had been.

The data obtained with the Year 9/97 Group are discussed in Chapter 5. The investigation was repeated with a new Year 9 class, the Year 9/98 Group, the following year. Some changes were made to the Teaching Unit to include a greater emphasis on the role of the medium and more 'hands-on activities' for the second group of students. These are discussed in Section 4.11.2.

4.11.2 The 1998 teaching unit

For the second trial of the Teaching Unit, with the Year 9/98 Group, demonstrations and activities were interspersed with the questions where it was considered these would aid understanding, rather than addressing all the questions at the beginning of the unit. More activities were included that the students carried out for themselves. These were designed to place greater emphasis on the role of the medium, as this was the concept which had been identified with the Year 9/97 Group as being the major 'stumbling block' to student understanding. Slight modifications were made to the questions and to their sequence for this group. However, they still followed the hierarchical Development Map for Hearing. Six questions were posed rather than the seven used in the first trial. The complete 1998 Teaching Unit is contained in Appendix 16. It includes comprehensive notes for the teacher.

The first two questions were unchanged, however, the question '*What is sound?*' replaced '*What are sound waves?*'. This was followed by activities in which the students investigated for themselves the vibrations of a tuning fork, the strings of a guitar, and the skin of a drum. This introduced students to the notion of 'vibrations'. The students were encouraged to feel the vibrations, for example by touching the vibrating tuning fork to their cheek or tongue, and to test what happened when the vibrating tuning fork was touched to the bench. What had they observed and why? Why did the tuning fork mounted on the wooden box sound so much louder? What was vibrating? What vibrated when the drum was struck or when the guitar string was plucked? These activities were designed to make the students aware of vibrations and how the vibrations of one object could be transferred to neighbouring objects. Following the discussion of 'sound waves', a student commented that "a sound wave was like a Mexican Wave" (a progressive wave activity favoured by spectators at a football match), which was quite a good analogy for the transfer of sound through the air.

The next questions - '*How do the vibrations, for example, from the tuning fork, get to the ear?*', '*What happens when the vibrations reach the ear?*', and, '*How do the vibrations get through the air?*' - were designed, as before, to 'lead' students along the pathway of developing understanding proposed in the Development Map for Hearing. The middle question was unchanged, however, the other two questions were worded slightly differently from those used in 1997. When the teacher asked the class, "Have you any idea how they (vibrations) get through the air?", one student responded, "When they hit other air particles like dominoes." This was an interesting response as the class had discussed how vibrating objects set other objects vibrating but no mention had been made of 'dominoes'. This is an example of a student using prior experience to interpret what happens. The intuitive response is based upon the student's observation of what happens when a row of dominoes bump into each other.

The students were given the diagrams of the tuning fork shown in Figure 4.7. This prompted one student to ask if the vibrations go up into the air above the tuning fork. This was an interesting question because the diagram showed only the air on either side of the tuning fork. Discussion then followed with the class in which it was agreed that the air all around the tuning fork was set vibrating. This prompted the teacher to ask, "Which ones (of the vibrations) are you going to hear?" Some of the students said, "All", but one student immediately responded, "Ones that come to your ear". Another member of the class then asked, "Do they have things which attract them to the ears?".

An activity, designed to illustrate how vibrations are passed through the air, and that had not been performed with the Year 9/97 Group, followed. This was a useful activity in that some of the students in the 1997 Group had experienced difficulty visualising how the 'bunching up' of the air particles around a tuning fork moved along through the adjoining air. Five students were lined up shoulder to shoulder, but not quite touching. The investigator pushed the first student gently so that she bumped the second student who bumped the third student, and so on down the line. The students observing noted that each student bumped the next successively like a row of dominoes but, unlike dominoes, each student quickly recovered her original position. What moved down the line was the disturbance, the individual students did not move very far. One of the students then asked "Is that like echoes?" and so a discussion of echoes followed.

The analogy was made between the above activity and the transmission of sound through the vibrating particles of the air. As the students push together and then pull apart again as they regain their original position they are creating regions of high pressure (the squashes) and regions of low pressure (the stretches). This is how vibrations are passed through the air, in alternating regions of high pressure (compressions) and low pressure (rarefactions). These alternating areas of high and low pressure give rise to a pressure wave called a 'sound wave'. When these sound waves reach the ears they cause the eardrums to vibrate. It was thought that by participating in this 'game' students would remember how sound is transmitted through the air.

Another useful analogy for the transmission of sound (Stevens and Warshofsky, 1965, p. 10-11) presented to the Year 9/98 Group was that of a waiter stepping on to the edge of a dance floor crowded with dancers, forcing the dancers nearby to give way; they in turn bump into other dancers creating a chain reaction. The bumping progresses across the room in a wave of jostling that flows outwards from the waiter through the dancers to the opposite edges of the floor. A sound wave moves through the air in the same way. A vibrating object, for example, a vibrating bell, pushes repeatedly against molecules of air. The disturbed molecules bump against their neighbours, then bounce back to their original positions, only to be pushed again. The neighbouring molecules do the same and so on. In the process an individual molecule never travels very far. What does travel is the disturbance.

The same activities with the 'slinky', and determining the range of frequencies that the students could hear, were carried out, as well as the demonstration of sound in a vacuum. These were unchanged from those for the Year 9/97 Group. However, the students in the Year 9/98 Group were given the opportunity to test for themselves how sound is transmitted through air, wood, and steel, as well as through the 'string telephone'. It was considered that by further increasing the opportunity to experience, at first hand, various phenomena associated with the transmission of sound that students would more readily acquire the Standard Hearing Framework and, more importantly, would retain their scientific understanding over time.

4.12 Conclusion

At the conclusion of the Teaching Units, particularly the 1998 Unit, it was felt that students had a good scientific understanding of 'sound and hearing'. They had been encouraged to progress along the pathway of cognitive development postulated in the Development Map for Hearing. Each element involved in an understanding of the transmission of sound from a source to the ear had been dealt with in turn and all the elements linked together. Care was taken to allow the students ample time for discussion in order for them to explore their understanding of the nature of sound and its transmission, and appropriate demonstrations and/or practical activities were included.

The Teaching Unit used with the Year 9/98 Group contained more 'hands-on' activities, designed to place even greater emphasis on the role of the medium, in order to assist the students to develop a scientific understanding of 'sound and hearing', and to better retain that understanding over an extended period of time.

As a result of undertaking most of the activities for themselves, it was observed by the teacher/investigator that the students asked many more questions and discussed events much more frequently with the teacher and with each other. This in turn stimulated further discussion. For example, following a discussion of the ear drum and how it receives the sound vibrations, and measuring the students' range of hearing, one student asked, "What do hearing aids do?". Discussion between the teacher and the students then followed on hearing aids, types of deafness, and how the old-fashioned hearing trumpets worked.

The teaching had, therefore, followed the *social constructivist* approach of Vygotsky. Guidance and assisted discovery by the teacher and the other students had combined to *lead* the development of a scientific understanding of 'sound and hearing'.

The data obtained with both the Year 9/97 and the Year 9/98 Groups of students at each phase of the practical component of the investigation are discussed in detail in Chapter 5. From the data, it was possible to determine whether the Teaching Unit had been successful in terms of learning outcomes. Did the students now have a scientific understanding of the topic, had conceptual change taken place, and, if so, was it longlasting?

Chapter 5

Sound and hearing: results with the target group

5.1 Introduction

The previous chapter discussed in detail the methodology for the investigation of 'sound and hearing', the formulation and testing of the theoretical cognitive model, and the design of the Teaching Unit closely linked to the theoretical model used in the instruction phase of the investigation. This chapter deals with the results obtained with Year 9 students, the target group in this research. The practical component of the investigation (see Section 4.2) was carried out over two successive years with two different groups of Year 9 students. The two year groups have been designated as the Year 9/97 Group and the Year 9/98 Group. Within each year group, the students were divided into two smaller groups: the Instruction Group, composed of those students who participated in the Teaching Unit on 'sound and hearing' discussed in Section 4.11, and the Non-Instruction Group consisting of students who did not receive tuition on the topic of sound during the year. Each student has been assigned a number; those in the Instruction Group have (I) after their number.

The total number of students in the Year 9/97 Group was thirty-seven but only twenty-seven students were present on all the occasions on which the questionnaire was administered. In order to compare the cognitive levels of individual students at each phase of the investigation, it was decided to exclude from the analysis those students who had not been present when required. Therefore, the total number of students in the Instruction Group was fourteen and, in the Non-Instruction Group, thirteen. In the Year 9/98 Group the total number of students was eight in the Instruction Group and thirteen in the Non-Instruction Group.

As discussed in Section 4.2, the practical component of the investigation consisted of five phases: Phase 1, pre-instruction; Phase 2, instruction (implementation of Teaching Unit); Phase 3, immediate post-instruction; Phase 4, delayed post-instruction; and Phase 5, 12-month delayed post-instruction. The second or instruction phase was applicable to the Instruction Group only. Data were collected by administering the questionnaire (Section 4.3.3) at four of the five phases of the investigation, that is, at Phases 1, 3, 4, and 5. In the pre-instruction and delayed post-instruction phases, the questionnaire was given to **all** Year 9 students involved in the study. The questionnaire was not administered to the Non-Instruction Group in the immediate post-instruction phase as it was not expected that any change would occur in the three-week period during which tuition and the administration of the immediate post-instruction questionnaire took place with the Instruction Group. The questionnaire was given to the Non-Instruction Group in the delayed post-instruction phase in order to determine whether any change in their understanding of 'sound and hearing' had taken place over the period, even though they had not studied the topic, and, if a change had taken place, to what extent. In the fifth phase, the 12-month delayed post-instruction phase, of the investigation, the questionnaire was given to all students in the Year 9/97 Group but to the Instruction Group only in the Year 9/98 Group.

As stated in Section 4.1, the main aim of this research was to formulate a theoretical cognitive model for the development of an understanding of 'sound and hearing' and to design and evaluate a teaching unit, closely linked to the theoretical model, that would 'lead' students to a scientific understanding of how they hear a sound, that is, how a sound reaches their ears, but not including what happens after that sound reaches the ears. Therefore, in this chapter, the prime concern will be to determine the effectiveness of the Teaching Unit using the theoretical cognitive model. It is the improvement in understanding observed in the students who have undergone instruction that will give a measure of the success of the Teaching Unit.

A further indicator of success is if the students retain their scientific understanding over a prolonged period. In order to ascertain this, as already mentioned, the questionnaire was administered to the students five and twelve months after completion of the Teaching Unit. At the 12-month phase some students were no longer at the school so the numbers were slightly smaller for this phase of the investigation. However, these students were not excluded from the analysis as they had been present for all the earlier phases of the investigation.

The data obtained from the responses of students in the Year 9/97 and Year 9/98 Groups to each of the three questions of the questionnaire, at each phase of the investigation, are presented in the following sections: Sections 5.2 to 5.5, inclusive (Year 9/97), and Sections 5.6 to 5.9, inclusive (Year 9/98). The levels of cognitive functioning of each individual student in the Instruction Group, determined from Question One and Question Three, are compared for each phase. As each SOLO level corresponds with a score for the number of Key Elements present in the student's responses to Questions One and Three, the change in score for each student in the Instruction Group from one phase to another is tabulated for both questions together with the average change over both questions for all students. A summary of the total percentages of students operating at each SOLO level is also presented and a comparison is made between the levels observed with the Instruction and Non-Instruction Groups. The overall performances of students in the Instruction and Non-Instruction Groups, at each phase of the investigation, are compared using the combined total scores for Question One and Question Three. In Section 5.10, the data for the two year groups are combined and the Instruction and Non-Instruction Groups compared. Finally, in Section 5.11, the statistical significance of the observed outcomes of the combined year groups is determined using a paired 't' test (Moore & McCabe, 1989). The complete responses of all students, at each phase of the investigation at which they completed the questionnaire, are contained in Appendices 17 (Year 9/97) and 18 (Year 9/98).

5.2 Analysis of the year 9/97 responses to question one

The responses to Question One (Figure 4.1) of the questionnaire were analysed by looking for the words or ideas that formed the Key Elements of the Development Map for Hearing discussed in Section 4.5. Using the scoring system devised to facilitate the analysis of students' responses (see Section 4.4.3), each response was assigned a score for the number of Key Elements present. The SOLO level at which each student was functioning was thus determined. The relationship between the number of Key Elements present in each response and the SOLO level is given in Table 4.4.

When analysing the effect of the Teaching Unit, two related aspects of the data can be considered. The first is the improvement in the SOLO level from one phase to the next, how near to the 'top' of the Development Map the student is after tuition, and whether the student retains that position over time. The second aspect is the change in the score for the number of Key Elements present in the student's responses from one phase to the next. Both are discussed in Section 5.2.1.

In Section 5.2.2, a comparison is made of the SOLO levels of the Instruction and Non-Instruction Groups as a whole. The Non-Instruction Group was included in the investigation as a control or comparison group. However, this group cannot be considered as a true 'control' group as it was not possible to ensure that discussions did not take place between the Instruction and Non-Instruction students outside the classroom. In addition, the allocation of the students into these two groups was not random and the abilities of the students in each group were not necessarily equivalent. Therefore, the term 'comparison' group is more appropriate for the Non-Instruction Group as the group was used as a referent for the change observed with the Instruction Group following the implementation of the Teaching Unit. As little or no change was expected with the Non-Instruction Group, the SOLO levels of individual students are not discussed.

5.2.1 Comparison of the SOLO levels and of the changes in scores for key elements of individual students in the year 9/97 instruction group determined from question one

Responses to Question One for the Year 9/97 Instruction Group with the Key Elements highlighted and the corresponding SOLO level assigned, at each phase of the investigation, are shown in Table 5.1. The score for each individual element has been included in brackets within the student's response. As there were only fourteen students in this group the complete responses have been included in Table 5.1. Thus changes in the levels of cognitive functioning can be compared easily for each student over the course of the investigation.

Table 5.1: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question one at each phase of the investigation

Stud No.	Pre-Instruction Response	Immediate Post-Instruction Response	Delayed Post-Instruction Response	12-month Delayed Post-Instruction Response
2(I)	**Sound waves** [0.5] **travel** [0.5] from the bird who is singing in the tree and go out in all directions. Some of these sound waves hit the child's **ear** [0.5] and because of this he hears the sound of the bird singing. His ear drum is the part of the ear that picks up the sound.	The bird's **vocal chords make a noise** and **set the air vibrating** [1][1]. This **vibration of the air reaches** [1] the child's ear. The **vibrating goes into the ear** [1] and the ear drum turns it into noise.	The child can hear the sound of the bird singing because when the bird **makes a noise**, this **sends vibrations** [1] **through the air** [0.5][1], which **travel** and hit the child's **ear** [1], and in the ear the vibrations are picked up and converted to sound.	The bird sings and its voice box makes the **air** in its mouth **vibrate** [1] and this pushes **particles of air** [1] outside and the air vibrates, the **vibrating air** [1] (sound waves) **reaches the child's ear** [0.5] and goes into its ear drum where it gets turned into an electrical sound which the child hears. Thus the child hears the bird singing.
	1.5	**4**	**3.5**	**3.5**
	IK R	**CS R_b**	**CS R_a**	**CS R_a**

3(I)	When the bird sings, it sends out "**sound waves**" [0.5] into the air. They **travel through the air** [0.5][1] and reach your **ear**. They enter the ear and **vibrations** [1] are caused which allows you to hear. **3** **CS M**	The bird is the source of sound. It **tweets** and it **creates vibrations** [1] that form sound waves. Because the sound waves go off in all directions, the boy can hear it. The sound waves **reach the boy's ear** [0.5], and it **vibrates the ear drum** [1] and the boy is able to hear. **2.5** **CS M**	The bird is the sound source. It makes the **air particles move** [1]. It creates sound waves that **travel through the air** [0.5][1] and to the child. The sound waves **vibrate in the ear** [1] and the child can hear the sound. **3.5** **CS R_a**	• The bird makes a **sound** [0.5] • The **sound waves travel through the air** [0.5][1] • The sound waves reach the boy and they enter the ear • The **vibrations in the ear** [1] travel through past the 3 smallest bones and in through the liquid and into the cochlea. The vibrations are sent off as electrical pulses to the brain and the sound is heard. **3** **CS M**

4(I)	The **sound** that the bird is making is made up of lots of **vibrations** [1]. The vibrations all have different wavelengths. The wavelengths **travel through the air** [0.5][1] towards the boy's **ears** which pick up the **vibrations** [1] as a sound. The shorter the wavelengths the higher the sound. **3.5** **CS R_a**	The bird makes **vibrations** [1] deep down in its voice box. These **vibrations** then **travel to the boy's ears** [1] in wavelengths. The smaller and closer together the wavelengths are the higher the sound would be. **Sound** cannot **travel** through a vacuum only through **air** [0.5][1]. **3.5** **CS R_a**	When the bird sings it sends out **sound waves** [0.5] that **travel through the air** [0.5][1] and the boy's **ears** pick up these **vibrations** [1]. **3** **CS M**	With its ears. The **sound travels** [0.5] out of the birds mouth or whatever and then gets picked up in the **boy's ears** [0.5]. The **sound travels through the air in vibrations** [1][1] called sound waves and at different pitches. The sound waves are different lengths. **3** **CS M**
5(I)	**Vibrations** [1] are made when the bird sings. The **vibrations travel** [0.5] into the childs **ear** [1] and [are] heard. The less distance the sounds have to vibrate the louder the sounds. **2.5** **CS M**	The bird singing sends **vibrations** [1] **into the air** [1]. The **vibrations travel through the air** [1] to the child's **ear** [1]. In the ear tiny hairs pick up the vibrations and the brain recognises these vibrations as different sounds. **4** **CS R_b**	The bird makes a **sound** which makes the **air** [1] **vibrate** [1] and the **vibrations travel** [1] to the childs **ears** [0.5]. **3.5** **CS R_a**	Bird sends **vibrations** [1] **into the air** when it sings. The **vibrations travel through the particles in the air** [1][1] to the childs ear, and set the **ear vibrating** [1] and the child hears the sound. **4** **CS R_b**

9(I)	The sound of the bird **travels** by invisible **sound waves** [0.5] **through the air** [0.5][1]. The sound waves are picked up by the child's **ear** [0.5] and amplified in the ear drum. **2.5** **CS M**	The bird makes a **sound** which **sets the air particles vibrating** [1]. The particles transfer energy **through the air** [1][1] in sound waves.The boy's **ear** picks up the sound waves which set a membrane **vibrating** [1] Delicate hairs inside the ear pick up the sound. **4** **CS R_b**	The bird emits **sound waves** which **set** the surrounding **air** [1][1] **vibrating** [1]. The tiny hairs in the child's **ears** pick up the **vibrations** [1] and send messages to the brain which is translated into sound. **4** **CS R_b**	When the bird sings the sound **travels through the air** [0.5][1] in **vibrations** [1]. The vibrations reach the **ear** [0.5] of the boy where they go through air, liquid, air and are picked up by minute hairs which transfers them to messages to the brain of the sound, its pitch, and loudness. **3** **CS M**
10(I)	The child can hear the bird singing in the tree because **sound waves** [0.5] from the birds voice **travelling through the air** [0.5][1] and the child has **ears** [0.5] which are able to pick up the sound. **2.5** **CS M**	**Sound waves** from the birds mouth **vibrate** [1] **the air** [1] and these **vibrations travel** [1] to the **ear** and **vibrate** [1] hairs in the air [sic]. **4** **CS R_b**	**Sound vibrations** [1] from the bird **travel through the air** [1][0.5] and the child picks up the **vibrations** through his **ear** [1]. **3.5** **CS R_a**	The **vibrations** [1] from the birds mouth **vibrate** [1] and **travel through the air** [1] and are picked up by the boys **ear** [0.5]. **3.5** **CS R_a**

11(I)	The child can **hear** the **singing** [0.5] of the bird because he has **ears** [0.5]. These are two organs that belong to many animals. The ear is made up of lots of other small nerves that connect to the brain which enables the child to hear the singing of the bird in the tree. **1** **IK M**	He can hear the bird singing because he has ears. He can hear the singing through his ears because when the bird starts **singing** its glands [sic] in its neck start to **vibrate** [1] which starts **air particles vibrating** [1] right **to** [1] the boys **ears**. This then sets the **ear drum vibrating** [1] and causes the boy to hear the singing of the bird. **4** **CS Rb**	The child may hear the bird through his ears, the **sound** from the bird **sends the air particles vibrating** [1][1]. The **vibration of the air sends** [1] the tiny hairs in our **ears vibrating** [1] which enables the child to hear the singing of the bird. **4** **CS Rb**	The boy can hear the bird because the **sound** of the bird's singing **viabrates** [1] [sic] **the air particles** [1][1] which **viabrate** [1] [sic] the boy's **eardrum** therefore he can hear the bird's singing. **4** **CS Rb**

12(l)	Well your ear can pick up **sound waves** [0.5] that **travel through the air** [1][0.5] so when a bird chirps the noise gets picked up by these sound waves and our **ears** [0.5] pick up these sounds. **2.5** **CS M**	Well the bird makes his **noise** and the sound waves or **vibrations** [1] **in the air** [1] **carry it all around** [1] and once they reach the person their **ear** drums start to **vibrate** [1] as well and that is how you hear a bird sing. **4** **CS R_b**	Sound from the bird is picked up by the **vibrations** [1] **in the air** [1], depending on how loud the bird sings as to how far the noise is carried. We hear the noise because the **vibrations in the air go** [1] **into the ear** and make the ear drum **vibrate** [1] as well. **4** **CS R_b**	–

13(I)	**Sound waves** [0.5] are sent out from the birds voice box and these waves **travel** [0.5] **to the childs ears** [0.5]. The waves are then interpreted by the brain, which recognises the sound. **1.5** **IK R**	The birds **voice box begins vibrating** [1] and then **sets the air particles vibrating** [1]. The **vibrations travel through the air** [1] in waves. The waves then reach the childs **ear** and the **vibrations** [1] are sent through the nerves and other things in the ear. **4** **CS R_b**	**Particles in the air** near the bird are **set vibrating** [1][1] when the bird makes a noise. These particles then set other particles vibrating - these are called sound waves. The **waves travel to** [1] **the childs ear** [1] and eventually a message is sent to the brain which enables the child to identify the sound. **4** **CS R_b**	–

16(I)	The child can hear the bird in the tree through his ears.The **sound** [0.5] from the bird **travels through the air** [0.5][1] and **into his/her ears** [0.5]. The ears are always listening to all of the sounds that are happening and the sound of the bird goes into the child's head and the child registers it as a bird. **2.5** **CS M** **with IK support**	The child can hear the sound of the bird through his/her ear. The **sound** [0.5] of the bird **travels** [0.5] in sound waves to the childs ear the sound waves fluctuate as to how loud and the pitch of the sound is. The **air** [0.5] **vibrates inside** the child's **ear** [1] and this is how the child can hear the sounds of the bird in the tree. **2.5** **CS M**	When the bird sings the **vibrations** [1] of the sound waves **travel through the air** [1][0.5] to the child's **ears** [0.5]. The child can hear the sound through his/her ear lobe. **3** **CS M**	The child can hear this because he/she has **ears** [0.5] that pick up **sound waves** [0.5] that **run through the air** [1][0.5]. If the sound waves are very soft there is a chance that they can't hear it, and if they are loud it is most likely they would hear it. **2.5** **CS M**

22(I)	The bird sings which makes **sound waves** [0.5] which **travel through the air** [1][0.5] and enter our **ear** [0.5] drums. Then something happens and a message is sent to our brain which says that a bird is singing in a tree. **2.5** **CS M**	The bird's voice box **vibrates** [1] and the **vibrations** (sound) **travel through the air** [1][0.5] **to the child's ears.** The **vibrations** [1] enter the child's **ear drum** and nerves react to send a message to the brain saying that a bird is singing in a tree. **3.5** **CS R_a**	The bird sings and makes **vibrations** [1] which **travel through the air** [1][0.5] and into the child's **ear** [1]. The vibrations hit the cochlea in the ear and a message is sent to the brain telling the child that there is a bird singing in the tree. **3.5** **CS R_a**	The bird sings and the **sound** travels through the air in sound waves. The **sound waves** [0.5] **travel through the air** [1][0.5] and to the boys **ears** [0.5]. Once in the boys ears they travel through to the cochlea and move tiny little hairs inside it. The little hairs then create a message that travels through to the brain. The boy then knows that there is a bird singing in the tree. **2.5** **CS M**

30(I)	The **sound** [0.5] the bird makes **travels through the air** [1][0.5] in waves of varying lengths to the childs **ear** [0.5] which transmits the information to the brain which recognises the sound as a bird singing. **2.5** **CS M**	The bird **singing sets the air** surrounding bird **vibrating** [1][1] and the **vibrations travel through the air** [1] to your ears and set child's **ear drum vibrating** [1] which sends a message to the brain. **4** **CS R_b**	The child can hear the sound of the bird singing because 1) The bird **singing makes vibrations** [1], 2) The **vibrations travel through the air** [1][0.5], 3) The child's **ear** [1] receives the **vibrations**, 4) The vibrations are sent as messages to the brain, 5) The brain recognises the sound, 6) From there the child is able to recognise the sound of a bird and locate it. **3.5** **CS R_a**	The bird makes a **sound** which **sets the air vibrating** [1][1]. The **vibrations travel through the air** [1] in the form of sound waves to the child's **ear** [0.5]. The brain then recognises the sound and direction from which the waves have come as a bird singing in the tree. **3.5** **CS R_a**

32(I)	The bird **singing causes the air to vibrate** [1][1] and move, which in turn hit other **particles of air** [1] like dominoes until it reaches the childs **ears** [1] where the **vibrations** are received and turned into sound by the brain depending on the intensity and frequency of the vibrations. **4** **CS R_b**	When the bird **sings** it makes the **air vibrate** [1][1]. The **vibrations travel through the air** [1] - as the particles hit eachother and transfer the energy. The vibrations travel through the air and to the **ear** where the **vibrations** [1] are picked up by the ear drum. **4** **CS R_b**	The bird sings and **makes the air vibrate** [1][1]. The air particles vibrate and hit each other sending the **vibrations** [1] **continuing on**. The **vibrations** reach the **ear** [1] of the child and are picked up by the ear. **4** **CS R_b**	When the bird sings it makes **particles in the air vibrate** [1][1]. These **vibrations travel through the air** [1] as one particle hits the one next to it and transfers the energy. This continues on and when the **vibrations** pass the child they are picked up in the **ear** [1] and transferred into sound by the brain. **4** **CS R_b**

33(I)	The **sound** [0.5] produced by the bird **travels through the air** [1][0.5] in waves. These sound waves travel slower than the light waves do so therefore the child sees the bird before he hears it. His **ears** [0.5] pick up the sound waves and the nerves send it to the brain. **2.5** **CS M**	The birds **vocal chords produce vibrations** [1] **that travel through the air** [1][1] in sound waves. These vibrations reach the childs **ear** and set the air inside the ear **vibrating** [1] until the vibrations reach the ear drum. **4** **CS R_b**	The noise of the bird's **voice** makes **vibrations** [1] **which travel through the air** [1] in sound waves of different frequencies. The **air vibrates** [1] along these waves and eventually the vibrations reach the boy's ear and set the **ear vibrating** [1] and then the ear drum. The boys brain picks up these vibrations and tells the boy what it is he is hearing. **4** **CS R_b**	–

In Table 5.1 it is possible to see the cognitive levels of individual students at each of the four phases and, thus, to determine whether the students have improved, remained the same, or regressed, during the course of the investigation. For ease of comparison, a summary of each individual student's cognitive level, as determined from her responses to the questionnaire, at each phase of the investigation, is shown in Table 5.2.

Table 5.2: Comparison of the SOLO levels of individual students in the year 9/97 instruction group at each phase of the investigation

	SOLO Level at each Phase of the Investigation			
Student Number	Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction	12-month Delayed Post-Instruction
2(I)	IK R	CS R_b	CS R_a	CS R_a
3(I)	CS M	CS M	CS R_a	CS M
4(I)	CS R_a	CS R_a	CS M	CS M
5(I)	CS M	CS R_b	CS R_a	CS R_b
9(I)	CS M	CS R_b	CS R_b	CS M
10(I)	CS M	CS R_b	CS R_a	CS R_a
11(I)	IK M	CS R_b	CS R_b	CS R_b
12(I)	CS M	CS R_b	CS R_b	
13(I)	IK R	CS R_b	CS R_b	
16(I)	CS M (with IK support)	CS M	CS M	CS M
22(I)	CS M	CS R_a	CS R_a	CS M
30(I)	CS M	CS R_b	CS R_a	CS R_a
32(I)	CS R_b	CS R_b	CS R_b	CS R_b
33(I)	CS M	CS R_b	CS R_b	

From the data shown in Table 5.2, it can be seen that, between the pre-instruction and the immediate post-instruction phases, ten students (71%) improved their SOLO levels and four (29%) were unchanged. All students were operating in the Concrete Symbolic (CS) mode immediately following the completion of the Teaching Unit. No students decreased their level immediately following tuition. Of the ten students whose level improved, nine were subsequently CS R_b, the highest level in the Development Map for Hearing (see Figure 4.6), and one was CS R_a. Of the four students whose level did not change, one was already at the top level of CS R_b, one was CS R_a, and the two remaining were CS M. The greatest improvement was observed with Student 11(I) whose cognitive level improved from IK M to CS R_b. Prior to instruction she stated, "the child can hear the singing of the bird because he has ears". This Ikonic response made no mention of the Concrete Symbolic elements 'air' (medium) or 'vibration'. However, immediately following instruction, the student demonstrated a scientific understanding of the vibration of air particles as the mechanism for transmission of the sound. She had made the transition from the Ikonic to the Concrete Symbolic mode of cognitive functioning in the Development Map for Hearing. Five months later this student was still operating at this level and there was no further change over the 12-month period.

It is interesting to note that Student 16(I) in the pre-instruction phase stated, "The sound from the bird travels through the air and into his/her ears". This part of her response was indicative of the CS mode, Multistructural level. However, she then went on to say, "The ears are always listening to all of the sounds that are happening and the sound of the bird goes into the child's head ....". This was an example of an Ikonic response linking the two elements 'sound' and 'ear' as in 'we listen, we hear' and appeared indicative of Ikonic support for a Concrete Symbolic response. This too was the notion of 'active listening' observed by earlier researchers (Watt & Russell,1990; Boyes & Stanisstreet, 1991).

Between the immediate post-instruction and the delayed post-instruction phases (a period of five months) one student demonstrated a further slight improvement, from CS M to CS R_a. This improvement was demonstrated by her specifically mentioning 'air' in her response to the delayed post-instruction questionnaire. Eight students (57%) did not change their SOLO level and five (36%) decreased one level, four from CS R_b to CS R_a, and one from CS R_a to CS M. No students reverted to their pre-instruction levels. Those students who decreased from CS R_b to CS R_a still demonstrated a good understanding of how a sound reaches their ears but failed to mention specifically in their responses that the air itself vibrated to transmit the sound. For example, Student 2(I) in her immediate post-instruction response said the sound "set the air vibrating" whereas, in her delayed post-instruction response, she stated that the sound "sends vibrations through the air", which did not say specifically that the air itself vibrated. It is important to remember that the SOLO model is a 'response' model and unless a student specifically states a particular notion in her response she cannot be credited with holding that notion.

Between the delayed post-instruction and the 12-month delayed post-instruction phases (a period of seven months) the majority of students showed no change to their SOLO level. Two students (18%) decreased from CS R_a to CS M and one (9%) from CS R_b to CS M. Only one student increased, from CS R_a to CS R_b.

Two students only did not change levels at all during the course of the investigation. Student 32(I) was already at the CS R_b level at the commencement of the investigation and remained at this level throughout. Student 16(I) was CS M with Ikonic support, pre-instruction, and remained at the CS M level. Her understanding improved slightly in that she no longer had an Ikonic notion ('we listen, we hear') as part of her response. In her responses, both five months and twelve months after completing tuition, she mentioned 'sound waves' and 'vibration' but did not link the two together and did not demonstrate a clear understanding of what was happening.

Since, as mentioned at the beginning of Section 5.2, there are two ways in which the data can be presented in order to monitor the changes in performance, a comparison of the corresponding changes in the scores for the number of Key Elements present in the responses of these students, over the course of the investigation, was made. These changes in scores, from pre-instruction to immediate post-instruction (P/IP), from immediate post-instruction to delayed post-instruction (IP/DP), and from immediate post-instruction to 12-month delayed post-instruction (IP/12DP), are shown in Table 5.3. The average change observed for each of these phase transitions is shown in the table also.

Table 5.3 does not give any indication of the SOLO level at which each student was functioning, prior to and as a consequence of the Teaching Unit, but it does show whether the student's score for the number of Key Elements present in her response had increased, decreased, or remained the same, over the course of the investigation.

It can be seen that, immediately following the completion of the Teaching Unit, the average change in score was +1.21, which pointed to an improvement in student understanding as evidenced by the increased average number of elements of the Development Map for Hearing present in their responses.

Over the five month period between the immediate post- and the delayed post-instruction questionnaires there was a very slight decrease in the average change in score. Seven months later, that is at the 12-month delayed post-instruction phase, the average change in score had decreased even further. The group now consisted of only eleven members of the original Instruction Group as three students were no longer attending the school.

The observed slight decrease in the number of elements held by students may have been due to their failure to state clearly the role of the medium in the transmission of sound. These students correctly identified vibration of the source, vibration of the ear, the presence of the medium, and the passage of sound through that medium, but failed to say specifically that the medium itself vibrated. As discussed in Section 4.5, this is the difference between the notion of air merely as space and the notion of air as an interactive medium. Unless this was stated clearly, the student was not deemed to hold all elements of the Development Map for Hearing.

Table 5.3: **Changes in individual scores and the average change in score for students in the year 9/97 instruction group for question one, pre- to immediate post- (P/IP), immediate to delayed post- (IP/DP), and immediate to 12-month delayed post-instruction (IP/12DP)**

	Phases of the Investigation		
Student Number	**P/IP**	**IP/DP**	**IP/12DP**
2(I)	+2.5	-0.5	0
3(I)	-0.5	+1	-0.5
4(I)	0	-0.5	0
5(I)	+1	-0.5	+0.5
9(I)	+1.5	0	-1
10(I)	+1.5	-0.5	0
11(I)	+3	0	0
12(I)	+1.5	0	–
13(I)	+2.5	0	–
16(I)	0	+0.5	-0.5
22(I)	+1	0	-1
30(I)	+1.5	-0.5	0
32(I)	0	0	0
33(I)	+1.5	0	–
Average Change	**+1.21**	**-0.07**	**-0.23**

[+ (plus) sign preceding number indicates score increased; – (minus) sign preceding number indicates score decreased; 0 (zero) indicates no change in score]

Thus it appeared that the Teaching Unit had been successful in giving students a better or more scientific understanding of the topic. Although, over a prolonged period (five to twelve months), there was a slight decrease in the level of understanding, that level remained higher than it was prior to instruction.

5.2.2 Comparison of the SOLO levels of the year 9/97 instruction and non-instruction groups determined from question one

In the previous section the responses, the corresponding SOLO levels, and the scores for the Key Elements present in the responses of each student in the Instruction Group, at each phase of the investigation, were examined in order to see whether the Teaching Unit had been successful in improving the understanding of the students and whether that level of understanding had been maintained. In this section a comparison is made of the percentages of students functioning at each SOLO level in the Instruction and Non-Instruction Groups, at each phase of the investigation. This is shown in Table 5.4. One student in the Non-Instruction Group, in the pre-instruction phase, did not respond to the question and has, therefore, not been included in the total number (n) of students. As no students in either group gave responses that contained zero Key Elements or were observed functioning at the Unistructural level in the Ikonic mode, these data have not been included in the table.

Table 5.4: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level in question one at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=14)	12-month Delayed (n=11)	Pre-Instruct (n=12)	Delayed Post (n=13)	12-month Delayed (n=12)
IK M	1 (7)	0	0	0	1 (8)	3 (23)	1 (8)
IK R	2 (14)	0	0	0	4 (33)	2 (15)	2 (17)
CS U	0	0	0	0	0	0	1 (8)
CS M	9 (64)	2 (14)	2 (14)	5 (46)	6 (50)	6 (46)	6 (46)
CS R_a	1 (7)	3 (21)	6 (43)	3 (27)	1 (8)	2 (15)	2 (17)
CS R_b	1 (7)	9 (64)	6 (43)	3 (27)	0	0	0

Although the questionnaire was not administered to the Non-Instruction Group at the immediate post-instruction phase of the investigation, the data obtained at this phase for the Instruction Group have been included in Table 5.4 to enable the increase in SOLO level observed as a result of the Teaching Unit and the subsequent slight regression to be more readily apparent compared with the Non-Instruction Group.

In Table 5.4 it can be seen that the results obtained for the Non-Instruction Group were similar to those obtained with the Instruction Group in the pre-instruction test but, six months later, in contrast to the Instruction Group, the results of the Non-Instruction Group were virtually unchanged. Six students (46%) in the Non-Instruction Group were operating in the Concrete Symbolic mode, Multistructural level, and five students (38%) were operating in the Ikonic mode in both the pre-instruction and delayed post-instruction phases. These results were virtually unchanged seven months later. This was as expected for students who had not received any instruction on the topic either prior to or over the course of the investigation. These students, however, provided a base line for the measurement of improvement for the Instruction Group.

It is interesting to note that, prior to instruction, 64% of the Instruction Group were operating at the Multistructural level in the Concrete Symbolic mode compared with 50% in the Non-Instruction Group. It would be expected that these figures should be the same as neither group had, at that point, received instruction in 'sound and hearing'. Although the sample size is small and may account for the difference, the difference may also be accounted for by the fact that the Instruction Group is made up of students who have elected to study additional science and, therefore, may have a greater interest in and possibly a greater aptitude for science.

5.3 Analysis of the year 9/97 responses to question two

Responses to Questions Two (Figure 4.2) were used as a further indication of students' understanding of the nature of sound and how it reaches the listener's ear. These responses allowed the researcher to determine how clearly each student understood the mechanism of sound transmission in terms of vibration of source, medium, and receptor. The complete responses of the students, at each phase of the investigation, are contained in Appendix 17.

This was a multiple choice question in which the students were asked to select the one sentence that best described how they hear the sound of a gong when it is struck and to explain what was wrong with all the statements other than the one they selected. As discussed in Section 4.7, each of the sentences reflected elements of the Development Map that were indicative of a particular cognitive level. Option 4 which stated that 'the gong sets the air vibrating and the vibrations travel to your ears' was the **best** description of how the student hears the sound of the gong when it is struck and was indicative of the CS R_b level in the Development Map for Hearing. Options 1 (IK U), 2 (IK M), 5 (IK R), and 6 (CS M) were not incorrect but did not describe the situation as well as did Option 4. Option 3 was incorrect as it stated that sound waves travel from the ear to the gong, which is the reverse notion, however, as discussed in Section 4.7, it was taken as indicative of the CS U level. In a number of cases, the students did not respond other than by circling their preferred option. For those who did respond their comments provided little further insight into their understanding. Students' responses to Question Two were certainly not as definitive of their level of cognitive functioning as their responses to Question One since, as discussed also in Section 4.7, it was observed that students generally performed better on this multiple choice question than on the questions (One and Three) in which they had to generate their own responses.

Table 5.5 shows the number (percentage) of students in both the Instruction and Non-Instruction Groups selecting a particular option at each phase of the investigation. In the Non-Instruction Group, one student selected two options in the pre-instruction test as did two students in the delayed post-instruction test. For this reason the percentages of students selecting a particular option total more than 100%.

From the data presented in Table 5.5, it can be seen that there is little change in the percentage of students in the Non-Instruction Group selecting Option 4 over the course of the investigation, whereas an increase was observed in the percentage of the Instruction Group selecting this option immediately following instruction. The percentage of students in both groups selecting the reverse notion (Option 3) was the same prior to instruction but this notion was not selected again by the Instruction Group, with one exception in the 12-month phase. With the Non-Instruction Group, however, the percentage selecting Option 3 remained approximately the same over the course of the investigation.

As can be seen in the data for the Instruction Group shown in Table 5.5, virtually no change took place over the twelve months elapsing after the completion of the Teaching Unit. The number of students in the Instruction Group had decreased slightly, but there was little change in the percentage of students selecting Option 4, the 'best' option, at each of the three phases after completion of the Teaching Unit. The Non-Instruction Group also showed little change over this period of time. It is of interest to note that no students in the Instruction Group chose Option 2, the notion of 'active listening', at any stage in the investigation, and only one student in the Non-Instruction Group selected this option, in the pre-instruction phase only.

Table 5.5: Number (percentage) of year 9/97 students in the instruction and non-instruction groups selecting a particular option in question two at each phase of the investigation

	Instruction Group				Non-Instruction Group		
Option Selected	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=14)	12-month Delayed (n=11)	Pre Instruct. (n=13)	Delayed Post (n=13)	12-month Delayed (n=12)
1	0	0	0	0	1 (8)	2 (15)	1 (8)
2	0	0	0	0	1 (8)	0	0
3	3 (21)	0	0	1 (9)	3 (23)	3 (23)	2 (17)
4	9 (64)	13 (93)	13 (93)	9 (82)	7 (54)	9 (69)	9 (75)
5	1 (7)	0	0	0	0	0	0
6	1 (7)	1 (7)	1 (7)	1 (9)	2 (15)	1 (8)	0

A discrepancy was observed between the percentages of students selecting Option 4, the SOLO level CS R_b, in their responses to Question Two, and those observed at this level in their responses to Question One (see Table 5.4). The percentages of students in the Non-Instruction Group selecting Option 4 were quite high at each phase of the investigation and yet none of these students was observed functioning at the CS R_b level at any time with Question One. Similarly, with the Instruction Group, although students were observed functioning at the CS R_b level in Question One, the percentages observed for Question Two again were higher.

Despite the concern at the rather inflated levels of cognitive functioning observed in the responses to Question Two, it, nonetheless, still appeared that the Teaching Unit was effective in improving the understanding of students. Question Two still showed similar trends in improvement in understanding for the Instruction Group compared with the Non-Instruction Group.

5.4 Analysis of the year 9/97 responses to question three

Responses to Question Three were used as a further indication of students' understanding of 'sound', in particular, the transmission of sound in different media and the importance of the medium for transmission. The complete responses are contained in Appendix 17.

As discussed in Section 4.8, each picture in Question Three (Figure 4.3) depicted a situation with which students may have been familiar but the medium involved in the transmission of the sound was not always air. In the Teaching Unit the transmission of sound in different media was discussed in class by the students and the teacher, and the absence of sound in a vacuum was demonstrated by the teacher. The responses to Picture (v), the transmission of sound in a vacuum, were of particular interest as this gave a clear indication of students' understanding of the necessity of a medium for the transmission of sound.

The responses to Question Three were analysed by determining the number of Key Elements present and the corresponding SOLO level, as discussed in Section 4.8. Using the scoring system devised to facilitate the analysis of students' responses (see Section 4.8.3), each response was assigned a score for the number of Key Elements present. As discussed in Section 4.8, the most important factor was to identify whether or not students understood the need for a medium in the transmission of sound, the interactive role of that medium, and the ability of other materials besides air to function as media for the transmission of sound.

As was discussed for Question One (Section 5.2), there are two ways of looking at the responses of each student; in terms of the SOLO level, and in terms of the change in the score for the number of Key Elements present in the responses from one phase to the next. The change in SOLO level observed for each student in the Instruction Group and the change in the score for the number of Key Elements, over the course of the investigation, are discussed in Section 5.4.1. In Section 5.4.2, a comparison is made of the SOLO levels of the Instruction and Non-Instruction Groups as a whole, in the same manner as for Question One.

5.4.1 Comparison of the SOLO levels and the changes in scores for key elements of individual students in the year 9/97 instruction group determined from question three

The number of Key Elements contained in the responses of each student in the Instruction Group to Question Three were identified and a score assigned as shown in Table 4.12. On the basis of this score, and relating the response to the Development Map for Hearing, the SOLO level for each response was identified. Although the Key Elements for Question Three were slightly different from those identified in Question One, the relationship between the number of Key Elements and the SOLO level was the same (see Table 4.4). The number of Key Elements and the SOLO level in the responses, at each phase of the investigation, are given in Tables 5.6 to 5.11. Because of the variety of situations presented in the pictures, the number of Key Elements and the SOLO level for each student are tabulated separately for each picture. Examples of responses for each picture, some of which have been taken from the Non-Instruction Group, are included.

Picture (i): The results obtained for Picture (i), which showed the transmission of sound through water, are given in Table 5.6. The scene in Picture (i) was a situation with which many of the students may have been familiar, and 64% of students in the Instruction Group demonstrated a good understanding of the mechanism for this transmission, in the pre-instruction phase. These students were operating in the Concrete Symbolic mode and held between 2.5 and 3.5 elements of the Development Map for Hearing. No student held all 4 elements. Twenty-one percent of students were operating in the Ikonic mode and held only 1 or 1.5 elements of the Development Map. Two students held no elements and demonstrated a lack of scientific understanding. The two students in the pre-instruction phase whose responses contained zero Key Elements either gave an incorrect response and no explanation (Student 5(I)), or wrote, "No. I don't know. I just think you wouldn't be able to." (Student 22(I))

One student in the Non-Instruction Group wrote, "Yes, the water contains air and sound vibrations can travel through the air, so you can hear under water" (Student 23, delayed post-instruction). This student was considered to be operating at the Relational level in the Ikonic mode for this situation. She had demonstrated an understanding of air as a medium and had intuitively applied that understanding by analogy to water. If air had been the medium involved, this would have been considered a Concrete Symbolic response.

An interesting response, given by Student 30(I) in the pre-instruction phase, was "No, water absorbs most of the sound as the particles are packed together." This student appeared aware that water is denser than air but regarded this as an impediment to transmission.

Table 5.6: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (i) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	3.5 CS R_a	4 CS R_b	3.5 CS R_a	3.5 CS R_a
3(I)	3 CS M	4 CS R_b	3.5 CS R_a	3.5 CS R_a
4(I)	3 CS M	3 CS M	3 CS M	3 CS M
5(I)	0	3.5 CS R_a	no response	3 CS M
9(I)	3 CS M	4 CS R_b	3 CS M	3 CS M
10(I)	1.5 IK R	3.5 CS R_a	3.5 CS R_a	3 CS M
11(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	3.5 CS R_a
12(I)	1 IK M	3 CS M	1 IK M	–
13(I)	3 CS M	4 CS R_b	3.5 CS R_a	–
16(I)	3.5 CS R_a	3 CS M	3 CS M	3 CS M
22(I)	0	3.5 CS R_a	3.5 CS R_a	3 CS M
30(I)	1.5 IK R	3 CS M	3 CS M	2.5 CS M
32(I)	2.5 CS M	4 CS R_b	3.5 CS R_a	3 CS M
33(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	–

Upon completion of the Teaching Unit, all students were operating in the Concrete Symbolic mode. Fifty percent of students held all elements of the Development Map for Hearing and were considered to be functioning at the Relational (R_b) level in the Concrete Symbolic mode, the highest cognitive level in the Development Map. The remaining students held 3 or 3.5 elements.

Five months later (the delayed post-instruction phase), the cognitive level of a number of students in the Instruction Group had decreased slightly from CS R_b to CS R_a. The total percentage of students operating at the Relational level in the Concrete Symbolic mode was approximately the same but the majority of these students now held 3.5 rather than 4 elements of the Development Map. This was similar to the situation observed with Question One of the questionnaire (see Section 5.2.1).

Twelve months after instruction, a further slight decrease in the cognitive level was observed. No students held all elements of the Development Map and only 27% held 3.5 elements. All students were still operating in the Concrete Symbolic mode but the majority were now operating at the Multistructural level. This was marginally better than in the pre-instruction phase in which 21% of students were operating in the Ikonic mode.

Picture (ii): A similar situation was observed with the results for Picture (ii), the hammer striking the girder, shown in Table 5.7. In this situation the sound vibrations were transmitted principally by the girder but both the air around and the wall through which the girder passed could have been involved also. An improvement in scientific understanding, although not quite so marked as with Picture (i), was observed immediately following the completion of the Teaching Unit and a similar slight regression five and twelve months later. Only 31% of students in the Instruction Group held all elements of the Development Map for Hearing in the immediate post-instruction phase for Picture (ii) compared with 50% for Picture (i). Thirty-nine percent of students held 3 elements and were operating at the CS M level at this phase. Five months later only one student held all elements; the majority held either 3 or 3.5 elements. There was little further change seven months later.

Table 5.7: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (ii) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	3 CS M	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a
3(I)	1.5 IK R	4 CS R_b	3.5 CS R_a	3 CS M
4(I)	1 IK M	3 CS M	3 CS M	3 CS M
5(I)	1 IK M	2 CS U	no response	1 IK M
9(I)	1 IK M	3 CS M	3 CS M	1 IK M
10(I)	3.5 CS R_a	3 CS M	3.5 CS R_a	3.5 CS R_a
11(I)	2 CS U	3 CS M	3 CS M	4 CS R_b
12(I)	2.5 CS M	4 CS R_b	1 IK M	–
13(I)	1.5 IK R	4 CS R_b	3 CS M	–
16(I)	2.5 CS M	3 CS M	3.5 CS R_a	2.5 CS M
22(I)	3 CS M	no response	3 CS M	3 CS M
30(I)	3 CS M	3.5 CS R_a	2 CS U	2.5 CS M
32(I)	3.5 CS R_a	4 CS R_b	3.5 CS R_a	3.5 CS R_a
33(I)	1.5 IK R	3.5 CS R_a	4 CS R_b	–

Student 30(I) in the pre-instruction phase, gave a response which indicated again that density was an impediment to transmission, although in a slightly different way to her notion for Picture (i). She wrote, "No, the solidness of the brick wall blocks the vibrations, therefore sound is unable to travel through the girder." Her response appeared to indicate an understanding of the notion of vibrations and of the girder as a medium for the transmission of sound, and was considered Multistructural in the Concrete Symbolic mode. However, she appeared to believe that the density of the wall was such that it stopped the vibrations. Immediately after completion of the Teaching Unit, she demonstrated a clearer understanding of the transmission of sound when she wrote, "Yes, the vibrations travel along the girder" (CS R_a).

Five months later, Student 30(I) had returned to the idea that the wall would block the vibrations, "No, the bricks would absorb the sound waves (vibrations)." On this occasion she had not mentioned the girder in her response although she had mentioned 'vibrations'. Her response was considered to be indicative of a student functioning on the border of the transition from the Ikonic to the Concrete Symbolic mode, that is, at the CS U level.

Student 11(I) was considered to be functioning at the Unistructural level in the Concrete Symbolic mode as her response included the single element 'vibration'. In her response, "Yes, because the vibrations can travel through the wall", it appeared that she may have meant along the girder and through the wall, rather than that the wall was a medium for the transmission of sound.

Picture (iii): The string telephone, shown in Picture (iii), represented a popular activity for young children. A number of the students appeared familiar with it and knew that it worked even if they did not know how. The results for this picture are shown in Table 5.8. In this situation some vibrations would have been transmitted by the surrounding air but the principal medium was the string.

Prior to instruction, 43% of students in the Instruction Group were operating at the Relational level in the Concrete Symbolic mode and held 3.5 elements of the Development Map. This is higher than was observed with the other five pictures; however, no students held all elements. Twenty-nine percent of the students held only 0.5 to 1.5 elements and were operating in the Ikonic mode. One student held no elements of the Development Map. Immediately following instruction, 64% of students held 3.5 or 4 elements and showed a good scientific understanding of the transmission of sound via string. Almost no regression was observed five months nor even twelve months later.

Table 5.8: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (iii) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	3 CS M	3.5 CS R_a	3 CS M	3 CS M
3(I)	3.5 CS R_a	4 CS R_b	3.5 CS R_a	3.5 CS R_a
4(I)	3.5 CS R_a	3.5 CS R_a	3 CS M	3 CS M
5(I)	0	1.5 IK R	no response	3.5 CS R_a
9(I)	1.5 IK R	3 CS M	3.5 CS R_a	3.5 CS R_a
10(I)	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a	4 CS R_b
11(I)	2.5 CS M	3 CS M	3 CS M	3 CS M
12(I)	1 IK M	1.5 IK R	0	–
13(I)	0.5 IK U	3.5 CS R_a	3.5 CS R_a	–
16(I)	1.5 IK R	3 CS M	3 CS M	1 IK M
22(I)	3 CS M (with IK support)	3.5 CS R_a	3.5 CS R_a	3 CS M
30(I)	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a
32(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	3.5 CS R_a
33(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	–

The student who said, "Yes, because the tins vibrate" (Student 1, delayed post-instruction) demonstrated an understanding that talking into the tin of the string telephone produced vibrations even if she had not said how those vibrations reached the listener. This student was considered to be operating in the Concrete Symbolic mode as she had acknowledged that the tin was a medium that vibrated to transmit sound.

An interesting example of a Concrete Symbolic response with Ikonic support was given in the pre-instruction phase for Picture (iii) by Student 22(I) who wrote, "Yes, because the sound waves travel down the rope and therefore you hear it at the other [sic]. Also I have done this and know it works". The student had used her experience of this activity to support her scientific explanation. Immediately following the completion of the Teaching Unit, she demonstrated a slightly better understanding of how the sound is transmitted and no longer included the Ikonic support in her response, "Yes, because the vibrations travel down the string".

Picture (iv): The situation of the two friends talking on either side of a high wall shown in Picture (iv) appeared conceptually more difficult for the students. These results are contained in Table 5.9. Although the students had discussed the transmission of sound in solid media as well as in air, they appeared to have difficulty relating the discussions to this situation. Some students appeared to feel that the wall was a barrier to sound and did not consider either that the material of which the wall was composed could vibrate and transmit the sound or that the surrounding air could act as a medium for transmission.

Prior to instruction, 86% of students in the Instruction Group were operating in the Ikonic mode and only 7% in the Concrete Symbolic mode. Immediately following the Teaching Unit, 43% were still operating in the Ikonic mode. Five months later this had increased slightly to 57% but did not change further over the 12-month period.

In one situation only, a response to Picture (iv) did not receive a score of zero if the student was deemed to have displayed some understanding of the transmission of sound. If the student answered "No" (she couldn't hear her friend), without any further explanation, then it was considered that the student was saying that the wall was a barrier to sound which indicated an understanding that sound must travel from the source at least to the wall. The response thus received a score of 1, 0.5 each for parts of the Key Elements 'correct answer plus correct explanation' and 'travel through the medium'. This was the only instance in which the researcher took the response to indicate an awareness of sound travelling even though it was not specifically stated.

Table 5.9: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (iv) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	1 IK M	1.5 IK R	4 CS R_b	2 IK R
3(I)	1 IK M	3 CS M	1.5 IK R	2 IK R
4(I)	1.5 IK R	3 CS M	1.5 IK R	1.5 IK R
5(I)	1 IK M	1.5 IK R	1.5 IK R	1.5 IK R
9(I)	1.5 IK R	3.5 CS R_a	3.5 CS R_a	2 CS U
10(I)	1.5 IK R	3.5 CS R_a	1.5 IK R	3.5 CS R_a
11(I)	1 IK M	1.5 IK R	3 CS M	2.5 CS M
12(I)	1 IK M	1.5 IK R	1 IK M	–
13(I)	1 IK M	3 CS M	1.5 IK R	–
16(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
22(I)	0	no response	3.5 CS R_a	1 IK M
30(I)	1.5 IK R	2 CS U	1.5 IK R	2 CS U
32(I)	1.5 IK R	3 CS M	3 CS M	3.5 CS R_a
33(I)	3 CS M	4 CS R_b	4 CS R_b	–

The response, "Yes, you could hear over the top of the wall depending on how loudly they spoke" (Student 16(I), pre-instruction) was considered to be an Ikonic response. The student knew that sound travelled from the source to the listener but made no mention of the medium. Similarly, a student who said, "No, because the sound waves cannot travel through the brick" (Student 32(I), pre-instruction) demonstrated an understanding that sound travelled, but not that it can travel through solid materials. Intuitively the student appeared to believe that a brick wall was a barrier. This student too was considered to be operating in the Ikonic mode.

Student 30(I), immediate post-instruction, stated, "No, the air vibrations would rebound from the wall". She understood that sound vibrations travelled through the air and that the air itself vibrated. However, she has not understood that these vibrations travel out from the source, in all directions, not merely straight ahead, and could, therefore, travel through the air and over the wall. This is an example of a Unistructural response in the Concrete Symbolic mode where there is no recognition of the conflict between the notion of vibrations travelling through the air and the notion that they can only travel towards the wall.

Picture (v): The results for Picture (v), which showed a sound source in a vacuum, are shown in Table 5.10. The Teaching Unit included a practical demonstration of the situation shown in Picture (v), in which the air was gradually removed from a bell jar until the sound of the clock inside could no longer be heard. Prior to instruction, 50% of students were operating in the Concrete Symbolic mode and 50% in the Ikonic mode. Following instruction, the majority of students had made the transition to the Concrete Symbolic mode with 43% holding 3.5 or 4 elements of the Development Map for Hearing and demonstrating an understanding that, in the absence of air, sound cannot be transmitted. Twenty-one percent continued to operate in the Ikonic mode. Five months and twelve months later there was little change in the cognitive levels at which the students were functioning.

Prior to instruction, some students believed that the glass bell jar prevented the sound from getting out and this was why they could not hear the sound. For example, "No, there is no way the sound waves can get out" (Student 2(I), pre-instruction). This student has demonstrated an understanding that sound waves travel but has not understood the role of the medium and that, in this situation, there is no medium for the transmission of the sound. She appeared instead to see the glass as the barrier to the transmission. Immediately following the Teaching Unit, she demonstrated a more scientific understanding when she wrote, "No, because there is no air in a vacuum to set vibrations".

Table 5.10: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (v) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	1.5 IK R	3 CS M	3 CS M	4 CS R_b
3(I)	3 CS M	4 CS R_b	3.5 CS R_a	3 CS M
4(I)	3.5 CS R_a	3 CS M	3 CS M	2.5 CS M
5(I)	1.5 IK R	3.5 CS R_a	3 CS M	3 CS M
9(I)	3 CS M	3.5 CS R_a	4 CS R_b	3.5 CS R_a
10(I)	3 CS M	1.5 IK R	1.5 IK R	3.5 CS R_a
11(I)	1.5 IK R	2.5 CS M	2.5 CS M	2.5 CS M
12(I)	1.5 IK R	3 CS M	1 IK M	–
13(I)	3.5 CS R_a	4 CS R_b	3.5 CS R_a	–
16(I)	1.5 IK R	1.5 IK R	1.5 IK R	1 IK M
22(I)	2.5 CS M	3 CS M	3 CS M	3 CS M
30(I)	1.5 IK R	1.5 IK R	2.5 CS M	2 CS U
32(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	4 CS R_b
33(I)	1.5 IK R	4 CS R_b	4 CS R_b	–

Picture (vi): The results obtained with the final picture, Picture (vi), are given in Table 5.11. This picture showed a situation that most students were likely to have experienced, that of a police siren passing by, and yet the improvement in cognitive functioning following instruction was not so marked with this context. Students did not appear to understand that the vibrations in the air can travel in all directions from the source and will, therefore, continue travelling to the listener even after the source has passed.

Prior to instruction, 93% of students held only 1 or 1.5 elements of the Development Map for Hearing and showed little understanding of this situation. Upon completion of the Teaching Unit, 57% still showed little understanding and only 21% demonstrated a scientific understanding and held 3.5 or 4 elements of the Development Map. This latter figure had decreased to 14% five months later with a further decrease to 9% by the 12-month phase, by which time the majority of students had returned to their pre-instruction level of cognitive functioning.

Of the six situations illustrated in the pictures, this last showed the least improvement in understanding following tuition with the majority of students continuing to function in the Ikonic mode at each phase of the investigation. For example, Student 4(I) in the pre-instruction phase wrote, "Yes, because the noise a siren makes is very loud". This response appeared to be based upon her experience of police sirens. Following the completion of the Teaching Unit, her understanding was a little better, "Yes, because sound can travel for quite a while before not being able to hear it", but her response made no mention of 'air' or 'vibrations' and was indicative still of the Ikonic mode. Her mode of functioning did not change over the ensuing twelve months.

During the Teaching Unit, mention had been made of the Doppler effect, the change in frequency of the sound observed when a car with siren sounding passes by. A small number of students then gave this as their response to Picture (vi), for example, Student 30(I) in the 12-month delayed post-instruction phase, who wrote, "Yes, Doppler effect". As she had not explained what the effect was, this response did not demonstrate her level of understanding with respect to the transmission of sound in this situation, and yet her response to Question One had indicated a good scientific understanding of the transmission of sound through air. As stated previously (Section 5.2.1), the SOLO model is a 'response' model and, unless a student specifically states a particular notion in her response, she is not deemed to hold that notion.

Table 5.11: Number of key elements and SOLO level in the responses of students in the year 9/97 instruction group to question three picture (vi) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed Post
2(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
3(I)	1 IK M	1.5 IK R	1.5 IK R	1.5 IK R
4(I)	1 IK M	1.5 IK R	1.5 IK R	1 IK M
5(I)	1 IK M	3 CS M	3 CS M	1 IK M
9(I)	1.5 IK R	1.5 IK R	2 CS U	1.5 IK R
10(I)	1.5 IK R	4 CS R_b	3.5 CS R_a	3.5 CS R_a
11(I)	1.5 IK R	3 CS M	3 CS M	1 IK M
12(I)	1 IK M	3.5 CS R_a	1 IK M	–
13(I)	1.5 IK R	1.5 IK R	1.5 IK R	–
16(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
22(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
30(I)	1.5 IK R	1.5 IK R	1.5 IK R	1 IK M
32(I)	3 CS M	3 CS M	3 CS M	2.5 CS M
33(I)	1.5 IK R	3.5 CS R_a	3.5 CS R_a	–

Of the six situations depicted in Question Three, it was observed that students appeared to find Picture (iv) (talking over the wall) and Picture (vi) (the police siren) conceptually the most difficult. The improvement in SOLO levels following tuition observed with these two situations was less than with the other pictures. The decline in the cognitive level over the twelve months following tuition was also more obvious.

Thus it appeared that the role of the medium in the transmission of sound was the main 'stumbling block' to student understanding. Students reverted to intuitive notions when they encountered a situation that they may have experienced but for which they did not have a scientific understanding. It appeared that, unless they can link the scientific explanation to their experiences, the majority of students do not retain a complete scientific understanding of the phenomenon.

The importance of each student's responses lay in determining whether her understanding had changed following instruction and whether or not any further change had taken place over the ensuing months. In order to observe these changes more readily, a table was drawn up, in the same way as for Question One, showing the changes in the scores for the number of Key Elements of individual students in the Instruction Group for Question Three, from pre-instruction to immediate post-instruction (P/IP), from immediate post-instruction to delayed post-instruction (IP/DP), and from immediate post-instruction to 12-month delayed post-instruction (IP/12DP). The results are shown in Table 5.12. The average change in the score observed with these phase transitions is shown in the table also.

In Table 5.12, it can be seen that, immediately following the completion of the Teaching Unit, the scores for the number of Key Elements in the responses of nearly all students had increased. The most marked average increase was seen with Pictures (i) and (ii) and the least with Picture (v), although, as the size of the group used in this investigation was small, the differences were not large. However it is interesting to note that the average change for each situation was positive immediately after instruction which is an indicator of the success of the Teaching Unit in improving student understanding.

It is of some concern, although perhaps not totally surprising, that, for each picture, there was a decrease in the average score over the five months subsequent to the teaching. The change was not large but was an indication that the students had not retained their full scientific understanding over time. However, it was pleasing to note that in no case did students on average return to their pre-instruction levels.

No further decrease of note was observed with Pictures (i) to (iv) over the twelve month period. However with Picture (v) there was a slight increase in the average score and with Picture (vi) a further slight decrease. In both situations these were due to one or two students exhibiting larger changes than the others in the group and, because the total number of students was small, this had a marked influence on the average change.

Table 5.12: Changes in individual scores and the average change in score for students in the year 9/97 instruction group for question three pre- to immediate post- (P/IP), immediate to delayed post- (IP/DP), and immediate to 12-month delayed post-instruction (IP/12DP)

	Picture in Question Three																	
	(i)			(ii)			(iii)			(iv)			(v)			(vi)		
Student No.	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP
2(I)	+0.5	-0.5	-0.5	+0.5	0	0	+0.5	-0.5	-0.5	+0.5	+2.5	+0.5	+1.5	0	+1	0	0	0
3(I)	+1	-0.5	-0.5	+2.5	-0.5	-1	+0.5	-0.5	-0.5	+2	-1.5	-1	+1	-0.5	-1	+0.5	0	0
4(I)	0	0	0	+2	0	0	0	-0.5	-0.5	+1.5	-1.5	-1.5	-0.5	0	-0.5	+0.5	0	-0.5
5(I)	+3.5	–	-0.5	+1	–	-1	+1.5	–	+2	+0.5	0	0	+2	-0.5	-0.5	+2	0	-2
9(I)	+1	-1	-1	+2	0	-2	+1.5	+0.5	+0.5	+2	0	-1.5	+0.5	+0.5	0	0	+0.5	0
10(I)	+2	0	-0.5	-0.5	+0.5	+0.5	0	0	+0.5	+2	-2	0	-1.5	0	+2	+2.5	-0.5	-0.5
11(I)	+0.5	0	-0.5	+1	0	+1	+0.5	0	0	+0.5	+1.5	+1	+1	0	0	+1.5	0	-2
12(I)	+2	-2	–	+1.5	-3	–	+0.5	-1.5	–	+0.5	-0.5	–	+1.5	-2	–	+2.5	-2.5	–
13(I)	+1	-0.5	–	+2.5	-1	–	+3	0	–	+2	-1.5	–	+0.5	-0.5	–	0	0	–
16(I)	-0.5	0	0	+0.5	+0.5	-0.5	+1.5	0	-2	0	0	0	0	0	-0.5	0	0	0
22(I)	+3.5	0	-0.5	–	–	–	+0.5	0	-0.5	–	–	–	+0.5	0	0	0	0	0
30(I)	+1.5	0	-0.5	+0.5	-1.5	-1	0	0	0	+0.5	-0.5	0	0	+1	+0.5	0	0	-0.5
32(I)	+1.5	-0.5	-1	+0.5	-0.5	-0.5	+0.5	0	-0.5	+1.5	0	+0.5	+0.5	0	0	0	0	-0.5
33(I)	+0.5	0	–	+2	+0.5	–	+0.5	0	–	+1	0	–	+2.5	0	–	+2	0	–
Average Change	+1.29	-0.39	-0.50	+1.23	-0.42	-0.45	+0.79	-0.14	-0.14	+1.12	-0.27	-0.20	+0.68	-0.14	+0.09	+0.82	-0.18	-0.55

[+ (plus) sign preceding number indicates score increased; - (minus) sign preceding number indicates score decreased; 0 (zero) indicates no change in score; – (dash) indicates student did not respond on one or more occasions]

5.4.2 Comparison of the SOLO levels of the year 9/97 instruction and non-instruction groups determined from question three

In the previous section the responses, the SOLO levels, and the corresponding scores for the number of Key Elements present in the responses of each student in the Instruction Group, at each phase of the investigation, were examined, as had been done for Question One, in order to see whether the Teaching Unit had been successful. In this section a comparison is made of the total percentages of students operating at each SOLO level in the Instruction and Non-Instruction Groups, at each phase of the investigation. The data, which are presented separately for each picture, are shown in Tables 5.13 to 5.18, inclusive. What is of interest here is how the levels of cognitive functioning of the students in the Non-Instruction Group changed over the period of the investigation in comparison with the changes observed with the Instruction Group. If a student did not respond to any of the pictures she has not been included in the total number (n) of students in the Group. The number of students who responded but whose responses contained zero Key Elements (Zero K. E.) are shown in the table also.

With Picture (i), shown in Table 5.13, the SOLO levels of the Instruction and Non-Instruction Groups were not greatly different pre-instruction, although it can be seen that the spread of observed levels was slightly greater with the Instruction Group. Two students in the Instruction Group gave responses that contained zero Key Elements and four students were observed at the CS R_a level but there were no students at either of these levels in the Non-Instruction Group.

In the delayed and 12-month delayed post-instruction phases, the observed SOLO levels for the Non-Instruction Group remained virtually unchanged, although, in both phases, two students were now observed at the higher CS R_a level. By comparison, in the Instruction Group in which all students were observed functioning in the Concrete Symbolic mode, with 50% at the CS R_b level, immediately following the completion of the Teaching Unit, five months later a backward slide was observed. By the 12-month delayed post-instruction phase, although all the students continued to function in the Concrete Symbolic mode, the majority were now at the Multistructural level only. However, in spite of the observed decrease in levels with the Instruction Group, the improvement brought about by the Teaching Unit could still be seen when comparing this group with the relatively unchanged Non-Instruction Group.

Table 5.13: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (i) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=13)	12-month Delayed (n=11)	Pre Instruct. (n=13)	Delayed Post (n=13)	12-month Delayed (n=11)
Zero K. E.	2 (14)	0	0	0	0	0	0
IK U	0	0	0	0	0	0	0
IK M	1 (7)	0	1 (8)	0	3 (23)	2 (15)	1 (9)
IK R	2 (14)	0	0	0	2 (15)	3 (23)	3 (27)
CS U	0	0	0	0	3 (23)	0	0
CS M	5 (36)	4 (29)	4 (31)	8 (73)	5 (39)	6 (46)	5 (46)
CS R_a	4 (29)	3 (21)	6 (46)	3 (27)	0	2 (15)	2 (18)
CS R_b	0	7 (50)	2 (15)	0	0	0	0

With Picture (ii), shown in Table 5.14, the distribution of SOLO levels observed in the pre-instruction phase was again very similar in both the Instruction and Non-Instruction Groups. At the delayed and 12-month delayed post-instruction phases, the Non-Instruction Group showed almost no change in observed SOLO levels whereas a slight decrease in levels was seen with the Instruction Group, particularly between the immediate post- and the delayed post-instruction phases, a period of five months.

Table 5.14: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (ii) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	Pre Instruct. (n=14)	Immed. Post (n=13)	Delayed Post (n=13)	12-month Delayed (n=11)	Pre Instruct. (n=11)	Delayed Post (n=11)	12-month Delayed (n=11)
Zero K. E.	0	0	0	0	1 (9)	2 (18)	1 (9)
IK U	0	0	0	0	0	0	0
IK M	3 (21)	0	1 (8)	2 (18)	2 (18)	2 (18)	2 (18)
IK R	4 (29)	1 (8)	1 (8)	0	1 (9)	2 (18)	2 (18)
CS U	0	0	0	0	2 (18)	2 (18)	1 (9)
CS M	5 (36)	5 (38.5)	5 (38.5)	5 (46)	4 (36)	2 (18)	4 (36)
CS R_a	2 (14)	3 (23)	5 (38.5)	3 (27)	1 (9)	1 (9)	0
CS R_b	0	4 (31)	1 (8)	1 (9)	0	0	1 (9)

With Picture (iii), shown in Table 5.15, the observed pre-instruction SOLO levels of the Instruction Group were slightly higher than those of the Non-Instruction Group. The subsequent improvement in level observed with the Instruction Group following the Teaching Unit was only small but so too was the regression over the ensuing twelve months.

What was of particular interest was that an improvement in SOLO levels was observed with the Non-Instruction Group also despite the fact that they had not participated in the Teaching Unit. This may be accounted for by the fact that this was an activity which many of the students had played and, as a result, they may have been aware that it worked even if they could not explain the mechanism. For example, one student in the Non-Instruction

Group stated that she had seen it used successfully on the children's television programme "Sesame Street".

Table 5.15: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (iii) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=13)	12-month Delayed (n=11)	Pre Instruct. (n=13)	Delayed Post (n=12)	12-month Delayed (n=11)
Zero K. E.	1 (7)	0	1 (8)	0	0	1 (8)	1 (9)
IK U	1 (7)	0	0	0	0	0	0
IK M	1 (7)	0	0	1 (9)	5 (38.5)	1 (8)	0
IK R	2 (14)	2 (14)	0	0	1 (8)	1 (8)	3 (27)
CS U	0	0	0	0	1 (8)	1 (8)	0
CS M	3 (21)	3 (21)	4 (31)	4 (36)	5 (38.5)	5 (42)	7 (64)
CS R_a	6 (43)	6 (43)	6 (46)	5 (46)	1 (8)	3 (25)	0
CS R_b	0	3 (21)	2 (15)	1 (9)	0	0	0

As mentioned in Section 5.4.1, Picture (iv), shown in Table 5.16, appeared conceptually more difficult for the students. Prior to instruction, the distribution of cognitive levels at which students were functioning was almost the same for the Instruction and Non-Instruction Groups. Nearly all students in both groups were functioning in the Ikonic mode. The Non-Instruction Group continued to function in this mode and little change was observed over the period of the investigation. However, what was somewhat surprising was that, although a small number of students in the Instruction Group were observed functioning in the Concrete

Symbolic mode in the immediate post-instruction phase, almost 50% continued to function in the Ikonic mode, and the difference observed between the Instruction and the Non-Instruction Groups was not as great as had been observed with some of the other pictures.

Table 5.16: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (iv) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	**Pre Instruct.** (n=14)	**Immed. Post** (n=13)	**Delayed Post** (n=14)	**12-month Delayed** (n=11)	**Pre Instruct.** (n=12)	**Delayed Post** (n=12)	**12-month Delayed** (n=12)
Zero K. E.	1 (7)	0	0	0	1 (8)	0	0
IK U	0	0	0	0	0	0	0
IK M	6 (43)	0	1 (7)	1 (9)	4 (33)	3 (25)	2 (17)
IK R	6 (43)	6 (46)	7 (50)	5 (46)	6 (50)	8 (67)	8 (67)
CS U	0	0	0	2 (18)	0	0	0
CS M	1 (7)	4 (31)	2 (14)	1 (9)	1 (8)	1 (8)	2 (17)
CS R_a	0	2 (15)	2 (14)	2 (18)	0	0	0
CS R_b	0	1 (8)	2 (14)	0	0	0	0

With Picture (v), shown in Table 5.17, the SOLO levels observed in the pre-instruction phase were slightly higher in the Instruction Group than in the Non-Instruction Group, although in both groups almost 50% of students were functioning in the Concrete Symbolic mode and 50% in the Ikonic mode.

Following completion of the Teaching Unit, the levels in the Instruction Group improved slightly and did not decrease significantly over the ensuing five and twelve month periods. In comparison, a slight decrease in the SOLO levels of the Non-Instruction Group was observed in the delayed post-instruction phase, although these levels did not change further.

Table 5.17: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (v) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=14)	12-month Delayed (n=11)	Pre Instruct. (n=13)	Delayed Post (n=11)	12-month Delayed (n=10)
Zero K. E.	0	0	0	0	1 (8)	2 (18)	1 (10)
IK U	0	0	0	0	0	0	1 (10)
IK M	0	0	1 (7)	1 (9)	4 (31)	4 (36)	4 (40)
IK R	7 (50)	3 (21)	2 (14)	0	2 (15)	3 (27)	3 (30)
CS U	0	0	0	1 (9)	1 (8)	1 (9)	0
CS M	4 (29)	5 (36)	6 (43)	5 (46)	5 (39)	1 (9)	1 (10)
CS R_a	3 (21)	2 (14)	2 (14)	2 (18)	0	0	0
CS R_b	0	4 (29)	3 (21)	2 (18)	0	0	0

With Picture (vi), shown in Table 5.18, it was interesting to note that the observed SOLO levels of the Instruction and Non-Instruction Groups were not greatly different at any stage in the investigation. Although three students in the Instruction Group were observed functioning at the Relational level in the Concrete Symbolic mode immediately following the Teaching Unit, the majority of students continued to function in the Ikonic mode and the percentages at each level were similar in both the Instruction and Non-Instruction Groups. This was somewhat similar to the outcomes observed with Picture (iv). As stated in Section

5.4.1, it was with these two pictures that the least improvement in level of cognitive functioning was observed.

Table 5.18: Number (percentage) of year 9/97 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (vi) at each phase of the investigation

	Instruction Group				Non-Instruction Group		
SOLO Level	**Pre Instruct.** (n=14)	**Immed. Post** (n=14)	**Delayed Post** (n=14)	**12-month Delayed** (n=11)	**Pre Instruct.** (n=13)	**Delayed Post** (n=13)	**12-month Delayed** (n=12)
Zero K. E.	0	0	0	0	1 (8)	1 (8)	0
IK U	0	0	0	0	0	0	0
IK M	4 (29)	0	1 (7)	4 (36)	2 (15)	2 (15)	2 (17)
IK R	9 (64)	8 (57)	8 (57)	5 (46)	4 (31)	6 (46)	6 (50)
CS U	0	0	0	0	1 (8)	1 (8)	1 (8)
CS M	1 (7)	3 (21)	3 (21)	1 (9)	4 (31)	3 (23)	3 (25)
CS R_a	0	2 (14)	2 (14)	1 (9)	0	0	0
CS R_b	0	1 (7)	0	0	1 (8)	0	0

From the data presented in Tables 5.13 to 5.18, it can be seen that the SOLO levels at which the students in the Non-Instruction Group were operating showed little variation over the course of the investigation and, as expected, remained similar to the levels observed with the Instruction Group in the pre-instruction phase. Slight variations may be associated with fluctuations in measurement and any small improvements were most probably due to external factors such as books, television or discussions with peers in the Instruction Group.

At the 12-month phase the latter was less likely as the students had moved on to a new year group and different classes.

In the previous sections, changes in levels of understanding following the implementation of the Teaching Unit have been monitored using each of the three questions of the questionnaire separately. In Section 5.5, the scores allocated for the responses to Question One and for the six pictures of Question Three are together used to provide a more discriminating tool for comparison of the levels of cognitive functioning of students in the Instruction and Non-Instruction Groups, at each phase of the investigation.

5.5 Comparison of the overall performances of students in the year 9/97 instruction and non-instruction groups at each phase of the investigation using the combined total scores for question one and question three

As discussed in Section 4.10, the levels of cognitive functioning had been determined from the responses to Question One and from the responses to the six pictures of Question Three. The scores for these two questions were combined in order to facilitate the comparison of the overall performance across tasks of the students. Question Two was not included as the outcomes observed with this 'multiple choice' question were higher than for the 'free response' Question One and Question Three and did not discriminate well between students. By combining the scores for Questions One and Three, it was possible to discriminate more effectively between the performances of students in the Instruction and Non-Instruction Groups, at each phase of the investigation, and to obtain further information as to how successful the Teaching Unit had been. The combining of scores across seven items, that is Question One plus the six pictures of Question Three, also served to eliminate the ceiling effect observed for some individual items where there was insufficient discrimination between students receiving the same score for a particular response. Seven items allowed greater variation to become more obvious.

In the analysis of students' responses to Questions One and Three, a score was allocated for the number of Key Elements, or parts thereof, present in each response, out of a maximum score of 4 per response. Therefore, combining the score for Question One with the scores for each of the six pictures in Question Three, the maximum score a student could obtain would be 28. This calculation was carried out for each student involved in the research at each phase of the investigation at which she had completed the questionnaire. For example, in the pre-instruction phase, Student 4(I) received a score of 3.5 for Question One and scores of 3, 1, 3.5, 1.5, 3.5, and 1 for each of the six pictures in Question Three, respectively, giving her a combined total score of 17. She was observed functioning in the Ikonic mode for some contexts (a score of 1 or 1.5) and in the Concrete Symbolic mode in other contexts (a score of 3 or 3.5). Thus the combined total score for Student 4(I), in the pre-instruction phase, was in the designated range 15.1 to 20. Students who were observed functioning generally in the Ikonic mode would have combined total scores in the range 0–5 or 5.1–10. Students who were well advanced along the pathway for the development of a scientific understanding of 'sound and hearing', and were observed functioning at the Relational level in the Concrete Symbolic mode, would be expected to have combined total scores in the range of 20.1 to 25 or 25.1 to 30. The Non-Instruction Group would be expected to have scores in the lower ranges.

The number (percentage) of students in the Instruction and Non-Instruction Groups in each designated range of combined total score for Question One and Question Three, at each phase of the investigation, is given in Table 5.19. From the data presented in the table, graphs were drawn. These are shown in Figure 5.1 (Instruction Group) and Figure 5.2 (Non-Instruction Group).

Table 5.19: Number (percentage) of students in the year 9/97 instruction and non-instruction groups in each range of combined total score for question one and question three at each phase of the investigation

	Number (Percentage) of Students in each Group						
	Instruction Group				Non-Instruction Group		
Combined Total Score	Pre Instruct. (n=14)	Immed. Post (n=14)	Delayed Post (n=14)	12month Delayed (n=11)	Pre Instruct. (n=13)	Delayed Post (n=13)	12month Delayed (n=12)
0–5	0	0	0	0	1 (8)	0	1 (8)
5.1–10	1 (7)	0	1 (7)	0	3 (23)	4 (31)	2 (17)
10.1–15	8 (57)	1 (7)	1 (7)	1 (9)	4 (31)	5 (38.5)	3 (25)
15.1–20	4 (29)	3 (21)	3 (21)	6 (55)	5 (38.5)	4 (31)	6 (50)
20.1–25	1 (7)	8 (57)	8 (57)	4 (36)	0	0	0
25.1–30	0	2 (14)	1 (7)	0	0	0	0

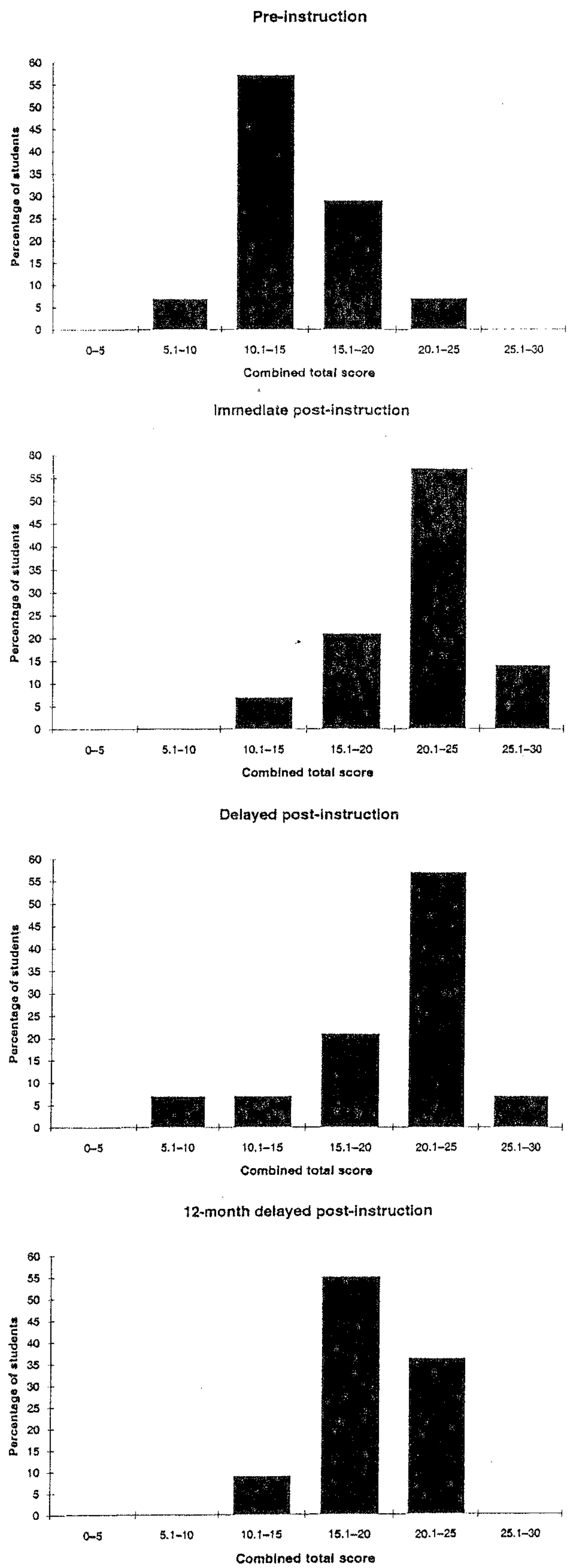


Figure 5.1: **Graphs showing the percentage of students in the year 9/97 instruction group in each range of combined total score for question one and question three at each phase of the investigation**

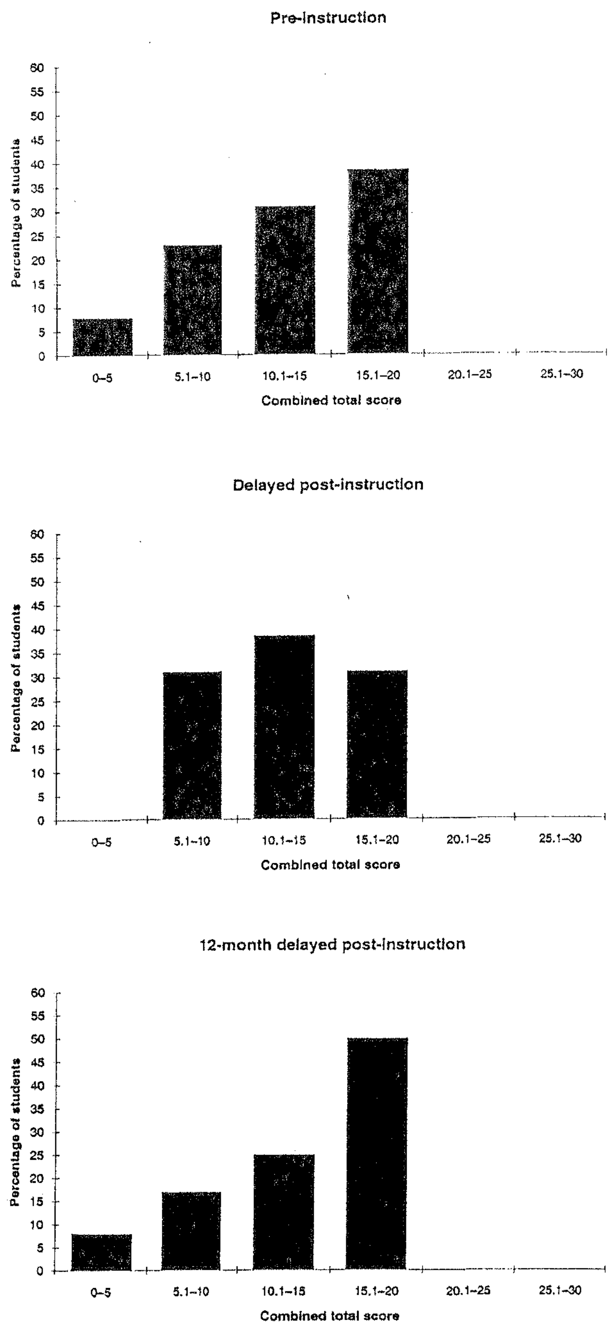


Figure 5.2: Graphs showing the percentage of students in the year 9/97 non-instruction group in each range of combined total score for question one and question three at each phase of the investigation

By aligning the four graphs for the Instruction Group one above the other, changes in the observed outcomes prior to and following the implementation of the Teaching Unit could be seen easily. The combined total score for Questions One and Three was related to the cognitive level at which the student was functioning over the course of the investigation. Individual scores for the separate questions provided the researcher with information as to the level of cognitive functioning for that context only. Total scores served to demonstrate consistency of understanding across contexts. Therefore, the higher the combined total score for Questions One and Three, the better or more scientific the overall understanding of the student was with respect to 'sound and hearing'. The student demonstrated the ability to apply her scientific understanding to situations involving a number of diffferent media for the transmission of sound. The prime concern here was to determine whether the combined total scores had increased immediately following the Teaching Unit and whether that level had been maintained over the following twelve months, and to discriminate more effectively between the performances of students in the Instruction and Non-Instruction Groups over the course of the investigation.

In the graphs for the Instruction Group, shown in Figure 5.1, it can be seen that a marked increase in the percentage of students with high combined total scores has occurred immediately following the implementation of the Teaching Unit (the immediate post-instruction phase). This gives a good indication of the success of the Teaching Unit in improving the understanding of the students. The decline in understanding, as evidenced by the slight decrease in the percentage of students with high score, at the delayed post-instruction phase (five months later), and the further slight regression observed at the 12-month delayed post-instruction phase, can be seen also. Although it can be seen that the figures do not revert to the pre-instruction levels, the fact that some students do not retain fully their scientific understanding over the twelve months following the instruction phase, is a cause for concern.

Comparing the results for the Non-Instruction Group, shown in Figure 5.2, with those for the Instruction Group, it can be seen that almost no change has taken place in the Non-Instruction Group over the course of the investigation. The graphs for the Non-Instruction Group at the pre-instruction and the 12-month delayed post-instruction phases were almost identical, and, although the distribution of students over the range of scores was slightly different in the delayed post-instruction phase from the other phases, the highest combined total scores observed were still lower than those observed with the Instruction Group.

Overall it can be concluded that the Teaching Unit was successful in improving the understanding of the Year 9/97 students in the Instruction Group. Using the Non-Instruction Group as a Comparison Group, it can be seen that the levels of cognitive functioning and, therefore, the levels of understanding of the students with respect to 'sound and hearing', improved following participation in the Teaching Unit, and remained higher than prior to instruction despite the observed slight backward trend over the ensuing twelve months. The observed decline in understanding, especially with respect to the interactive role of the medium, gave some cause for concern. In an effort to address this, the Teaching Unit was modified to include greater emphasis on the role of the medium prior to repeating the practical component of the investigation with the Year 9/98 Group. These modifications are discussed more fully in Section 4.11.2. The data obtained with the Year 9/98 Group are discussed in Sections 5.6 and 5.7.

5.6 Analysis of the year 9/98 responses to question one

Although the Year 9/98 Group was smaller than the Year 9/97 Group, data were collected and analysed in the same manner as for the 1997 investigation. The questionnaire was given to **all** students in the pre-instruction and delayed post-instruction phases, and to the Instruction Group only in the immediate post-instruction and 12-month delayed post-instruction phases. At the 12-month phase, two students in the Instruction Group were no longer attending the school. The data obtained from the responses of the Year 9/98 students to each of the three questions of the questionnaire, at each phase of the investigation, are presented in the following sections.

The responses to Question One were analysed in the same manner as for the Year 9/97 Group and each response was assigned a score for the number of Key Elements present. The SOLO level at which each student was functioning was thus determined. As discussed in Section 5.2, there are two ways of considering the data obtained from the responses to the questionnaire over the course of the investigation, namely in terms of the change in SOLO level and in terms of the change in score for the number of Key Elements present in the responses. Both the change in SOLO level from one phase to the next and the change in score for Key Elements are discussed in Section 5.6.1. In Section 5.6.2, a comparison is made of the SOLO levels of the Instruction and Non-Instruction Groups as a whole.

5.6.1 Comparison of the SOLO levels and of the changes in scores for key elements of individual students in the year 9/98 instruction group determined from question one

The complete responses of the Year 9/98 Instruction Group to Question One with the Key Elements highlighted and the corresponding SOLO level assigned, at each phase of the investigation, are given in Table 5.20. The score for each individual element has been included in brackets within the student's response.

Table 5.20: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question one at each phase of the investigation

Stud No.	Pre-Instruction Response	Immediate Post-Instruction Response	Delayed Post-Instruction Response	12-month Delayed Post-Instruction Response
1 (I)	The birds chirping is carried by sound waves, like tiny **vibrations** [1], **through the air** [1] [0.5] to the ear and picked up by the ear drum. The **ear drum vibrates** [1] and sound is heard. **3.5** **CS R_a**	The **air molecules vibrate** [1] from the **sound** [1] of the birds singing, the air molecules bunch up and relax alternately so that the sound is passed **through the air** [1] by sound waves. They reach the **ear** [0.5] and enter. **3.5** **CS R_a**	When the bird sings its voice hits the **air** [1] and **travels** [1] towards the boys ear in waves, the tiny **air particles vibrate** [1] and when they reach the boys **ear** [0.5] they enter it. The waves get weaker the further away they are from the thing making the sound waves. **3.5** **CS R_a**	The air in the birds throat **moves the cords** [sic] **in its voice box** [1], then the bird opens its mouth and the **air vibrations** [1] are **carried through the air** [1] to the child on sound waves. The sound waves then reach the childs **ear** [0.5] and enter. **3.5** **CS R_a**

2(I)	When the bird sings it sets off **vibrations** [1] **in the air** [1]. The **vibrations travel** along **through the air** [1] reaching your **ear** [1]. The things in your ear decode the vibrations into sound and you can hear the bird singing. **4** **CS R_b**	When the bird sings it makes the **air particles** [1] **vibrate** [1]. That vibration gets **passed along** [1] the air particles until it reaches the childs **ears** [0.5]. **3.5** **CS R_a**	When the bird sings the **air** [1] around it **vibrates** [1]. It **passes these vibrations on** [1] like a set of dominoes but the air never actually changes place.The air keeps on vibrating towards the childs ear and the bits in the **ear vibrate** [1] and send messages to the brain and the child can understand what the noise was. **4** **CS R_b**	The bird sings. Its **vocal chords vibrate** [1] and set the **air** around them **vibrating** [1] as well. The vibration (sound waves) **travel** from the bird's beak **through the air** [1] all around in all different directions. Your ear picks up the vibrations and the vibrations make your **ear drum vibrate**. [1] **4** **CS R_b**
3(I)	When the bird sings it **sends sound waves** or **vibrations** [1] **across** [0.5]. It then hits our **ear drum** [0.5], enabling us to hear the bird singing. **2** **CS U**	When the bird sends a **noise** [0.5] the noise **travels through the air** [1] [0.5] - or **sound waves**- it then hits the **ear drum** and that **vibrates** [1] letting us hear. **3** **CS M**	The bird sends **vibrations** [1] **through the air** [1] [0.5] - these vibrations travel at a great speed and then it hits your **ear drum** [0.5] and you can hear. **3** **CS M**	The bird will let out a sound that will **vibrate** [1] – by hitting **the air** and the **vibrations** [1] will pass **through the air** [1] and hit the **ear drum** [0.5]. **3.5** **CS R_a**

5(I)	When the bird sings, the **noise** [0.5] **travels through the air** [1] [0.5] and if there is a child nearby, the bird can be heard by the child. The child can determine where the noise of the singing bird is coming from because one **ear** [0.5] will be closer to the direction of the bird and will pick up the noise more. Then the brain uses the sense of direction to indicate that the singing bird is in the particular tree. **2.5** **CS M**	When the bird sings, the **noise** [0.5] **travels through the air** [1] [0.5] (vibration method) and reaches the child's ear. The child knows what direction the bird is because of where the sound and vibrations are coming from. The **vibration** hits the childs **ear drum** [1] so that he senses the noise and hears it. **3** **CS M**	The **sound** [0.5] of the bird singing **travels** [0.5] out of the tree and the boy can determine where the bird is because the sound will be closer to one **ear** [0.5] or another and so it will give him some sense of direction. **1.5** **IK R**	–

6(I)	A child can hear a bird singing in a tree because the bird makes a **sound** [0.5] and it **travels in sound waves** [0.5] into the child's **ear** [0.5] to its brain where it registers. **1.5** **IK R**	Because the bird makes a **sound** from its voice box and the **vibrations** [1], that are high, hit other **air particles** [1] that hit more and so **move in a wavelike movement outward** [1] till it reaches your ear which receives the sound and then it travels through the ear, the little hairs in your ear register, it hits your **ear drum** and the **vibrations** [1] are sent to your brain where it tells the child that what it is hearing is a bird singing in the tree. **4** **CS R_b**	The birds voice box lets off **vibrations** [1] of sound. These vibrations hit the **air particles** [1] and continually set off the **surrounding air** [1] in a domino effect. When the **vibrations** reach the childs **ear** [1] they resonate in the ear drum and registering [sic] in the brain as a birds song. **4** **CS R_b**	The bird in the tree makes a noise by its **voice box vibrating** [1] and then these **vibrations hit air particles** [1] in the air and they go on hitting another and another in a domino or wave like fashion until the **air particles vibrating reaches** [1] the child. The childs ears then pick up the **vibrations** from the air particles onto the childs **ear drum** [1]. **4** **CS R_b**

7(I)	The bird's voice is actually **waves** [0.5] **travelling through the air** [1] [0.5] to the kid's **ears** [0.5]. Ears are like radars and they pick up the frequencies in the air (sound waves). **2.5** **CS M**	The bird makes a **sound** [0.5] and makes the **air particles push each other** [1] and it makes different patterns depending on the frequency of the sound. The waves **travel** [0.5] to the kid's ears and make the **ear drum vibrate** [1] - so he can hear the sound. **3** **CS M**	The child can hear the bird because **sound waves** [0.5] **are travelling through the air** [1] **to the child's ears** [0.5]. The wave length of the sound determine the frequency of the sound. The waves of sound travel by **pushing air molecules** [1] to form a domino effect. **3** **CS M**	–

13(I)	The birds voice carries in **sound waves** (**vibration**) [1] (**moving air**) [0.5] these **reach** [0.5] the child's **ears** [0.5] entre [sic] them and the ear drums pick up the different frequencies of sound. The faster the vibration the higher the sound.	The birds **voice box vibrates** [1] sending waves of **vibrating air** [1] out of its mouth. These waves **travel through the air** [1] and reach the childs ears the vibrating goes in the childs ear **vibrating the ear drum** [1] the brain changes those vibrations into electronic waves and registers as a bird singing.	The birds **voice box makes vibrations** [1] and sends them out into the **air** [0.5], sound waves. These **travel** [1] until they reach the child, the childs ears collect these sound waves, they go into the childs ear and **vibrate his ear drum** [1] which sends messages to the brain where they are translated into sound.	The air travelling through the birds **voice box vibrates** [1] it producing sound. This then **travels through the air** [1] [0.5] in sound waves. The waves reach the boys ears and **vibrate** his **ear drum** [1].
	2.5 **CS M**	**4** **CS R_b**	**3.5** **CS R_a**	**3.5** **CS R_a**

15(I)	**Vibrations** [1] from the birds' singing **travel through the air** [1] [0.5] on sound waves. These sound waves travel to the child's **ear** [0.5] and with the help of his brain, it is worked out what he can hear and where it is coming from. **3** **CS M**	The warbling of the bird's song **vibrates the air** [1] and creates sound waves. The **vibrating air** [1] **travels** [1] **to the childs ear** [0.5] and his/her ear drum accepts the sound and the brain registers and tells him what he can hear. **3.5** **CS R_a**	As the bird sings, it **vibrates the air** [1] around it and the **sound travels** [1] on wavelengths **through the vibrating air** [1] to the childs **ear** [0.5]. **3.5** **CS R_a**	When the bird sings, the **sound** is carried by **vibrations** [1] on sound waves **towards** [0.5] the boy's ear. Inside the **ear**, the **vibrations** [1] resonate and the sound is processed by the brain. **2.5** **CS M**

In Table 5.20 it is possible to see the cognitive levels of individual students at each of the four phases and, thus, to determine whether the students have improved, remained the same, or regressed during the course of the investigation. For ease of comparison, a summary of each individual student's cognitive level, as determined from her responses to the questionnaire, at each phase of the investigation, is shown in Table 5.21.

From Table 5.21 it can be seen that, between the pre-instruction and the immediate post-instruction phases, four students (50%) improved their SOLO level and three (37.5%) were unchanged. The level of one student decreased from CS R_b to CS R_a. All students were operating in the Concrete Symbolic mode immediately following the completion of the Teaching Unit but only two students (25%) held all four elements of the Development Map for Hearing. This figure is less than that obtained with the Year 9/97 Group in which 64% of students held all elements immediately following tuition. The majority of students in the Year 9/98 Group held either 3 or 3.5 elements at this stage of the investigation and thus were operating at the CS M and CS R_a levels, respectively.

Table 5.21: Comparison of the SOLO levels of individual students in the year 9/98 instruction group at each phase of the investigation

	SOLO Level at each Phase of the Investigation			
Student Number	Pre-Instruction	Immediate Post-Instruction	Delayed Post-Instruction	12-month Delayed Post-instruction
1(I)	CS R_a	CS R_a	CS R_a	CS R_a
2(I)	CS R_b	CS R_a	CS R_b	CS R_b
3(I)	CS U	CS M	CS M	CS R_a
5(I)	CS M	CS M	IK R	–
6(I)	IK R	CS R_b	CS R_b	CS R_b
7(I)	CS M	CS M	CS M	–
13(I)	CS M	CS R_b	CS R_a	CS R_a
15(I)	CS M	CS R_a	CS R_a	CS M

Five months later (the delayed post-instruction phase), little change was observed in the cognitive levels at which the students were operating. Two students only had decreased the level of their responses, one from CS M to IK R, and one from CS R_b to CS R_a, although another student had moved up from CS R_a to CS R_b. The slight regression in cognitive level from CS R_b to CS R_a, which had been observed with a number of students in the Year 9/97 Group, was not observed with the Year 9/98 Group. With the Year 9/97 Group the percentage of students holding all elements of the Development Map for Hearing had decreased from 64% to 43% between the immediate post-instruction and the delayed post-instruction phases. With the Year 9/98 Group these figures were unchanged.

Between the delayed post-instruction and the 12-month delayed post-instruction phases, the majority of students showed no change in their SOLO levels. One student only decreased from CS R_a to CS M and one increased from CS M to CS R_a.

As mentioned previously there are two ways in which the data can be used to monitor students' performances over the course of the investigation. The changes in scores for Key Elements, from pre-instruction to immediate post-instruction (P/IP), from immediate post-instruction to delayed post-instruction (IP/DP), and from immediate post-instruction to 12-

month delayed post-instruction (IP/12DP), are presented, therefore, in Table 5.22. The average change observed for each of these phase transitions is shown in the table also.

Table 5.22: Changes in individual scores and the average change in score for students in the year 9/98 instruction group for question one, pre- to immediate post- (P/IP), immediate to delayed post- (IP/DP), and immediate to 12-month delayed post-instruction (IP/12DP)

	Phases of the Investigation		
Student Number	**P/IP**	**IP/DP**	**IP/12DP**
1(I)	0	0	0
2(I)	-0.5	+0.5	+0.5
3(I)	+1	0	+0.5
5(I)	+0.5	-1.5	–
6(I)	+2.5	0	0
7(I)	+0.5	0	–
13(I)	+1.5	-0.5	-0.5
15(I)	+0.5	0	-1
Average Change	**+0.75**	**-0.19**	**-0.08**

[+ (plus) sign preceding number indicates score increased; –(minus) sign preceding number indicates score decreased; 0 (zero) indicates no change in score]

In Table 5.22 it can be seen that, immediately following the completion of the Teaching Unit, the average change in score was +0.75. This is less than the average change of +1.21 observed with the Year 9/97 Group, but is still an indication of an improvement in student understanding as demonstrated by the increased number of elements of the Development Map for Hearing present in the students' responses.

Over the five-month period between the immediate post-instruction and the delayed post-instruction phases a decrease in the average score was observed. Although this decrease appeared slightly greater than that obtained with the Year 9/97 Group, this was influenced by the small sample size and by the decrease of 1.5 observed with Student 5(I). The majority of students (63%) showed no change in score. With the Year 9/97 Group, 50% of students showed no change in score for this phase transition. At the 12-month delayed post-instruction phase, no further average decrease had taken place with the Year 9/98 Group, in comparison to the Year 9/97 Group with whom a further backward slide was observed.

As was concluded from the outcomes observed with the Year 9/97 Group, the Teaching Unit appeared to have been successful in giving the Year 9/98 students a better or more scientific understanding of 'sound and hearing'. The average starting score, that is pre-instruction, of the Year 9/97 and Year 9/98 Groups was approximately the same, although the improvement in SOLO levels following tuition was less marked with the Year 9/98 Group than with the Year 9/97 Group. Fewer students in the Year 9/98 Group were found to be operating at the CS R_b level following tuition, but their cognitive levels and, therefore, their understanding, appeared to remain slightly more stable over the twelve months subsequent to the completion of the Teaching Unit. Although the sample size was small, the improved retention of a scientific understanding could possibly be attributed to the increased emphasis on the interactive role of the medium, the inclusion of more 'hands-on' activities in the 1998 Teaching Unit, and the inclusion of analogies.

5.6.2 Comparison of the SOLO levels of the year 9/98 instruction and non-instruction groups determined from question one

In the previous section the responses, the corresponding SOLO levels, and the scores for the Key Elements present in the responses of each student in the Instruction Group, at each phase of the investigation, were examined, as had been done for the Year 9/97 Group, in order to see whether the Teaching Unit had been successful. In this section a comparison is made of the percentages of students operating at each SOLO level in the Instruction and Non-Instruction Groups, at each phase of the investigation. This is shown in Table 5.23. As the researcher was no longer teaching at the school involved in the study, the questionnaire was administered to the Instruction Group only in the 12-month delayed post-instruction phase. Although the questionnaire was not administered to the Non-Instruction Group in the immediate post-instruction and 12-month delayed post-instruction phases, the data obtained with the Instruction Group at these phases have still been included here. This enabled any trends observed with the Instruction Group over the months following the teaching to be compared with the Non-Instruction Group, in order to see whether the Instruction Group returned to their pre-instruction levels or to levels similar to those observed with the Non-Instruction Group.

Table 5.23: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level in question one at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=13)	Delayed Post (n=13)
IK U	0	0	0	0	0	0
IK M	0	0	0	0	1 (8)	0
IK R	2 (25)	0	1 (12.5)	0	2 (15)	5 (39)
CS U	0	0	0	0	0	0
CS M	4 (50)	3 (37.5)	2 (25)	1 (17)	8 (61.5)	6 (46)
CS R_a	1 (12.5)	3 (37.5)	3 (37.5)	3 (50)	1 (8)	2 (15)
CS R_b	1 (12.5)	2 (25)	2 (25)	2 (33)	1 (8)	0

In Table 5.23 it can be seen that the results obtained for the Non-Instruction Group were virtually the same as those obtained with the Instruction Group in the pre-instruction phase. Following instruction, all students in the Instruction Group were observed functioning in the Concrete Symbolic mode, and five months later, there had been little change in the SOLO levels. In comparison, the students in the Non-Instruction Group had not changed the cognitive levels at which they were functioning from that observed in the pre-instruction phase. This confirmed the data obtained for the Year 9/97 Non-Instruction Group. The levels observed with the Instruction Group did not change further over the ensuing seven months.

5.7 Analysis of the year 9/98 responses to question two

The responses to Question Two of the questionnaire were analysed in the same way as for the Year 9/97 Group. The number (percentage) of students in both the Instruction and Non-Instruction Groups selecting a particular option at each phase of the investigation is shown in Table 5.24. In the table if a student selected more than one option then the percentage will total more than 100%, but if a student did not respond then she has not been included in the total number (n) of students. The complete responses of the students, at each phase of the investigation, are contained in Appendix 18. Although the questionnaire was administered to the Non-Instruction Group at only two phases, both these data and the data obtained at each phase of the investigation with the Instruction Group have been included, This allows changes observed with the Instruction Group over the course of the investigation to show more clearly, at the same time as comparisons are made with the Non-Instruction Group.

Table 5.24: Number (percentage) of year 9/98 students in the instruction and non-instruction groups selecting a particular option in question two at each phase of the investigation

	Instruction Group				Non-Instruction Group	
Option Selected	**Pre Instruct.** (n=8)	**Immed. Post** (n=8)	**Delayed Post** (n=8)	**12-month Delayed** (n=6)	**Pre Instruct.** (n=12)	**Delayed Post** (n=12)
1	0	0	0	0	1 (8)	2 (17)
2	0	0	0	0	0	0
3	1 (12.5)	0	0	0	2 (17)	2 (17)
4	6 (75)	7 (87.5)	8 (100)	6 (100)	6 (50)	7 (58)
5	2 (25)	1 (12.5)	0	0	0	0
6	0	0	0	0	3 (25)	1 (8)

The results given in Table 5.24 showed similar trends to those observed with the Year 9/97 Instruction and Non-Instruction Groups. The SOLO levels observed with the Non-Instruction Group did not change in the intervening period between the pre-instruction and the delayed post-instruction phases. Almost no change was observed in the SOLO levels of the students in the Instruction Group either, over the period of the investigation. Despite the small number of students involved, this appeared to support the observation that Question Two did not differentiate well between the levels of cognitive functioning of individual students. As discussed in Section 4.7, students performed better on the 'multiple choice' Question Two than on the 'free response' Questions One and Three.

No students in either the Instruction or the Non-Instruction Group selected Option 2 ('active listening') at any stage in the investigation, which confirmed the observations made with the Year 9/97 Group.

5.8 Analysis of the year 9/98 responses to question three

The responses to Question Three, which dealt with the transmission of sound in different media, were analysed in the same manner as for the Year 9/97 investigation. The complete responses are contained in Appendix 18. From the outcomes observed with the Year 9/97 Group it appeared that the role of the medium was the major 'stumbling block' to student understanding. As a result, modifications were made to the 1998 Teaching Unit to place a greater emphasis on the importance of the medium, with the inclusion of analogies and more 'hands-on' activities, such as investigating the transmission of sound in different media as a laboratory exercise. The change in SOLO level observed for each student in the Instruction Group and the change in score for the number of Key Elements, over the course of the investigation, are discussed in Section 5.8.1. In Section 5.8.2, a comparison is made of the SOLO levels of the Instruction and Non-Instruction Groups as a whole.

5.8.1 Comparison of the SOLO levels and the changes in scores for key elements of individual students in the year 9/98 instruction group determined from question three

The number of Key Elements of the Development Map for Hearing and the corresponding SOLO level in the responses of individual students were identified and are shown separately for each picture in Tables 5.25 to 5.30, respectively.

Picture (i): As had been stated with the Year 9/97 data, Picture(i) (Table 5.25) represented a situation with which many of the students may have been familiar and, as observed previously, the majority of the students were operating in the Concrete Symbolic mode and demonstrated a good understanding in the pre-instruction phase. The figure of 75%

observed with the Year 9/98 Group was slightly higher than the 64% obtained in 1997, although the numbers in 1998 were considerably smaller. The remaining students were operating in the Ikonic mode.

Upon completion of the Teaching Unit, all students were operating in the Concrete Symbolic mode, but on this occasion only 25% held all elements of the Development Map compared with 50% in 1997. The remaining students held 3 or 3.5 elements. At the delayed and the 12-month delayed post-instruction phases, virtually no change was observed in the levels at which the students were functioning, although, in 1997, a slight regression had been observed at both these phases.

Table 5.25: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (i) at each phase of the investigation

	Phase of the Investigation			
Student Number	**Pre Instruction**	**Immediate Post**	**Delayed Post**	**12-month Delayed**
1(I)	1 IK M	2.5 CS M	3 CS M	3 CS M
2(I)	3 CS M	3.5 CS R_a	4 CS R_b	3 CS M
3(I)	1.5 IK R	3 CS M	2.5 CS M	2 CS U
5(I)	3.5 CS R_a	3.5 CS R_a	1.5 IK R	–
6(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	4 CS R_b
7(I)	2.5 CS M	2.5 CS M	2.5 CS M	–
13(I)	3 CS M	3.5 CS R_a	3.5 CS R_a	4 CS R_b
15(I)	3.5 CS R_a	4 CS R_b	3.5 CS R_a	4 CS R_b

Picture (ii): The results for Picture (ii), the hammer striking the girder, shown in Table 5.26, were similar to those obtained with the previous year group. An improvement in scientific understanding was observed immediately following the completion of the Teaching Unit but, unlike the 1997 group, no regression was observed at either the delayed or the 12-month delayed post-instruction phases. Twenty-five percent of students held all elements of the Development Map in the immediate post-instruction phase and 50% held 3 elements, compared with the figures of 31% and 39%, respectively, observed for the Year 9/97 Group.

Table 5.26: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (ii) at each phase of the investigation

	Phase of the Investigation			
Student Number	**Pre Instruction**	**Immediate Post**	**Delayed Post**	**12-month Delayed**
1(I)	1.5 IK R	2.5 CS M	1.5 IK R	1 IK M
2(I)	3 CS M	4 CS R_b	4 CS R_b	4 CS R_b
3(I)	1.5 IK R	2 CS U	2 CS U	3.5 CS R_a
5(I)	1 IK M	1 IK M	2.5 CS M	–
6(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	3 CS M
7(I)	3 CS M	3 CS M	3 CS M	–
13(I)	no response	3 CS M	3 CS M	2 CS U
15(I)	1 IK M	3 CS M	3 CS M	2.5 CS M

Picture (iii): With the results for Picture (iii), the string telephone, shown in Table 5.27, similar trends were observed as in 1997. Prior to instruction, all students were operating in the Concrete Symbolic mode, and held 3 or 3.5 elements of the Development Map. This again was higher than was observed with the other five pictures and, as stated previously, was possibly due to the fact that the string telephone is a popular children's activity. In contrast to the Year 9/97 Group, no students were functioning in the Ikonic mode prior to instruction.

Immediately following instruction, although no students held all elements of the Development Map, the majority (62.5%) held 3.5 elements. This was slightly different to the Year 9/97 outcome when the same total percentage were operating at the Relational level in the Concrete Symbolic mode but 21% of these held all four elements. As had been observed with the 1997 group, little change was observed in the levels of cognitive functioning over the ensuing twelve-month period.

Table 5.27: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (iii) at each phase of the investigation

	Phase of the Investigation			
Student Number	**Pre Instruction**	**Immediate Post**	**Delayed Post**	**12-month Delayed**
1(I)	3 CS M	3.5 CS R_a	3 CS M	4 CS R_b
2(I)	3 CS M	3 CS M	3 CS M	3 CS M
3(I)	3 CS M	3 CS M	3.5 CS R_a	3.5 CS R_a
5(I)	3.5 CS R_a	3.5 CS R_a	3 CS M	–
6(I)	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a	4 CS R_b
7(I)	3 CS M	3 CS M	3 CS M	–
13(I)	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a	3.5 CS R_a
15(I)	3 CS M	3.5 CS R_a	3.5 CS R_a	3 CS M

Picture (iv): Similar trends were observed with Picture (iv), the friends talking on either side of a high wall. These results are given in Table 5.28. It had been observed with the previous year group that this situation appeared conceptually more difficult for the students and that they appeared to have difficulty relating the results of their in-class discussions to this context. This was confirmed by the data obtained with the Year 9/98 Group, despite the fact that this group had investigated the transmission of sound in different media as a laboratory exercise.

Table 5.28: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (iv) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed
1(I)	1 IK M	1.5 IK R	1.5 IK R	1 IK M
2(I)	2 CS U	2.5 CS M	1.5 IK R	1 IK M
3(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
5(I)	1 IK M	2.5 CS M	2.5 CS M	–
6(I)	2 CS U	2.5 CS M	2.5 CS M	2 CS U
7(I)	3 CS M	3 CS M	1.5 IK R	–
13(I)	3.5 CS R_a	3 CS M	3 CS M	1.5 IK R
15(I)	1 IK M	1.5 IK R	1.5 IK R	2.5 CS M

Prior to instruction, 50% of the students were operating in the Ikonic mode. Immediately following the Teaching Unit, 37.5% were still operating in this mode. No student held 3.5 or 4 elements of the Development Map; the majority (62.5%) held 3 elements only. Five months later, the percentage of students operating in the Ikonic mode had increased again to 62.5%; the remaining students held 3 elements only. This same backward slide had been observed with the Year 9/97 Group, but was not quite as marked as with the Year 9/98

Group. At the 12-month delayed post-instruction phase a further slight regression was observed.

Picture (v): The results obtained with Picture (v), transmission in a vacuum, shown in Table 5.29, were also similar to those obtained in 1997. Prior to instruction, the majority of students (62.5%) were operating in the Concrete Symbolic mode and held 3 or 3.5 elements of the Development Map for Hearing. Twenty-five percent were operating in the Ikonic mode. The latter figure was slightly higher for the Year 9/97 Group. Following instruction, all students held between 3 and 4 elements with 37.5% operating at the highest level in the Development Map. Five months and twelve months later almost no change had taken place. The outcomes following instruction were slightly better than those observed with the previous year group as no students were functioning in the Ikonic mode at the immediate and delayed post-instruction phases, whereas, in 1997, 21% were found to be operating in this mode on both occasions.

Table 5.29: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (v) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed
1(I)	3 CS M	3 CS M	4 CS R_b	2.5 CS M
2(I)	3 CS M	3 CS M	3 CS M	3 CS M
3(I)	2.5 CS M	3 CS M	3.5 CS R_a	4 CS R_b
5(I)	1.5 IK R	4 CS R_b	3 CS M	–
6(I)	1 IK M	4 CS R_b	4 CS R_b	4 CS R_b
7(I)	2 CS U	3.5 CS R_a	3 CS M	–
13(I)	3.5 CS R_a	4 CS R_b	4 CS R_b	3 CS M
15(I)	3.5 CS R_a	3 CS M	3.5 CS R_a	3.5 CS R_a

Picture (vi): The results for the final picture, Picture (vi), are shown in Table 5.30. The trends in the data were again similar to those observed with the Year 9/97 Group. Prior to instruction, the students were evenly distributed between the Ikonic and Concrete Symbolic modes with the majority holding 1.5 or 2 elements of the Development Map. Immediately following instruction, the majority still held only 1.5 elements and were operating in the Ikonic mode; no students were operating at the Relational level in the Concrete Symbolic mode. Five and twelve months later there had been little change. The results obtained with the Year 9/97 Group appeared slightly better immediately following tuition as 21% of students held 3.5 or 4 elements of the Development Map, but a backward slide was observed, with some students returning to their pre-instruction levels. The data obtained with the Year 9/98 Group supported the observation that this picture showed the least improvement in understanding following tuition.

Table 5.30: Number of key elements and SOLO level in the responses of students in the year 9/98 instruction group to question three picture (vi) at each phase of the investigation

	Phase of the Investigation			
Student Number	Pre Instruction	Immediate Post	Delayed Post	12-month Delayed
1(I)	2 CS U	1.5 IK R	1.5 IK R	1.5 IK R
2(I)	1.5 IK R	1.5 IK R	1.5 IK R	1.5 IK R
3(I)	0	1 IK M	3.5 CS R_a	3 CS M
5(I)	1.5 IK R	1.5 IK R	1.5 IK R	–
6(I)	2 CS U	1.5 IK R	2.5 CS M	4 CS R_b
7(I)	1.5 IK R	1.5 IK R	1.5 IK R	–
13(I)	3 CS M	3 CS M	3 CS M	1.5 IK R
15(I)	3.5 CS R_a	3 CS M	4 CSR_b	3 CS M

As discussed in Section 5.4 for the 1997 investigation, it was important to determine whether a student's understanding had changed following instruction, and whether any further change had taken place over the months following. Table 5.31 shows the change in the scores for the number of Key Elements of individual students in the Year 9/98 Instruction Group for Question Three, from pre-instruction to immediate post-instruction (P/IP), from immediate post-instruction to delayed post-instruction (IP/DP), and from immediate post-instruction to 12-month delayed post-instruction (IP/12DP). The average change in the score observed with these phase transitions is shown in the table also.

Table 5.31: Changes in individual scores and the average change in score for students in the year 9/98 instruction group for question three pre- to immediate post- (P/IP), immediate to delayed post- (IP/DP), and immediate to 12-month delayed post-instruction (IP/12DP)

	Picture in Question Three																	
	(i)			(ii)			(iii)			(iv)			(v)			(vi)		
Student No.	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP	P/IP	IP/DP	IP/ 12DP
1I)	+1.5	+0.5	+0.5	+1	-1	-1.5	+0.5	-0.5	+0.5	+0.5	0	-0.5	0	+1	-0.5	-0.5	0	0
2(I)	+0.5	+0.5	-0.5	+1	0	0	0	0	0	+0.5	-1	-1.5	0	0	0	0	0	0
3(I)	+1.5	-0.5	-1	+0.5	0	+1.5	0	+0.5	+0.5	0	0	0	+0.5	+0.5	+1	+1	+2.5	+2
5(I)	0	-2	–	0	+1.5	–	0	-0.5	–	+1.5	0	–	+2.5	-1	–	0	0	–
6(I)	+0.5	0	0	+0.5	0	-1	0	0	+0.5	+0.5	0	–0.5	+3	0	0	-0.5	+1	+2.5
7(I)	0	0	–	0	0	–	0	0	–	0	-1.5	–	+1.5	-0.5	–	0	0	–
13(I)	+0.5	0	+0.5	–	0	-1	0	0	0	-0.5	0	-1.5	+0.5	0	-1	0	0	-1.5
15(I)	+0.5	-0.5	0	+2	0	-0.5	+0.5	0	-0.5	+0.5	0	+1	-0.5	+0.5	+0.5	-0.5	+1	0
Average Change	+0.63	-0.25	-0.08	+0.63	+0.06	-0.42	+0.13	-0.06	+0.17	+0.38	-0.31	-0.5	+0.94	+0.06	0	-0.06	+0.56	+0.56

[+ (plus) sign preceding number indicates score increased; – (minus) sign preceding number indicates score decreased; 0 (zero) indicates no change in score; – (dash) indicates student did not respond on one or more occasions]

From Table 5.31, it can be seen that, immediately following the completion of the Teaching Unit, the average scores for the number of Key Elements had increased, with the exception of Picture (vi), where there was almost no change. With the exception of Picture (v), both the improvement following tuition, and the regression five months later, were less marked generally than had been observed with the Year 9/97 Group. This reflects the outcomes observed with the responses to Question One.

Picture (iii) was a little surprising in that the average change in score increased slightly immediately following the Teaching Unit, then remained virtually unchanged for five months, and then increased again over the ensuing seven months. This apparently erratic pattern in average scores, which had not been observed with the previous year group, was attributed to a small number of students influencing the data. As the string telephone is a familiar activity for many children, one would perhaps have expected an increase in average scores following the Teaching Unit, and little decline over the ensuing months as was observed for the Year 9/97 Group.

Picture (iv) was disappointing in that, after an initial increase following the Teaching Unit, five months later the average change in score had returned almost to the pre-instruction level, and a further seven months later, the gain following the teaching had disappeared altogether. This had not been observed with the previous year group. Although, with the Year 9/97 Group, a regression had taken place, the average change in score still remained above the pre-instruction level.

The highest observed increase was with Picture (v) which was in contrast to the 1997 investigation in which the smallest change had been observed with this picture. The increased emphasis on the role of the medium with the Year 9/98 Group may have accounted for this improvement, bearing in mind the fact the numbers in the 1998 Group were very small.

Picture (vi) was rather surprising in that there was almost no change in the average score observed immediately after tuition followed by an increase five months later. Of course it must be remembered that the Year 9/98 Group was very small and, therefore, one or two students exhibiting larger changes than the others will have had a marked effect on the average change. This applies to all the averages presented for this group.

5.8.2 Comparison of the SOLO levels of the year 9/98 instruction and non-instruction groups determined from question three

In the previous section the responses, the SOLO levels, and the corresponding scores for the number of Key Elements present in the responses, of each student in the Instruction Group, over the course of the investigation, were examined, as had been done for the 1997 data. In this section comparison is made of the total percentages of students operating at each SOLO level, at each phase of the investigation, for both the Instruction and Non-Instruction Groups. The data, which are presented separately for each picture, are shown in Tables 5.32 to 5.37, inclusive. Even though the questionnaire was not administered to the Non-Instruction Group at the immediate and 12-month delayed post-instruction phases, the data obtained with the Instruction Group in these phases have been included. This enabled any trends observed with the Instruction Group over the months following the teaching to be compared with the Non-Instruction Group, in order to see whether the Instruction Group returned to pre-instruction or to Non-Instruction Group levels.

Table 5.32: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (i) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	**Pre Instruct.** (n=8)	**Immed. Post** (n=8)	**Delayed Post** (n=8)	**12-month Delayed** (n=6)	**Pre Instruct.** (n=12)	**Delayed Post** (n=12)
Zero K. E.	0	0	0	0	1 (8)	0
IK U	0	0	0	0	2 (17)	2 (17)
IK M	1 (12.5)	0	0	0	0	1 (8)
IK R	1 (12.5)	0	1 (12.5)	0	5 (42)	2 (17)
CS U	0	0	0	1 (17)	0	0
CS M	3 (37.5)	3 (37.5)	3 (37.5)	2 (33)	4 (33)	3 (25)
CS R_a	3 (37.5)	3 (37.5)	2 (25)	0	0	3 (25)
CS R_b	0	2 (25)	2 (25)	3 (50)	0	1 (8)

As discussed in Section 5.4.2, if a student did not respond to any of the pictures she has not been included in the total number (n) of students. The number of students who responded but whose responses contained zero Key Elements (Zero K. E.) is shown in the table also.

With Picture (i), shown in Table 5.32, in the pre-instruction phase, the SOLO levels of the Instruction Group were slightly higher than those observed with the Non-Instruction Group. As previously commented, this may possibly be attributed to the fact that those in the Instruction Group have 'chosen' to study further science whereas, for the Non-Instruction Group, science was 'compulsory'.

It was interesting to observe that, between the pre-instruction and the delayed post-instruction phases, the levels of cognitive functioning of the Non-Instruction Group had improved slightly. In the initial phase the majority were functioning in the Ikonic mode but, six months later, the majority were functioning in the Concrete Symbolic mode, and yet these students had not undergone tuition in 'sound and hearing'.

The results obtained with Picture (ii), shown in Table 5.33, demonstrated a similar pattern to that observed with the 1997 data. The distribution of SOLO levels in the Instruction and Non-Instruction Groups was very similar in the pre-instruction phase. Six months later, the Non-Instruction Group was virtually unchanged compared with the Instruction Group in which nearly all students were observed functioning in the Concrete Symbolic mode.

Table 5.33: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (ii) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=7)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=11)	Delayed Post (n=12)
Zero K. E.	0	0	0	0	0	0
IK U	0	0	0	0	1 (9)	1 (8)
IK M	2 (29)	1 (12.5)	0	1 (17)	3 (27)	3 (25)
IK R	2 (29)	0	1 (12.5)	0	4 (36)	1 (8)
CS U	0	1 (12.5)	1 (12.5)	1 (17)	1 (9)	2 (17)
CS M	2 (29)	4 (50)	4 (50)	2 (33)	2 (18)	4 (33)
CS R_a	1 (14)	0	2 (25)	1 (17)	0	1 (8)
CS R_b	0	2 (25)	0	1 (17)	0	0

In Table 5.34, it can be seen that, in the pre-instruction phase, the observed SOLO levels for Picture (iii) of the Non-Instruction Group were similar to those observed with the Instruction Group. The levels of the Non-Instruction Group were unchanged over the ensuing six months compared with the Instruction Group in which a small improvement was seen following the Teaching Unit. With both the Instruction and Non-Instruction Groups, the observed cognitive levels were higher than with the other pictures. As stated previously, this may possibly be attributed to the fact that this was a children's game with which many of the students may have been familiar.

Table 5.34: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (iii) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=12)	Delayed Post (n=13)
Zero K. E.	0	0	0	0	0	1 (8)
IK U	0	0	0	0	0	0
IK M	0	0	0	0	1 (8)	1 (8)
IK R	0	0	0	0	0	0
CS U	0	0	0	0	1 (8)	0
CS M	5 (62.5)	3 (37.5)	4 (50)	2 (33)	10 (83)	10 (77)
CS R_a	3 (37.5)	5 (62.5)	4 (50)	2 (33)	0	1 (8)
CS R_b	0	0	0	2 (33)	0	0

With Picture (iv), shown in Table 5.35, the SOLO levels of the Instruction and Non-Instruction Groups were similar in the pre-instruction phase, and the Non-Instruction Group remained unchanged over the following months. In comparison, there was a slight improvement in the Instruction Group following the Teaching Unit, but not as much as might have been expected. This was one of the pictures with which students appeared to have the most difficulty and, as can be seen from the table, there was not great deal of difference between the Instruction Group and the Non-Instruction Group over the course of the investigation. As discussed in Section 5.8.1 in relation to Table 5.31, twelve months after the completion of the Teaching Unit the average change in score for students in the Instruction Group had returned to the pre-instruction level, which was very similar for both the Instruction and Non-Instruction Groups.

Table 5.35: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (iv) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=11)	Delayed Post (n=12)
Zero K. E.	0	0	0	0	0	0
IK U	0	0	0	0	1 (9)	0
IK M	3 (37.5)	0	0	2 (33)	0	2 (17)
IK R	1 (12.5)	3 (37.5)	5 (62.5)	2 (33)	7 (64)	8 (67)
CS U	2 (25)	0	0	1 (17)	2 (18)	0
CS M	1 (12.5)	5 (62.5)	3 (37.5)	1 (17)	1 (9)	2 (17)
CS R_a	1 (12.5)	0	0	0	0	0
CS R_b	0	0	0	0	0	0

It can be seen in Table 5.36 that, for Picture (v), the SOLO levels of the Non-Instruction Group again were slightly lower than those of the Instruction Group prior to instruction, and these levels had not changed at the delayed post-instruction phase. By comparison, the observed levels of the Instruction Group improved following the Teaching Unit and remained steady over the following months.

Table 5.36: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (v) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=12)	Delayed Post (n=12)
Zero K. E.	0	0	0	0	0	1 (8)
IK U	0	0	0	0	2 (17)	1 (8)
IK M	1 (12.5)	0	0	0	3 (25)	1 (8)
IK R	1 (12.5)	0	0	0	4 (33)	6 (50)
CS U	1 (12.5)	0	0	0	0	0
CS M	3 (37.5)	4 (50)	3 (37.5)	3 (50)	3 (25)	3 (25)
CS R_a	2 (25)	1 (12.5)	2 (25)	1 (17)	0	0
CS R_b	0	3 (37.5)	3 (37.5)	2 (33)	0	0

The results for the final picture, shown in Table 5.37, indicated that, as had been observed with several of the other pictures, the SOLO levels of the Non-Instruction Group in the pre-instruction phase were slightly lower than those of the Instruction Group and were spread over a wider range, with the majority functioning in the Ikonic mode. This distribution remained unchanged over the following six months. Although the observed levels of the Instruction Group were slightly higher than the Non-Instruction Group, surprisingly, they remained virtually unchanged following the Teaching Unit, and over the ensuing six months. This too was a picture with which the students appeared to experience some difficulty. Table 5.31 showed an apparent increase in average score over the months following the Teaching Unit but, as commented in Section 5.8.1, this change appeared to have been influenced by the results of only a few students.

Table 5.37: Number (percentage) of year 9/98 students in the instruction and non-instruction groups operating at a particular SOLO level for question three picture (vi) at each phase of the investigation

	Instruction Group				Non-Instruction Group	
SOLO Level	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=12)	Delayed Post (n=11)
Zero K. E.	0	0	0	0	1 (8)	2 (18)
IK U	0	0	0	0	1 (8)	0
IK M	0	0	0	0	2 (17)	1 (9)
IK R	3 (37.5)	5 (62.5)	5 (62.5)	3 (50)	6 (50)	5 (45.5)
CS U	2 (25)	0	0	0	1 (8)	1 (9)
CS M	1 (12.5)	3 (37.5)	2 (25)	2 (33)	1 (8)	2 (18)
CS R_a	1 (12.5)	0	0	0	0	0
CS R_b	0	0	1 (12.5)	1 (18)	0	0

From the data shown in Tables 5.32 to 5.37, it can be seen that the cognitive levels observed in the responses of students in the Non-Instruction Group remained virtually unchanged over the course of the investigation. As the Non-Instruction Group was included as the Comparison Group in this investigation, this was as expected. The purpose of including the Non-Instruction Group was to enable the researcher to observe the changes in levels of cognitive functioning of those students who participated in the Teaching Unit, compared with any changes that may have occurred in a parallel group who had not received tuition on 'sound and hearing'. It was the background changes observed with the Non-Instruction Group that were important, and that would add legitimacy to any positive changes or improvement observed with the test group of students. Despite the fact that the allocation of students into the Instruction and Non-Instruction Groups was a matter of choice by the students, and not random, the levels of both groups were not greatly different prior to instruction, and the levels observed in the Non-Instruction Group remained relatively stable over the period of the investigation. This allowed the researcher to observe the effect of the Teaching Unit on the SOLO levels of the Instruction Group.

5.9 Comparison of the overall performances of students in the year 9/98 instruction and non-instruction groups at each phase of the investigation using the combined total scores for question one and question three

As discussed in Section 5.5, the levels of cognitive functioning had been determined from the responses to Question One and from the responses to the six pictures of Question Three, and so the scores from these two questions were combined in order to facilitate the comparison of the overall performance across tasks of the students. Thus it was possible to discriminate more effectively between the performances of students in the Instruction and Non-Instruction Groups, at each phase of the investigation, and to obtain further information as to how successful the Teaching Unit had been. As stated in Section 5.5, the combining of scores across seven items served to eliminate the ceiling effect observed for some individual items where there was insufficient discrimination between students receiving the same score for a particular response. The maximum combined score a student could receive was 28. The number (percentage) of students in the Instruction and Non-Instruction Groups in each designated range of combined total score for Question One and Question Three, at each phase of the investigation, is given in Table 5.38. From the data presented in the table, graphs were drawn. These are shown in Figure 5.3 (Instruction Group) and Figure 5.4 (Non-Instruction Group).

Table 5.38: Number (percentage) of students in the year 9/98 instruction and non-instruction groups in each range of combined total score for question one and question three at each phase of the investigation

	Number (Percentage) of Students in each Group					
	Instruction Group				Non-Instruction Group	
Combined Total Score	Pre Instruct. (n=8)	Immed. Post (n=8)	Delayed Post (n=8)	12-month Delayed (n=6)	Pre Instruct. (n=13)	Delayed Post (n=13)
0–5	0	0	0	0	1 (8)	0
5.1–10	0	0	0	0	3 (23)	4 (31)
10.1–15	3 (37.5)	0	0	0	6 (46)	5 (38.5)
15.1–20	5 (62.5)	4 (50)	4 (50)	3 (50)	3 (23)	4 (31)
20.1–25	0	4 (50)	4 (50)	3 (50)	0	0
25.1–30	0	0	0	0	0	0

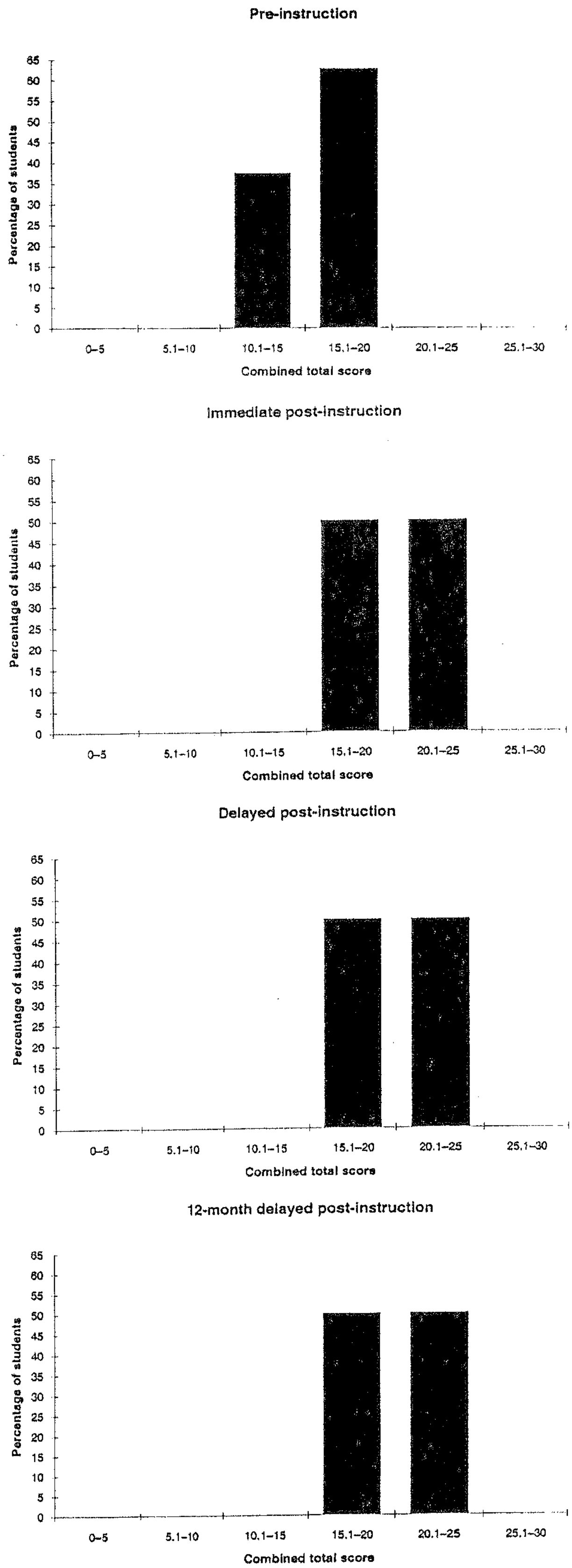
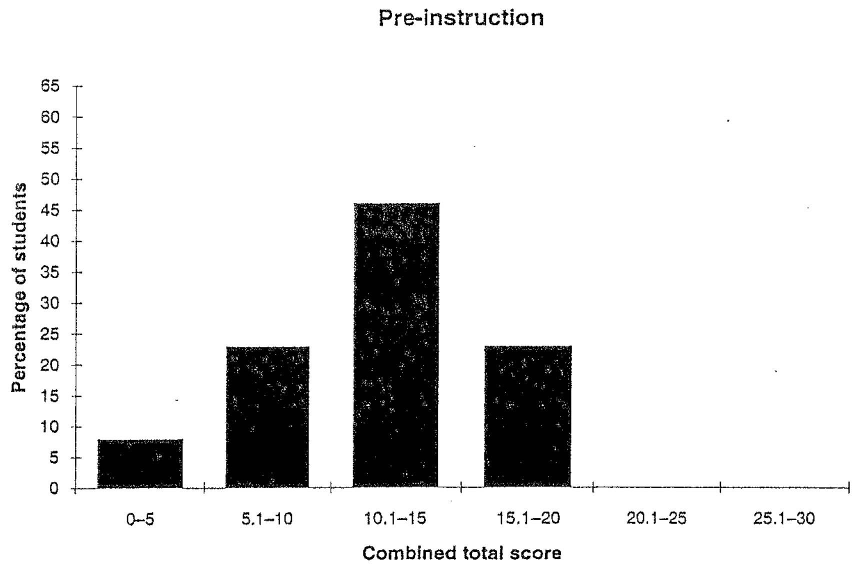


Figure 5.3: Graphs showing the percentage of students in the year 9/98 instruction group in each range of combined total score for question one and question three at each phase of the investigation



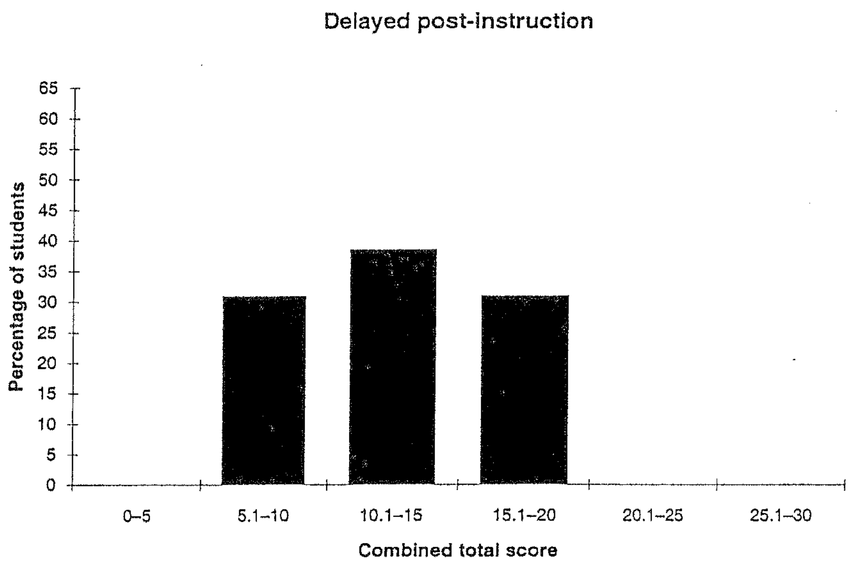


Figure 5.4: Graphs showing the percentage of students in the year 9/98 non-instruction group in each range of combined total score for question one and question three at each phase of the investigation

By aligning the four graphs for the Instruction Group one above the other, it can be seen that an improvement took place in the percentage of students with high combined total scores for Questions One and Three immediately following the Teaching Unit and that, in contrast to the Year 9/97 Group, this level remained stable over the ensuing twelve months and no regression appeared to have occurred. Almost no change can be seen in the graphs for the Non-Instruction Group, shown in Figure 5.4. With the 1998 students, it can be seen that the ranges of combined total score observed for the Instruction Group were noticeably higher than those for the Non-Instruction Group, even at the pre-instruction phase. This difference was more noticeable with the 1998 students than had been with the previous year group. As mentioned previously, this may be due to the fact that those in the Instruction Group have chosen to study science and have a greater interest in the topic than those in the Non-Instruction Group. However, despite this difference between the Instruction and Non-Instruction Groups at the commencement of the investigation, the improvement in the Instruction Group as a result of the Teaching Unit can be seen clearly.

Although combining the scores for responses to Question One and Question Three was more effective in illustrating the changes in overall performances of students in the Instruction Group, and the absence of change in the Non-Instruction Group, the data for the Year 9/98 Instruction Group showed very similar outcomes to those of the Year 9/97 Group. It was decided, therefore, to combine the data for the 1997 and 1998 groups. This is discussed in Section 5.10.

5.10 Comparison of the combined data for the year 9/97 and year 9/98 instruction and non-instruction groups

The combined total scores for Questions One and Three for both Instruction Groups, and the same data for both Non-Instruction Groups, were combined, but at the pre-instruction and delayed post-instruction phases only, as it was in these phases that the groups of both years had completed the questionnaire. The number (percentage) of students in the Instruction and Non-Instruction Groups in each range of combined total score, as designated in Sections 5.5 and 5.9, at these two phases of the investigation, is given in Table 5.39. Graphs were then drawn of these data so that comparisons between the Instruction and Non-Instruction Groups could be made easily. The graphs are shown in Figure 5.5, aligned one above the other to facilitate comparison.

Table 5.39: Number (percentage) of students in the combined year 9/97 and year 9/98 instruction and non-instruction groups in each range of combined total score for question one and question three at the pre-instruction and delayed post-instruction phases

	Number (Percentage) of Students in each Group			
	Instruction Group		Non-Instruction Group	
Combined Total Score	Pre Instruction (n=22)	Delayed Post (n=22)	Pre Instruction (n=26)	Delayed Post (n=26)
0–5	0	0	2 (8)	0
5.1–10	1 (4.5)	1 (4.5)	6 (23)	8 (31)
10.1–15	11 (50)	1 (4.5)	10 (38)	10 (38)
15.1–20	9 (41)	7 (32)	8 (31)	8 (31)
20.1–25	1 (4.5)	12 (54.5)	0	0
25.1–30	0	1 (4.5)	0	0

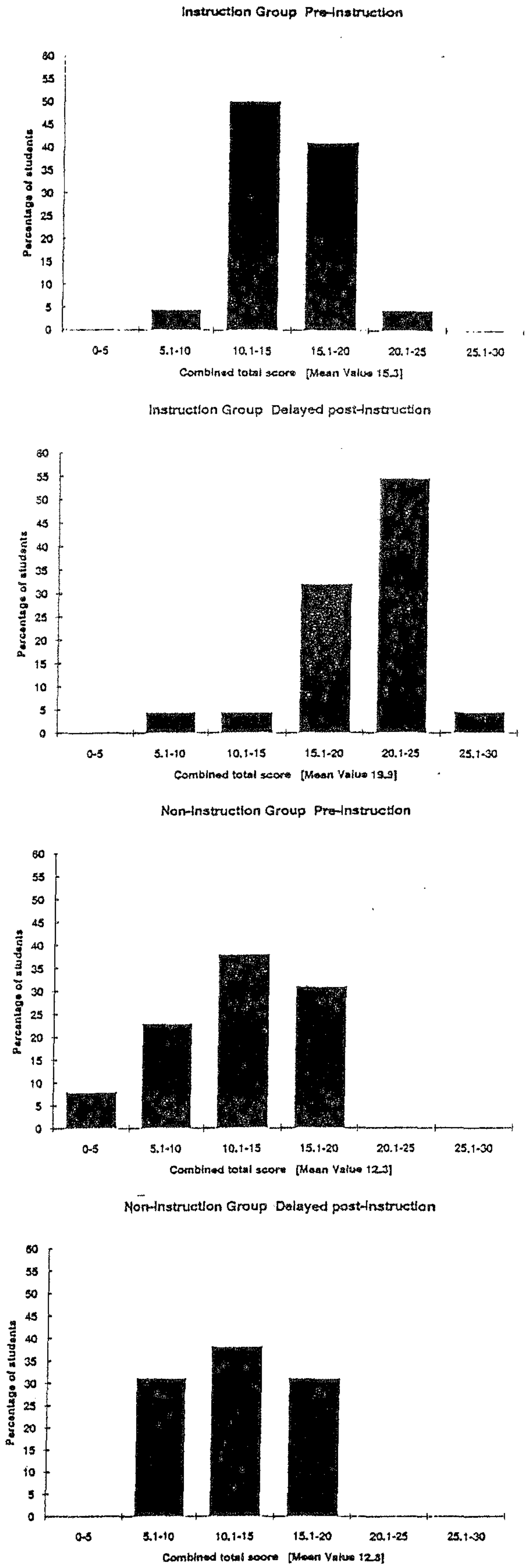


Figure 5.5: Graphs of combined data for year 9/97 and year 9/98 instruction and non-instruction groups showing the percentages of students in each range of combined total score at the pre- and delayed post-instruction phases

From the graphs shown in Figure 5.5, the differences between the Instruction and Non-Instruction Groups, and within the Instruction Group, prior to and five months after participation in the Teaching Unit, can be seen clearly.

In the Non-Instruction Group, the distribution of students in the designated ranges of combined total score was almost unchanged over the period between the pre-instruction and delayed post-instruction phases. At both phases, the mean values for the combined total scores were approximately the same. The only slight change observed was that the small percentage of students whose scores were in the range 0–5, pre-instruction, had shifted to the 5.1–10 range (from Table 5.39, it can be seen that this applied to two students only).

The Instruction Group showed a similar distribution to the Non-Instruction Group at the pre-instruction phase, although, in the Instruction Group, there were fewer students in the 5.1–10 range of combined total score and none in the 0–5 range. This group appeared perhaps to have a slightly bettter understanding than the Non-Instruction Group. This was confirmed by carrying out a two-sample 't' test (Moore & McCabe, 1998, p. 542) on the mean values of the data for the Instruction and Non-Instruction Groups. The 't' value obtained was 2.73 with a probability (p) value less than 0.01. This confirmed that there was a slight difference between the Instruction and Non-Instruction Groups, pre-instruction. This was due most probably to the fact that random assignment of students into the Instruction and Non-Instruction Groups was not possible, and those in the Instruction Group had elected to study additional science. However, despite this difference, five months after participation in the Teaching Unit, a shift had occurred in the Instruction Group towards the higher ranges of combined total score, with the majority of students exhibiting scores in the range 20.1–25. By comparison, almost no change had occurred in the Non-Instruction Group.

These graphs have thus pointed to the apparent effectiveness of the Teaching Unit. The final step was to determine the statistical significance of these observed changes. This is discussed in Section 5.11.

5.11 Determining the statistical significance of the observed outcomes for the combined year 9/97 and year 9/98 instruction and non-instruction groups

In order to show that the changes observed with the Instruction Group following the implementation of the Teaching Unit were statistically significant and not due merely to chance, a paired 't' test (Moore & McCabe, 1989, p. 516) was performed on the combined data for the two year groups discussed in Section 5.10. The data for the pre-instruction and delayed post-instruction phases were used in this test since, as noted in Section 5.10, these were the only phases in which the Non-Instruction Groups of both years completed the questionnaire. The differences between the combined total scores for Questions One and Three in the two phases were calculated for both the Instruction and Non-Instruction Groups. The fact that the difference between the mean values for the delayed post- and the pre-instruction data for the Instruction Group was greater than for the Non-Instruction Group indicated that there was an observable difference in learning outcomes between the Instruction and Non-Instruction Groups. The values required for the paired 't' test are shown in Table 5.40. The mean values for the Instruction and Non-Instruction Groups at the pre-instruction and delayed post-instruction phases are shown in the table for descriptive purposes only.

Table 5.40: Values used to determine the statistical significance of the observed outcomes for the combined year 9/97 and year 9/98 instruction and non-instruction groups

	Mean (Pre-instruct)	Mean (Delayed post)	Difference of Means	Standard Deviation	Paired 't' Value	Probability (p)
Instruction Group (n=22)	15.3	19.9	4.6	3.39	6.39	<0.0005 (df=21)
Non-Instruction Group (n=26)	12.3	12.8	0.5	3.89	0.64	>0.25 (df=25)

The very low p-value for the Instruction Group indicated that the improvement in combined total scores for Questions One and Three was very unlikely to be due to chance. By comparison, the higher p-value for the Non-Instruction Group indicated that, as observed, the small change was most probably due to chance. From these data, the researcher concluded that the Teaching Unit had achieved its aim of increasing the understanding of students with respect to 'sound and hearing'.

5.12 Conclusion

The objectives of this research into 'sound and hearing' were to formulate a theoretical cognitive model for the development of an understanding of the topic, to design and to implement a Teaching Unit on 'sound and hearing' that would give students a scientific understanding of the concepts, and to monitor the development and stability of that understanding. This has now been completed.

Chapters 4 and 5 have discussed this research into 'sound and hearing' in detail. Chapter 4 dealt with the methodology used, the development of the theoretical model, and the design of the Teaching Unit; Chapter 5 discussed the results obtained with the target groups of Year 9 students over two consecutive years. Within the constraints of the small classes and the relatively narrow range of abilities, the observed outcomes support the claim that the close alliance between the Teaching Unit and the psychological model has been successful in giving students a scientific understanding of 'sound and hearing'. The theoretical cognitive model has been extremely useful in directing the construction of the Teaching Unit as well as in enabling the researcher to monitor the changes in cognitive levels of individual students over the course of the investigation.

Chapter 6 will discuss the significance of the findings of this research, the potential of the theoretical model and the Teaching Unit for use by teachers or even by other researchers, as well as possible extensions to this study.

Chapter 6

Discussion, researcher's observations, suggestions for future research, and potential for implementation of the findings

6.1 Introduction

The present research looked at the learning and teaching of science from both a cognitive and a curriculum perspective and, therefore, took up the challenge of Lijnse (1995), who stated that 'developmental research' was needed in which curriculum development was coupled to classroom research of teaching-learning processes. Effective curriculum development is essentially a research activity (Driver & Scott, 1996; Lijnse, 1995). According to these researchers, such curriculum research results both in teaching schemes that are adapted to the needs of learners, and in documentation of the ways in which students respond. In the present research, curriculum units were designed to promote students' understanding of two scientific concepts. The development of an understanding of these concepts was monitored in terms of psychological models. As a result, the effectiveness of the teaching strategies was determined. A constructivist teaching strategy was utilised, but without losing sight of the fact that there was an established body of knowledge to be learned. The researcher believed that it was possible to combine the two.

The following sections discuss the findings of the present research and include comments, evaluations, and suggestions for future research. Section 6.2 reiterates the aims and objectives of the research. Section 6.3 considers the usefulness of the SOLO Taxonomy for this study. Sections 6.4 and 6.5 discuss and comment on the findings of the investigations into 'light and seeing' and 'sound and hearing', respectively. These two sections contain a summary of results and comparisons with the work of other researchers, as well as the researcher's observations on various aspects of the study and suggestions for further investigations. Section 6.6 discusses the potential for implementation of the findings of the research. Section 6.7 contains a brief conclusion to this research.

6.2 Aims and objectives of the research

The principal aims of this research were to investigate students' understanding of 'light' and of 'sound' in terms of theoretical cognitive models, to design and implement instructional units on these topics that would facilitate the development of a scientific understanding, and to monitor changes in the levels of understanding over the period of the investigation in terms of the theoretical models. 'Sound and hearing' was the main focus of the research; 'light and seeing' was the focus of the preliminary investigation or pilot study that preceded the research into 'sound and hearing', and that utilised the theoretical cognitive model and the questionnaire of Collis et al. (1998).

There were two principal components of this research. The first was a **psychological** component that, in the case of 'sound', established a theoretical framework, based on the SOLO Taxonomy of cognitive functioning, for students' developing understanding of 'sound and hearing'. The second component was a **curriculum** component in which Teaching Units for both 'light and seeing' and 'sound and hearing' were developed, structured in such a way as to follow the pathways postulated in the theoretical models of cognitive development. Although previous research into the design and implementation of curriculum units, particularly for 'light and seeing' (see Section 2.6), had been undertaken, this research had not been linked to a theoretical cognitive model for the development of understanding. Collis et al. (1998) had developed a theoretical cognitive model for 'light and vision', but their research had not been extended to incorporate curriculum design. It was the linking of cognitive developmental theory and curriculum design in science education that set the present research apart from the work of other researchers.

This was an action research project carried out whilst the researcher was employed as a science teacher. The school at which she was teaching provided the students for the investigation. The research was based on a constructivist view of learning and teaching at the heart of which is the notion that learning involves the active construction of knowledge by the learner. This process of constructing meaning is based on the prior conceptions of the learner and is influenced by his/her social setting. The role of the teacher is as a facilitator in the process. This was the view of constructivism held by the researcher. Under this approach, learning becomes more exciting and challenging for the student in that it encourages intellectual involvement and development.

As discussed in Section 2.3, the curriculum is conceptualised as a set of learning experiences. Tobin and Tippins (1993) maintain that this definition is consistent with constructivism since it does not regard knowledge as separate from the knower and the culture in which learning is to occur. As also discussed in Section 2.3, the science teacher has to balance the curriculum to be taught with constructivism as a process by which students deal with content. Often the curriculum takes precedence over the goal of understanding implicit in constructivism. As Tobin, Kahle, and Fraser (1990) point out, the major curriculum challenge for teachers is to focus on student learning and understanding rather than on content coverage. The curriculum units designed and implemented in the present research employed a constructivist strategy to enable students to develop an understanding of the selected physics concepts. This was considered possible with these particular concepts, although the researcher acknowledges the point made by Phillips (in press) that a constructivist strategy may not be as effective for Einstein's Theory of Relativity or Newton's Laws of Motion.

6.3 Researcher's observations on the usefulness of the SOLO taxonomy for this study

The SOLO theory has important implications for curriculum planning, for learning and teaching, and for assessment. As discussed in Section 2.5, SOLO provides a means of stating curriculum objectives in which qualitative levels of performance may be stipulated. It was in the context of assessment that the SOLO Taxonomy was first applied (Biggs & Collis, 1982; Collis & Davey, 1986). Many of the long-accepted methods of assessment had encouraged rote learning where value was placed on quantitative learning rather than on understanding. Biggs (1992) stated that the SOLO Taxonomy represented a breakthrough in assessment as criterion-referencing tended to have been limited to situations where the criterion level of performances was defined, for example, as 90% of items correct. The SOLO Taxonomy, which attempts to address the *quality* of students' understanding in terms of a model of how students learn, has the potential to address this imbalance (Levins & Pegg, 1994b). Using SOLO, teachers are able to see how far along the path towards expertise given students have progressed. The usefulness of SOLO for evaluation arises from the nature of the cycle(s) within the target mode. Each skill starts with the achievement of certain basic elements and reaches its final state of achievement, which is recognised as the skilled behaviour. It was in this context that SOLO was applied in the present research. Although the desired outcome, which, in the case of 'sound and hearing', was the attainment of the Standard Hearing Framework, was set in the Concrete Symbolic target mode, development of understanding in the Ikonic mode was monitored also. Thus the assessment can be said to have been *multimodal.* This was seen by Biggs (1992) as a desirable profile of student achievement, namely assessment of competence within the target mode and support assessments within other modes. In the present research, competence in the Concrete Symbolic mode was the primary goal, but, in some of the situations investigated, a small number of students demonstrated competence in the Ikonic mode and did not make the transition to the Concrete Symbolic mode, or, alternatively, made the transition to the higher mode but failed to attain the Standard Hearing Framework.

Using the SOLO model and the Development Maps for Seeing and for Hearing, it was possible to determine the cognitive levels at which students were observed to be functioning, and to monitor changes in observed levels of understanding brought about by participation in the Teaching Units. As discussed in Section 2.5, the SOLO model is a response model. Therefore, unless students wrote their responses in full, they were not credited with holding the relevant Key Elements of understanding. On some occasions, students received lower scores for the number of Key Elements present in their responses, and were deemed to be operating at lower cognitive levels, because they had not written full responses. This is perhaps a slight disadvantage of the SOLO model when applied to questionnaire data where students cannot be prompted to elaborate their responses as they can in an interview.

As discussed in Section 2.5, in upper primary and lower secondary schooling, the target mode is the Concrete Symbolic mode. However, Biggs (1992) maintains that good teaching should invoke a variety of means of encoding content instead of simply teaching in the Concrete Symbolic mode. He claims that the more an activity links the content in different modes, the more likely it is that learning will be remembered and used. Activity in a variety of dimensions reinforces learning and subsequent recall. In the present research, teaching took place in the Ikonic and Concrete Symbolic modes. The combination of demonstrations, 'hands-on' activities, and analogies, 'led' students along the pathway of developing understanding, first in the Ikonic mode and then in the Concrete Symbolic mode.

The SOLO Taxonomy thus proved a useful tool for determining the cognitive levels at which students were functioning. Profiles of student cognitive levels over the course of this research were compiled and levels of achievement compared. Thus the effectiveness of the Teaching Units at improving scientific understanding of the particular concepts could be determined.

6.4 Light and seeing: a preliminary investigation

Prior to addressing the main area of research, a preliminary investigation of students' understanding of 'light and seeing' was undertaken. The theoretical cognitive model for the development of an understanding of vision of Collis et al. (1998) was used in the psychological component of this preliminary investigation. The practical component consisted of the design and implementation of a Teaching Unit on 'light and seeing' to facilitate the development of an understanding of the topic. Changes in levels of cognitive functioning of students over the course of the investigation were determined by analysing their responses to the questionnaire of Collis et al. in terms of the theoretical model. The alliance between the curriculum unit and the theoretical cognitive model had been suggested as an extension to the work of Collis et al., but had not been carried out.

A measure of the success of the Teaching Unit was whether or not students had a scientific understanding of 'light and seeing' at the completion of the teaching, and whether they retained this understanding over time, rather than returning to their pre-instruction levels as other researchers had suggested might happen. In order to confirm the findings, the investigation was carried out over two consecutive years with two different groups of Year 9 students. Details of this preliminary investigation are contained in Chapter 3.

6.4.1 Discussion of results and comparison with the work of other researchers

As discussed in Section 3.3.2, the Development Map for Seeing is composed of nine paired combinations of the elements 'light', 'eye', and 'object', each of which has been assigned a status number that represents the postulated order of acquisition as understanding develops. Students' responses to Question One of the questionnaire were analysed by determining the total number and status of the paired elements present. Once the collection of data had been completed, a comparison was made of the levels of cognitive functioning of students at each phase of the investigation. A comprehensive discussion of the results of this investigation is contained in Chapter 3. Therefore, a brief analysis only of the findings will be included here.

A concise way of illustrating changes in students' understanding of 'light and seeing' was to look at the mean number of connections of the Development Map for Seeing made at each phase of the investigation. This is given in Table 3.5 for the Year 9/95 students and in Table 3.11 for the Year 9/96 students. A summary of this data is presented in Table 6.1. These figures show an improvement in the mean number of connections made immediately following the completion of the Teaching Unit, for both groups. The figures also show a slight backward slide with the Year 9/95 Group over the six months following the teaching. This differs from Fetherstonhaugh and Treagust (1992) who found that the majority of students did not revert to their prior conceptions. However, no regression was observed with the Year 9/96 Group, which supports the findings of the other researchers.

Table 6.1: Mean number of connections of the development map for seeing in the responses of year 9/95 and year 9/96 students at each phase of the investigation

	Mean Number of Connections Made	
Phase of Investigation	**Year 9/95**	**Year 9/96**
Pre-Instruction	7.3	7.6
Immediate Post-Instruction	8.4	8.2
Delayed Post-Instruction	7.7	8.1

The figures in Table 6.1 show that, on average, both groups were functioning in the Concrete Symbolic mode at all phases of the investigation. Although this was not true for all students (see Tables 3.1 and 3.7), it was true for the majority. From the Development Map for Seeing (Figure 3.3), it can be seen that a mean number of connections of 3 indicates a student functioning in the Ikonic mode, a mean number of 6, a student functioning at the Multistructural level in the Concrete Symbolic mode, and a mean number of 9, the Relational level in the Concrete Symbolic mode, that is, a student at the top of the Development Map for Seeing with a scientific understanding of the topic. Therefore, a figure between 6 and 9 means that the students as a group were operating between the Multistructural and the Relational levels in the Concrete Symbolic mode.

Collis et al. (1998) had collected data from students in three different schools; an independent girls' school, a State high school, and Year 5 in a State primary school. These researchers had related the mean number of connections observed in responses to Question One of the questionnaire to the Seeing Conception selected in Question Two (see Section 3.3.4). This relationship was discussed for the present research in Section 3.5. The data obtained in the pre-instruction phase can be compared with the data of Collis et al. In the present research, the mean number of connections observed for students selecting Conception 4 was 8.3 (Year 9/95) and 8.5 (Year 9/96). Collis et al. had obtained a figure of 8.3. The mean number of connections observed for Year 9/95 students selecting Conceptions 3 and 5, was 4 in both cases. Collis et al. had obtained 2.8 for students selecting Conception 3, and 4.9 for those selecting Conception 5. With the Year 9/96 Group, no students selected Conceptions 3 or 5 in the pre-instruction phase. Despite the smaller numbers and the limited range of abilities of students involved in the present research, the data obtained showed some similarity to that obtained by Collis et al., particularly with respect to students selecting Conception 4.

Responses to Question Two were analysed by looking at which of the Seeing Conceptions a student selected. Collis et al. (1998) had designated those who selected Conceptions 2 and 3 as the 'Seeing Happens' group (see Section 3.3.4), and had observed that the majority of these students were found to hold 3 or fewer connections of the Development Map for Seeing and to be functioning in the Ikonic mode. This was not observed in the present research. With the Year 9/95 Group, no students selected Conception 2, and those observed functioning in the Ikonic mode selected Conception 5 and to a lesser extent Conception 3. With the Year 9/96 Group, only two students selected Conception Two, one in the pre-instruction phase, and one in the immediate post-instruction phase, and on both occasions their responses to Question One were indicative of the Concrete Symbolic mode. Collis et al. designated students who selected Conceptions 1 or 5 as the 'Active Looking' group (see Section 3.3.4), and observed that these students were generally found to be functioning in the Concrete Symbolic mode and to hold 4 or more paired elements of the Development

Map for Seeing. This also was not observed in the present research. Conception 1 was selected by one student only in the Year 9/95 Group and one in the Year 9/96 Group. The number of connections held by these two students was 8 (indicative of Concrete Symbolic mode) and 3 (indicative of Ikonic mode), respectively. Students selecting Conception 5 were observed to hold 3 or 4 paired elements and to be functioning on the border of the transition from the Ikonic to the Concrete Symbolic mode.

The discrepancies between the data of Collis et al. (1998) and the outcomes observed in the present research would suggest that the present research should be repeated with larger numbers of students with a greater spread of abilities. The researcher agrees that this would give the data obtained in the present research greater reliability, however, the following section contains some of the researcher's observations concerning the model of Collis et al. vis-à-vis the present research.

6.4.2 Researcher's observations

The model of Collis et al. (1998) was useful in monitoring the changes in the numbers of paired connections of the Development Map for Seeing observed in the responses of students at each stage of the investigation, particularly following the implementation of the Teaching Unit. However, a difficulty was encountered in relating the paired elements of the Development Map to the level of cognitive functioning. If the student held all pairs with the same status numbers, for example, L/O.2, L/E.2, and E/O.2, the task was straightforward, but, if the response contained a mix of status numbers, then it was not always possible to determine the mode of functioning or, more particularly, the level within the mode. The correspondence between the number of paired elements of the Development Map for Seeing and the level of cognitive functioning was not always precise. This model thus differed from the theoretical cognitive model postulated for 'sound and hearing', as the latter model, with its associated scoring system, allowed the level of cognitive functioning to be determined more precisely for each student's response.

A further difficulty was encountered with the model of Collis et al. (1998). Counting the number of paired elements present in students' responses did not take into account the presence of alternative conceptions in their responses, particularly if they held alternative notions together with scientific notions of the same status. It seemed misleading to credit students with holding scientific notions that might then give them a total of nine paired elements, and appear as though they possessed a scientific understanding of 'light and seeing', when, concurrently, they held alternative notions. Although Solomon (1983) had said that students may retain both 'everyday notions' and 'scientific notions', she said also that they should be able to distinguish between the two and to know when each was appropriate (see Section 2.4). The researcher believes that once students have acquired the Standard

Seeing Framework, and hence have a scientific understanding of 'light and seeing', it is unlikely that they would still hold an alternative conception in the same context. Whereas students may hold alternative conceptions concurrently with their *developing* scientific notions, the researcher believes that, once they have acquired a scientific understanding, their alternative conceptions are unlikely to co-exist with it. Yet, using the model of Collis et al., it appeared that students could possess a scientific understanding and yet still hold an alternative conception. The model did not discriminate between the scientific notion and the alternative notion. This is an area in which further research would be informative.

Despite the limitations due to the small groups and the absence of a wide range of abilities, the trends over the course of the investigation could still be observed. These supported the conclusion that the theoretical model could be used to determine the level of cognitive functioning of students at each phase of the investigation. This allowed the cognitive change following participation in the Teaching Unit to be monitored in order to determine the effectiveness of the curriculum unit. The Teaching Unit structured to follow the theoretical pathway of developing understanding appeared to have been successful in improving students' scientific understanding of 'light and seeing'.

Thus the preliminary investigation into 'light and seeing' had been valuable as a pilot study as it allowed the researcher to determine if a theoretical cognitive model could be used for planning and evaluating teaching, that is, whether cognitive developmental theory could be linked successfully to curriculum design. The next step was to apply this experience to the main focus of 'sound and hearing'.

6.5 Sound and hearing

In the present research, the theoretical model for the development of an understanding of 'sound and hearing', implemented in the psychological component of the investigation, was formulated by the researcher. The sequence for the practical component was similar to that used for 'light and seeing', with the addition of a fifth or 12-month delayed post-instruction phase. The methods used in this investigation, including the formulation of the theoretical model, the design of the questionnaire, and the method of analysis of students' responses, are contained in Chapter 4. The outcomes observed with the target groups of students are discussed in Chapter 5. The prime concern of the investigation was to bring about an improvement in students' understanding of 'sound and hearing' using the Teaching Unit, and to determine whether students retained their scientific understanding over a prolonged period of time. The theoretical cognitive model and the Teaching Unit were applied to two different groups of Year 9 students over two consecutive years.

6.5.1 Discussion of results and comparison with the work of other researchers

The Development Map for Hearing (Figure 4.6) was postulated to represent the building of an understanding of 'sound and hearing', and showed the pathways most commonly followed by students as they developed an understanding, first in the Ikonic mode, then in the Concrete Symbolic mode. Once the student integrated the four Key Elements of the Development Map, 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear', then she was said to possess the Standard Hearing Framework and to have developed a scientific understanding of 'sound and hearing'. The distinction between the R_a and R_b levels in the Concrete Symbolic mode was an important indicator of how well students understood the mechanism by which sound reaches the ear. Those students observed functioning at the CS R_a level displayed an awareness that vibrations travelled through the air, but not that the air itself vibrated. It appeared that to these students 'air' was simply 'space'. Watt and Russell (1990) too had observed this notion of air as 'space'. Those students observed functioning at the CS R_b level appeared to have understood that the air particles themselves vibrated in order to transmit the sound. The vital role of the medium, and the mechanism by which it transmits sound, was observed as the main 'stumbling block' to students' understanding.

Prior to undertaking the research with the target group of Year 9 students, the theoretical model was tested on students of a range of ages and stages of development in order to be certain that the model could be used reliably to determine students' levels of cognitive functioning. Year 6, Year 10, and University Physics 1 students completed the questionnaire, and their responses to the three questions were analysed. The responses of all students were classified according to the theoretical model, and, on average, the observed outcomes were as expected (see Chapter 4 for a discussion of these results).

When analysing the effect of the Teaching Unit on 'sound and hearing', there were two aspects of the data to consider, one qualitative, the other quantitative. The first was the improvement in the SOLO level from one phase to the next: how near to the 'top' of the Development Map for Hearing the student was after tuition, and whether the student retained that position over time. The second aspect was the change in score for the number of Key Elements present in the students' responses from one phase to the next. The ideal situation was if all students improved greatly and finished at or very near the top of the Development Map. Both aspects represented cognitive development. However, since the desired outcome for each student was the attainment of the Standard Hearing Framework in the Concrete Symbolic mode, then it would appear that the first aspect, the improvement in SOLO level, was the better indicator of *individual* student achievement. The second aspect, the *change* in score for the number of Key Elements, enabled the researcher to make comparisons of observed changes in learning outcomes, across a range of tasks, for groups of students.

The combined scores for Questions One and Three were used to compare the Instruction and Non-Instruction Groups for 1997 (Section 5.5) and 1998 (Section 5.9), to compare the combined data for the two year groups (Section 5.10), and to determine the statistical significance of the observed outcomes (Section 5.11). Thus both the changing SOLO levels, and the changes in scores for Key Elements, provided valuable information as to the success of the Teaching Unit.

The change in SOLO levels over the course of the investigation, determined from Question One, are shown in Table 5.2 for the Year 9/97 Instruction Group, and in Table 5.21 for the Year 9/98 Instruction Group. The changes in scores for Key Elements are shown in Tables 5.3 and 5.22 for the two groups, respectively. With both groups it can be seen that there was an improvement in the SOLO levels, and an increase in the scores, for nearly all students. The average increase in score was slightly greater for the Year 9/97 Group than for the Year 9/98 Group, although it must be remembered that the numbers of students were small, particularly with the 1998 Group. Five months later, a decrease in the SOLO level had occurred for a number of students with a concomitant decrease in average score, suggesting a regression in understanding. It was observed that some students were omitting to state specifically that the air itself vibrated. The regression was slightly less with the Year 9/97 Group than with the Year 9/98 Group. However, with the Year 9/97 Group, a further decrease in understanding took place over the seven months elapsing between the delayed post-instruction and the 12-month delayed post-instruction phases. This tended to support the findings of earlier researchers that the conceptual change that students undergo as a result of instruction is not long-lasting. However, it is important to note that, although some regression in understanding was observed, students did not return to their pre-instruction levels. All students continued to operate in the Concrete Symbolic mode, only their level within the mode decreased slightly. The concern here was whether this represented a 'real' loss of understanding or whether the students had simply become 'bored' with the assessment tool and not bothered to write the full responses that were necessary to demonstrate their level of understanding. Students completed the questionnaire on four occasions, and, on the final occasion for the Year 9/97 Group, the comment was heard 'not again!'. In fact Pegg (1991) points out that students can choose to work at a lower level for a variety of reasons, such as a lack of motivation. Perhaps individual interviews interspersed with the questionnaire would overcome this problem. With the Year 9/98 Group, no further regression was observed between the delayed post-instruction and the 12-month delayed post-instruction phases.

The notion of 'active listening' identified by earlier researchers (see Section 2.7) was included as Option 2 in Question Two of the questionnaire. It was of interest to note that, in the present research, only one Year 9 student, on one occasion only, chose this option. This contrasted with the findings of Watt and Russell (1990), who found the 'active listening' idea, present in 18% of 11-year olds, was difficult to challenge. However the students they were working with were slightly younger than the students in the present investigation. Boyes and Stanisstreet (1991) on the other hand had found with students of a similar age to those involved in this study that the notion of 'active listening' was weakly held and quickly discarded. The results of this study appeared to support the finding of Boyes and Stanisstreet. In addition, no student in either Year 6 or Year 10, and only one Physics 1 student, selected this option. However, four students (17%) in Year 6 included the notion of 'active listening' in their responses to Question One. These Year 6 students were the same age as the students observed by Watt and Russell (1990). It was decided then to re-examine the responses to Question One of the Year 9 students to see what percentage of these students mentioned 'active listening'. However, only one student out of the two year groups included this notion in her response to Question One. So it was concluded from the present research that 'active listening', although observed in a small number of younger students, was not generally held by students of the age involved in this study.

Combining the scores for Question One and Question Three served to eliminate the ceiling effect observed for some items where there was insufficient discrimination between students receiving the same score for a particular response. Graphs of the combined total scores were used to compare the performances of Year 6, Year 10, and Physics 1 students (see Figure 4.7). The shift observed in the graphs towards the higher ranges of combined scores from Year 6 to Year 10, and, to a lesser extent, from Year 10 to Physics 1, were as expected according to the SOLO model of cognitive development. These trends illustrated the usefulness of the theoretical model for determining the cognitive levels at which students were functioning with respect to 'sound and hearing'. The graphs also pointed to the potential use of the model for predicting the cognitive levels at which other groups of students would be expected to be observed functioning. As the level of cognitive functioning is predicted to improve with tuition (Biggs & Collis, 1991), then the data also indicated that the model would serve as a useful tool for monitoring changes brought about by teaching. Similar graphs were drawn for the Year 9/97 and Year 9/98 Instruction and Non-Instruction Groups. Based on the greater percentage of students in the Instruction Groups with high combined total scores compared with the Non-Instruction Groups, these graphs indicated that the Teaching Unit had led to an improvement in the scientific understanding of students in the Instruction Groups. A slightly greater improvement was observed for the Year 9/97 Group than for the Year 9/98 Group. Virtually no change was observed in the Non-Instruction Groups. For a complete discussion of these graphs, see Sections 5.5 (Year 9/97) and 5.9 (Year 9/98).

Despite the slight modifications made to the 1998 Teaching Unit, no great difference in outcomes was observed between the 1997 and 1998 Instruction Groups. This was posssibly due to the fact that the Year 9/98 Group was so small. For this reason the combined scores for Questions One and Three for 1997 and 1998 were further combined, and a paired 't' test performed on the differences between the pre-instruction and delayed post-instruction data for the Instruction and Non-Instruction Groups. The probability values were calculated for the two groups (see Section 5.11). These values showed that the observed improvement in the Instruction Group following participation in the Teaching Unit was very unlikely to be due to chance. By comparison, the observed change in the Non-Instruction Group was most probably due to chance. The researcher thus concluded that the Teaching Unit had achieved its aim of increasing the scientific understanding of students with respect to 'sound and hearing'.

In his investigations with university physics students, Linder (1993) (see Section 2.7) had observed that some students believed that the molecules of the medium presented an obstruction to sound propagating through the medium. The greater the density of the molecules, the greater the obstacle they presented. This same notion was observed in the present research, but only with two students, one Physics 1 and one Year 9/97 student, in their responses to Question Three, Picture (i). However, the notion was not addressed specifically in the 'sound' questionnaire, so further investigation is needed to determine how widely this notion is held.

This section has considered the outcomes observed with the different groups of students involved in the research into 'sound and hearing'. The following section includes the researcher's observations on a number of aspects of the study.

6.5.2 Researcher's observations

Responses to the 'free response' Question One of the 'sound' questionnaire were more reliable for determining the levels of cognitive functioning of students, and for monitoring changes over the course of the investigation, than the 'multiple choice' Question Two. Again it was observed that some students selected the correct option and yet their responses to Question One indicated low levels of understanding. However, in hindsight, it was thought that perhaps another option should have been included for selection in Question Two, one indicative of the CS R_a level of cognitive functioning, as this level was not represented. Such an option would contain mention of 'air' and 'vibration' but would not state that the air itself vibrates, for example, 'the gong vibrates when it is struck and the sound travels through the air to your ears'. This inclusion of a further option may have resulted in a better discrimination between students.

With the Physics 1 students who completed the questionnaire, a ceiling effect was apparent in the observed levels of cognitive functioning of some students. According to Biggs and Collis (1991), these University students would be expected to be functioning in the Formal mode. However, the theoretical model used in the present research did not encompass the transition from the Concrete Symbolic mode to the Formal mode, and did not allow for assessment in the Formal mode. An appropriate extension to the present research would be to formulate a theoretical model for the development of understanding in the Formal mode, and to develop a tool for assessment in this same mode.

It was observed also that some University Physics students wrote in more sophisticated scientific terms than the younger students. Although this was not surprising, a decision had to be made as to whether the University students understood these terms. For example, one University student, referring to Question Three, Picture (vi) (Figure 4.3), wrote, "Yes, sound will behave according to Doppler Effect." This statement was correct but it did not answer the question. The student may have understood the connection between the Doppler Effect and frequency (vibrations per second). However, as the SOLO model is a response model, unless students specifically explained how they would hear the sound of the siren, then they were not deemed to hold the relevant Key Elements of Question Three. As a result some University students appeared to be functioning at lower cognitive levels with respect to 'sound and hearing'. Like the ceiling effect mentioned above, this was an example of the situation where the knowledge of the student and the level of cognitive functioning were beyond the scope of the theoretical model and the questionnaire used in the present research.

Watson et al. (1993) in their study of fractions noted a mutual interaction between Ikonic and Concrete Symbolic development with Ikonic processes appearing to provide support for Concrete Symbolic reasoning (see Section 2.5). This same observation was made in the present research. For example, Student 23 (Year 9/97) in the delayed post-instruction phase wrote in her response to Question Three, Picture (i), "Yes, the water contains air and sound vibrations can travel through the air so you can hear under water." The student's response demonstrated a good understanding of air as the medium for the transmission. She appeared then to have applied this understanding intuitively to the transmission of sound in water. It is possible that other students used imagery or intuitive notions to help frame their written responses, without this being detected. Individual interviews may have assisted in clarifying whether or not they used Ikonic functioning as support for the Concrete Symbolic mode. Determining the extent of this support would perhaps also make an interesting extension to the present work.

The use of analogies was considered a valuable aid to student understanding especially where they involved an activity to illustrate a concept (see Section 2.8). The use of analogies is often recommended as a method of making difficult concepts clear to students owing to their ability to evoke rich mental pictures that enhance student learning (Duit, 1991; Thiele & Treagust, 1992). Analogies may encourage Ikonic functioning and the use of imagery, which was observed by Watson et al. (1993) as a necessary support for the Concrete Symbolic mode. Watson et al. (1993) had suggested that teaching that encouraged ikonic functioning should be undertaken to determine whether intervention could improve the links between symbolic manipulations and referential meaning. Their suggestions related to the promotion of competence and understanding in mathematics. However, the researcher believes that this same idea could be applied to science. In the present research, teaching was undertaken to 'lead' students through the Ikonic mode to the Concrete Symbolic mode. The use of analogies appeared to have facilitated Ikonic support for understanding in the Concrete Symbolic mode by encouraging image formation. Further research should be undertaken in which Ikonic functioning is encouraged at the same time as teaching takes place in the Concrete Symbolic mode.

As a result of the analogies employed in the Teaching Unit, some students remembered how vibrations were transmitted and included an analogy in their responses to the questionnaire. For example Student 6(I) wrote in her delayed post-instruction response to Question One, "These vibrations hit the air particles and continually set off the surrounding air in a domino effect." She also referred to the domino effect in her 12-month delayed post-instruction response. It was interesting that she did not mention the domino effect in her immediate post-instruction response. This appeared to suggest that the mental image evoked by the analogy was used as a long-term memory aid. As already mentioned, one of the findings of this investigation was that the role of the medium in the transmission of sound was the main 'stumbling block' to student understanding. It appeared that if students can tie the scientific explanation in with their experience, then they may retain their understanding. The use of analogies appeared to help students make such links. An investigation of the effectiveness of analogies as an aid to the long-term retention of scientific understanding would make an interesting extension to the present research. Recent work by Mason (1996) on the self-generation of analogies by students suggests a further extension.

A further observation of the researcher is related to the use of appropriate language in instruction. Garnett, Garnett, and Hackling (1995) had observed in several studies that the use of everyday language in a scientific context was a potential source of students' alternative conceptions. They stated that teachers should use language that is unambiguous and that describes clearly the concept being taught. The researcher made similar observations in the present research. She found that the language used in structuring the Teaching Unit was vital to students' understanding. This may indeed be an area in which further research would be most informative.

The preceding sections have highlighted areas in which further research would be both interesting and informative. The next section in this chapter considers the potential for implementation of the findings of the present research with both students and teachers.

6.6 Potential for implementation of the findings

Despite the limitations of small numbers of students and a rather narrow range of abilities, trends were observed over the course of the investigation that allowed conclusions to be drawn and the implications for the implementation of these findings to be considered. The researcher believes that the potential for the application of cognitive developmental theory linked to curriculum design in science education is considerable. Some possible applications are listed under separate headings in the following paragraphs.

- **Curriculum development**

The implications from the research into 'sound and hearing' for the application of the theoretical cognitive model and the constructivist Teaching Unit to teaching, and to curriculum development, appear significant. They have the potential for use by practising teachers to improve not only the structure of their lessons but, more importantly, the understanding of their students with respect to 'sound and hearing'. In turn, as mentioned in Section 6.2, this will make learning more exciting and challenging for students. The same conclusions apply for the research into 'light and seeing'. Although the theoretical framework was not designed by the researcher, it was applied to the structuring of a Teaching Unit closely aligned with the theoretical model and, therefore, both could be applied to teaching and to curriculum development in the same manner as for 'sound and hearing'.

- **Monitoring the development of understanding across the science curriculum**

Linking the SOLO Taxonomy to the development of an understanding of specific physics concepts enabled changes in students' levels of cognitive functioning to be determined with respect to these particular concepts, and pointed to the future application of similar developmental models in other areas of the science curriculum, in both primary and secondary classrooms. The theoretical models of development enabled the researcher to assess the level of understanding of each student before and after instruction. The instruction was closely aligned with the theoretical models such that as instruction proceeded the student was 'led' up the hierarchical framework of understanding.

- **Development of generic cognitive skills**

The present research addressed the development of understanding of the specific topics of 'light and seeing' and 'sound and hearing' and, as such, was researching the development of domain specific skills. The application of the present findings to the development of generic cognitive skills would require further investigation.

- **Providing profiles of student achievement**

The linking of curriculum design and cognitive development could be applied to larger groups of students with a greater spread of ability levels. This would enable teachers to compare students' progress in developing an understanding of particular concepts. As discussed in Section 6.3, profiles of achievement of students could be prepared and used for assessment purposes. From the present research, it can be seen that profiles can be prepared in both the Ikonic and Concrete Symbolic modes for the development of an understanding of 'sound and hearing'. However, prior to using the theoretical model of Collis et al. (1998) to provide profiles of achievement in 'light and seeing', it would be necessary to develop a 'tighter' relationship between the paired elements and the levels of cognitive functioning (see Section 6.4.2).

- **Development of understanding at the tertiary level**

As discussed in Section 2.5, tertiary students are, on average, expected to be functioning in the Formal mode of the SOLO Taxonomy. Therefore, as mentioned in Section 6.5.2, further research could look at formulating a theoretical model for the development of understanding in the Formal mode, as well as designing an appropriate tool for assessing the level of understanding within this mode.

- **A vertical study of cognitive development**

This study looked principally at levels of achievement across a single year group, in this case Year 9. The data obtained with other year groups in the developmental stages of this research indicated that a vertical study across different year groups would make an interesting extension to this work. It appeared from this research that it would be possible to prepare profiles of cognitive development of students through consecutive years of schooling. A small amount of data only was obtained in the present research from individual interviews with Year 1 and Year 3 students, and from class interviews with Year 4 and Year 7 students. Therefore further investigations with these year groups would be an informative extension to this study.

- **Determining whether teachers involved in action research change their classroom pedagogy**

As mentioned in Section 2.8, little has been done to investigate whether teachers involved in action research actually change their classroom pedagogy as a result of their observations. This would make an interesting area for further investigation.

- **Teacher development**

In addition to the implications for learning and teaching in the classroom, the findings of the present research have implications for teacher development. Knowing how best to teach particular science concepts to students distinguishes the science educator and the science teacher from the scientist. It draws on and integrates science content knowledge, science education research, science teaching experience, and principles of pedagogy (Wandersee, Mintzes, & Novak, 1994). The application of constructivism to the design of teaching sequences requires a new set of skills on the part of teachers. Teachers now have to be more concerned with student learning and understanding instead of merely with content delivery. Beginning teachers, and those accustomed to teach in the traditional way, will require initiating into the 'constructivist' camp.

6.7 Conclusion

This research has demonstrated that designing a curriculum unit that identifies students' prior knowledge, and allows for interaction between students, and between students and teacher, is successful in promoting conceptual change. In other words, this research put into practice the findings of a number of researchers in the field of conceptual change discussed in Chapter 2, and monitors their effectiveness.

The research is not so much about addressing the current debates on the distinction between the psychological and social aspects of learning and development as about considering each aspect, discussed at length in Chapter 2, and incorporating the findings of a number of researchers, with which this researcher concurs, into the current research program. Recent literature on teaching for conceptual change stresses the importance not only of taking into account students' prior knowledge, and identifying their alternative conceptions (see, for example, Driver & Oldham, 1986; Scott, Asoko, & Driver, 1992) but also of the social aspects of learning and of the interaction between students and their teachers, peers, and parents (see, for example, Vygotsky, 1978; Lemke, 1990; Moll, 1990). As discussed in Section 2.3.1, there is growing recognition of the role of the social and cultural aspects in learning science as well as the personal constructivist aspects (see, for example, Solomon, 1987; Tobin, 1990; Driver et al., 1994). The notions of 'alternative conceptions', 'social constructivism', 'sociocultural views of learning', and 'the SOLO Taxonomy of cognitive functioning' are theoretically compatible in that each is applicable in a more social-constructivist paradigm. The prime concern in the present research was how students develop an understanding of a particular topic and what can be done to promote and increase the level of understanding. Biggs and Collis (1989, 1991) had demonstrated the effectiveness and usefulness of the SOLO Taxonomy in determining levels of understanding but, although they had suggested that it should be extended to monitoring changes in the classroom (see Collis & Davey, 1986), they had not done this.

In conclusion, the findings of this research have the potential to provide teachers with the tools to comprehend students' understanding, to design instructional strategies to promote their understanding, and to analyse the success of these strategies. The direction that a curriculum designed using a theoretical framework would give to the classroom teacher is most important. Teachers must understand their students' prior knowledge and alternative conceptions about a particular science topic, as well as how they develop an understanding, if they are to tailor their lessons to fit their students. With this in mind, it is considered that teacher training should include aspects of the alternative conceptions research, particularly in the discipline areas in which they may teach in the future, as well as an introduction to cognitive developmental theory and curriculum design.

References

Adams, R. J., Doig, B. A., & Rosier, M. (1990). *Science learning in Victorian schools: 1990.* (Vol. 41). Melbourne: The Australian Council for Educational Research.

Anderson, C. W., & Smith, E. L. (1987). Teaching science. In V. Richardson-Koehler (Ed.). *Educator's handbook: a research perspective.* New York: Longman.

Andersson, B., & Karrqvist, C. (1983). How Swedish pupils, aged 12–15 years, understand light and its properties. *European Journal of Science Education,* 5, 387–402.

Ausubel, D. P. (1967). *Learning theory and classroom practice.* Ontario Institute for Studies in Education, Toronto, Canada.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view.* Holt, Rinehart and Winston.

Bandura, A. (1969). *Principles of behaviour modification.* New York: Holt and Rinehart.

Bell, B. (1985). *The construction of meaning and conceptual change in classroom settings: case studies in plant nutrition.* Leeds: Centre for Studies in Science and Mathematics Education, University of Leeds.

Bell, B. (1991). Implications for curriculum. In J. Northfield & D. Symington (Eds.). *Learning in Science viewed as personal construction - an Australian perspective,* (Monograph Number 3). Perth, Western Australia: Key Centre for School Science and Mathematics, Curtin University of Technology.

Bell, B., & Gilbert, J. (1996). *Teacher development: a model from science education.* London: Falmer Press.

Bereiter, C., & Scardamalia, M. (1989). Intentional learning as a goal of instruction. In L. B. Resnick (Ed.). *Knowing, learning and instruction: Essays in honour of Robert Glaser.* Hillsdale, NJ: Lawrence Erlbaum Associates, pp. 361–392.

Bereiter, C., & Scardamalia, M. (1993). *Surpassing ourselves: An enquiry into the nature and implications of expertise.* La Salle, IL: Open Court.

Biggs, J. B. (1992). Modes of learning, forms of knowing, and ways of schooling. In A. Demetriou, M. Shayer, & A. Efklides (Eds.). *Neo-piagetian theories of cognitive development: Implications and applications for education.* London: Routledge, pp. 31–51.

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the Quality of Learning: The SOLO Taxonomy.* New York: Academic Press.

Biggs, J. B., & Collis, K. F. (1989). Towards a model of school-based curriculum development and assessment using the SOLO Taxonomy. *Australian Journal of Education,* 33 (2), 151–163.

Biggs, J. B., & Collis, K. F. (1991). Multimodal learning and the quality of intelligent behaviour. In H. Rowe (Ed.). *Intelligence: Reconceptualisation and Measurement.* Hillsdale, New Jersey: Laurence Erlbaum.

Boyes, E., & Stanisstreet, M. (1991). Development of pupils' ideas about seeing and hearing - the path of light and sound. *Research in Science and Technological Education,* 9 (2), 223–244.

Campbell, K. J., Watson, J. M., & Collis, K. F. (1992). Volume measurement and intellectual development. *Journal of Structural Learning,* 11 (3), 279–298.

Chan, C., Burtis, P. J., Scardamalia, M., & Bereiter, C. (1992). Constructive activity in learning from text. *American Educational Research Journal,* 29, 97–118.

Chan, C., Burtis, P. J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction,* 15, 1–10.

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction,* 4, 27–43.

Chuska, K. R. (1995). *Improving classroom questions.* Phi Delta Kappa Educational Foundation: Bloomington, Indiana.

Claxton, G. (1984). *Live and Learn.* London: Harper and Row.

Collis, K. (1991). *Assessment of the Learned Structure in Elementary Mathematics and Science.* Paper presented at the First National Conference on Assessment in the Mathematical Sciences, Geelong, Victoria.

Collis, K. F., & Biggs, J. B. (1983). Matriculation, degree requirements and cognitive demands in Universities and CAE's. *Australian Journal of Education,* 27, 41–51.

Collis, K. F., & Biggs, J. B. (1991). Developmental determinants of qualitative aspects of school learning. In G. Evans (Ed.). *Learning and teaching cognitive skills.* Melbourne: Australian Council for Educational Research.

Collis, K. F., & Davey, H. A. (1986). A Technique for Evaluating Skills in High School Science. *Journal of Research in Science Teaching,* 23 (7), 651–663.

Collis, K. F., Jones, B. L., Sprod, T., Watson, J. M., & Fraser, S. P. (1998). Mapping development in students' understanding of vision using a cognitive structural model. *International Journal of Science Education,* 20 (1), 45–66.

Cosgrove, M., & Osborne, R. (1985). Lesson frameworks for changing children's ideas. In R. Osborne & P. Freyberg (Eds.). *Learning in Science: The implications of children's science.* London: Heinemann.

Dana, T. M., & Davis, N. T. (1993). On considering constructivism for improving mathematics and science teaching and learning. In K. Tobin (Ed.). (1993). *The practice of constructivism in science education.* United Kingdom: Lawrence Erlbaum Associates.

Demetriou, A., Gustafsson, J-E., Efklides, A., & Platsidou, M. (1992). Structural systems in developing cognition, science and education. In A. Demetriou, M. Shayer, & A. Efklides (Eds). *Neo-Piagetian Theories of Cognitive Development.* London: Routledge.

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education,* 3 (1), 93–101.

Driver, R. (1983). *The Pupil as a Scientist?* Milton Keynes: Open University Press.

Driver, R. (1989a). Changing conceptions. In P. Adey (Ed.). *Adolescent Development and School Science.* London: Falmer Press.

Driver, R. (1989b). Students' conceptions and the learning of science. *International Journal of Science Education,* 11 (Special issue), 481–490.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher* 23 (7), 5–12.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: A constructivist view. *School Science Review,* 67, 443–456.

Driver, R., & Easley, J. (1978). Pupils and paradigms: a review of literature related to concept development in adolescent science students. *Studies in Science Education,* 5, 61–84.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education,* 13, 105–122.

Driver, R., & Scott, P. (1996). Curriculum development as research. A constructivist approach to science curriculum development and teaching. In D. F. Treagust, R. Duit, & B. F. Fraser (Eds.). *Improving teaching and learning in science and mathematics.* New York: Teachers College Press, pp. 94–108.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: research into children's ideas.* London: Routledge.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education,* 75, 649–672.

Duit, R. (1993). The constructivist view: a fashionable and fruitful paradigm for science education and practice. In L. Steffe (Ed.). *Epistemological foundations of mathematical experience.* New York: Springer-Verlag.

Duit, R. (1994). Research on students' conceptions - developments and trends. In H. Pfundt and R. Duit (Eds.). (1994). *Bibliography: Students' Alternative Frameworks and Science Education*, 4th Edition, Kiel, Germany, IPN at the University of Kiel.

Duit, R., & Confrey, J. (1996). Reorganizing the curriculum and teaching to improve learning in science and mathematics. In D. Treagust, R. Duit, & B. Fraser (Eds.). *Improving teaching and learning in science and mathematics.* Teachers College Press, Teachers College, Columbia University.

Duit, R., & Treagust, D. F. (1998). Learning in science - from behaviourism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.). (1998). *International handbook of science education.* Netherlands: Kluwer, pp. 3–25.

Dykstra, D. (1992). Studying conceptual change: constructing new understandings. In R. Duit, F. Goldberg, & H. Niedderer (Eds.). *Proceedings of the international workshop on research in physics learning: theoretical issues and empirical studies.* Bremen, Germany, pp. 40–58.

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education,* 76 (6), 615–652.

Eaton, J., Anderson, C., & Smith, E. (1983). *Students' misconceptions interfere with learning: case studies of fifth-grade students* (Research series 128). Institute for Research on Teaching, Michigan State University.

Eaton, J., Sheldon, T., & Anderson, C. (1986). *Light: A Teaching Module* (Occasional Paper 92). Institute for Research on Teaching, Michigan State University.

Fetherstonhaugh, A. R. (1990). Misconceptions and light: a curriculum approach. *Research in Science Education*, 20, 105–113.

Fetherstonhaugh, T., & Treagust, D. F. (1992). Students' understanding of light and its properties: teaching to engender conceptual change. *Science Education*, 76 (6), 653–672.

Freudenthal, H. (1991). *Revisiting mathematics education.* Dordrecht: Kluwer.

Freyberg, P., & Osborne, R. (1985). Assumptions about teaching and learning. In R. Osborne & P. Freyberg (Eds.). *Learning in Science: the implications of children's science.* London: Heinemann.

Galili, I., Bendall, S., & Goldberg, F. (1993). The effects of prior knowledge and instruction on understanding image formation. *Journal of Research in Science Teaching,* 30 (3), 271–301.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995) Students' alternative conceptions in chemistry: a review of research and implications for teaching and learning. *Studies in Science Education*, 25, 69–95.

Gergen, K. (1994). *Realities and relations: soundings in social construction.* Cambridge, MA: Harvard University Press.

Gilbert, J. K., Osborne, R. J., & Fensham, P. J. (1982). Children's science and its consequences for teaching. *Science Education,* 66, 623–633.

Good, R. G., Wandersee, J. H., & St. Julien, J. (1993). Cautionary notes on the appeal of the new 'ism' (constructivism) in science education. In K. Tobin (Ed.). (1993). *The practice of constructivism in science education.* United Kingdom: Lawrence Erlbaum Associates.

Goodrum, D. (1985). *The art of questioning.* West Australian Council of Adult Education.

Groundwater-Smith, S., Cusworth, R., & Dobbins, R. (1998). *Teaching challenges and dilemmas.* Sydney: Harcourt Brace.

Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien (Eds.). *Children's ideas in science* . Milton Keynes: Open University Press.

Gunstone, R. F. (in press). Constructivism and learning research in science education. In D. Phillips (Ed.). *99th National Society for the Study of Education Yearbook,* University of Chicago.

Gunstone, R. F., Champagne, A. B., & Klopfer, L. E. (1981) Instruction for understanding: A case study. *Australian Science Teachers Journal,* 27 (3), 27–32.

Hand, B., & Prain, V. (Eds.). (1995). *Teaching and learning in science: the constructivist classroom.* Australia: Harcourt Brace.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: a case study in Grade-10 optics. *Journal of Research in Science Teaching,* 30 (10), 1291–1307.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education,* 11 (5), 541–553.

Hubber, P. (1995). Year 10 understanding of light: a long-term study. Paper presented at the Conference of the Australian Science Education Research Association. Bendigo, Victoria, July 1995.

Jones, B., Collis, K., Sprod, T., & Watson, J. (1996). How children develop an understanding of vision. *Australian Science Teachers Journal,* 42 (4), 54–58.

Jones, B. J., Collis, K. F., Watson, J. M., Foster, K., & Fraser, S. P. (1994). Images in mirrors: recollections, alternative explanations and modes of cognitive functioning. *Research in Science Education,* 24, 191–200.

Jones, B. L., Collis, K. F., Watson, J. M., Sprod, T., & Fraser, S. P. (1995). *Building an understanding of vision: mapping development on a students' seeing framework.* Paper presented at the 26th Australian Science Education Research Association Conference, Bendigo, Victoria.

Kelly, G. A. (1955). *The psychology of personal constructs*. New York: Norton.

Kemmis, S., & McTaggart, R. (1982). *The action research planner*. Australia: Deakin University Press.

Kuiper, J. (1994). Student ideas of science concepts: alternative frameworks? *International Journal of Science Education*, 16 (3), 279–292.

Leach, J., & Scott, P. (1995). The demands of learning science concepts - issues of theory and practice. *School Science Review*, 76 (277), 47–51.

Leder, G. (Ed.). (1992). *Assessment and Learning in Mathematics*. Hawthorn, Australia: The Australian Council for Educational Research.

Lemke, J. L. (1982). Talking physics. *Physics Education*, 17, 263–267.

Lemke, J. L. (1990). *Talking Science: Language, Learning and Values*. Norwood, New Jersey: Ablex Publishing Corporation.

Levins, L. (1992). Students' understanding of concepts related to evaporation. *Research in Science Education*, 22, 263–272.

Levins, L., & Pegg, J. (1993). Students' understanding of concepts related to plant growth. *Research in Science Education*, 23, 165–173.

Levins, L., & Pegg, J. (1994a). An exploration of the notions of cycles of levels within modes of the SOLO Taxonomy. Paper presented at the Australian Association for Research in Education, Newcastle, New South Wales.

Levins, L., & Pegg, J. (1994b). A comparison of the developmental patterns in students' responses to questions in mathematics and science. Paper presented at the Australian Association for Research in Education, Newcastle, New South Wales.

Lijnse, P. L. (1995). "Developmental research" as a way to an empirically based "didactical structure" of science. *Science Education*, 79 (2), 189–199.

Linder, C. J. (1992a). Is teacher-reflected epistemology a source of conceptual difficulty in physics? *International Journal of Science Education*, 14 (1), 111–121.

Linder, C. J. (1992b). Understanding sound: so what is the problem. *Physics Education*, 27 (5), 258–264.

Linder, C. J. (1993). University physics students' conceptualizations of factors affecting speed of sound propagation. *International Journal of Science Education*, 15 (1), 655–662.

Linder, C. J., & Erickson, G. L. (1989). A study of tertiary physics students' conceptualizations of sound. *International Journal of Science Education*, 11 (Special Issue), 491–501.

Mason, L. (1996). Collaborative reasoning on self-generated analogies: Conceptual growth in understanding scientific phenomena. *Educational Research and Evaluation*, 2 (4), 309–350.

Mathews, M. R. (1994). Discontent with Constructivism. *Studies in Science Education*, 24, 165–172.

Maurines, L. (1986). *Premières notions sur la propagation des signaux mécaniques: analyse des difficultés des étudiants*. Unpublished PhD, University of Paris.

Maurines, L. (1992). Spontaneous reasoning on the propagation of visible mechanical signals. *International Journal of Science Education*, 14 (3), 279–293.

Maurines, L. (1993). *Spontaneous reasoning on the propagation of sound.* Paper presented at the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Cornell University.

McInerney, D. M., & McInerney, V. (1994). *Educational psychology: constructing learning.* Prentice Hall.

McNiff, J., Lomax, P., & Whitehead, J. (1996). *You and your action research project.* London: Routledge.

Minstrell, J. (1989). Teaching science for understanding. In L. Resnick & L. Klopfer (Eds.). *Toward the thinking curriculum: Current cognitive research.* Alexandria, VA: Association for Supervision and Curriculum Development.

Moll, L. C. (1990). *Vygotsky and Education.* Cambridge: Cambridge University Press.

Moore, D. S., & McCabe, G. P. (1989). *Introduction to the practice of statistics.* New York: W. H. Freeman & Co.

Moshman, D. (1982). Exogenous, endogenous and dialectical constructivism. *Developmental Review*, 2, 371–384.

Muthukrishna, N., Carnine, D., Grossen, B., & Miller, S. (1993). Children's alternative frameworks: should they be directly addressed in science instruction. *Journal of Research in Science Teaching*, 30 (3), 233–248.

Nussbaum, J., & Novick, S. (1981). The challenge of student alternative frameworks to teachers and researchers. In R. Osborne & P. Freyberg (Eds.). *Learning in Science: the Implications of Children's Science.* London: Heinemann.

Osborne, R. (1982). Conceptual change - for pupils and teachers. *Research in Science Education,* 12, 25–31.

Osborne, J. F., Black, P., Meadows, J., & Smith, M. (1993). Young children's (7–11) ideas about light and their development. *International Journal of Science Education,* 15 (1), 83–93.

Osborne, R., & Freyberg, P. (1985). *Learning in* science: *The implications of children's science.* London: Heinemann.

Osborne, R. J., & Wittrock, M. C. (1985). The generative learning model and its implications for science education. *Studies in Science Education,* 12, 59–87.

Pegg, J. (1991). Assessing students understanding at the primary and secondary level in the mathematical sciences. In M. Stephens & J. Izzard (Eds.). (1992). *Reshaping assessment practices: assessment in the mathematical sciences under challenge.* Victoria: Australian Council for Educational Research Ltd.

Pfundt, H., & Duit, R. (Eds.). (1991). *Bibliography of Students' Alternative Frameworks and Science Education* (3rd ed.). Kiel, Germany: Institute for Science Education, University of Kiel.

Phillips, D. C. (1995). The good, the bad, and the ugly: the many faces of constructivism. *Educational Researcher,* 24 (7), 5–12.

Phillips, D. C. (in press). An opinionated account of the constructivist landscape. In D. Phillips (Ed.). *99th National Society for the Study of Education Yearbook,* University of Chicago.

Piaget, J. (1929). *The child's conception of the world.* London: Routledge and Kegan Paul.

Piaget, J. (1959). *The language and thought of the child.* London: Routledge and Kegan Paul.

Piaget, J. (1974). *Understanding causality.* New York: W. W. Norton.

Pople, S. (1989). *Co-ordinated science: physics.* Oxford: Oxford University Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education,* 66 (2), 211–227.

Pressley, M., Harris, K. R., & Marks, M. B. (1992). But good strategy instructors are constructivists. *Educational Psychology Review,* 4, 3–31.

Ramadas, J., & Driver, R. (1989). *Aspects of secondary students ideas about light:* University of Leeds, Centre for Studies in Science and Mathematics Education.

Rowe, M B. (1973). *Teaching science as continuous inquiring.* New York: McGraw Hill.

Russell, T. (1993). Learning to teach science: constructivism, reflection, and learning from experience. In K. Tobin (Ed.). (1993). *The practice of constructivism in science education.* United Kingdom: Lawrence Erlbaum Associates.

Scardamalia, M., & Bereiter, C. (1984). Development of strategies in text processing. In H. Mandl, N. Stein, & T. Trabasso (Eds.). *Learning and comprehension of text.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc, pp. 379–406.

Scardamalia, M., & Bereiter, C. (1987). *The psychology of written composition.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Scott, P., Asoko, H., & Driver, R. (1992). Teaching for conceptual change: a review of strategies. In R. Duit, F. Goldberg, & H. Niedderer (Eds.). *Proceedings of the international workshop on research in physics learning: theoretical issues and empirical studies.* Bremen, Germany.

Skinner, B. F. (1957). *Verbal Behaviour.* New York: Appleton.

Solomon, J. (1983). Learning about energy: how pupils think in two domains. *European Journal of Science Education,* 5 (1), 49–59.

Solomon, J. (1984). *Children's explanations.* Paper presented at the Conference of the American Education Research Association.

Solomon, J. (1987). Social influences on the construction of pupils' understanding in science. *Studies in Science Education,* 14, 63–82.

Solomon, J. (1994). The rise and fall of constructivism. *Studies in Science Education,* 23, 1–19.

Stead, B. F., & Osborne, R. J. (1980). Exploring science students' concepts of light. *Australian Science Teachers Journal,* 26 (3), 84–90.

Steffe, L., & Gale, J. (Eds.). (1995). Constructivism in education. Hillsdale, NJ: Erlbaum.

Stevens, S. S., & Warshofsky, F. (1965). *Sound and Hearing*: Time-Life International (Nederland) N.V.

Strauss, S. (1981). Cognitive development in school and out. *Cognition,* 30, 295–300.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.). *Cognitive Structure and Conceptual Change,* (pp. 211–231). New York: Academic Press, Inc.

Suchting, W. A. (1992). Constructivism deconstructed. *Science & Education,* 1, 223–254.

Tasker, R. (1981). Children's views and classroom experiences. *Australian Science Teachers Journal,* 27 (3), 33–37.

Tasker, R., & Osborne, R. (1985). Science teaching and science learning. In R. Osborne & P. Freyberg (Eds.). *Learning in Science: the implications of children's science.* London: Heinemann.

Thiele, R., & Treagust, D. (1992). Using analogies in secondary chemistry teaching. *Australian Science Teachers Journal*, 37, 4–14.

Tobin, K. (1987). The role of wait time in higher cognitive level learning. *Review of Educational Research*, 57, 69–95.

Tobin, K. (1990). Social constructivist perspectives on the reform of science education. *Australian Science Teachers Journal*, 36 (4), 29–35.

Tobin, K. (Ed.). (1993). *The practice of constructivism in science education.* United Kingdom: Lawrence Erlbaum Associates.

Tobin, K., Kahle, J. B., and Fraser, B. J. (Eds.). (1990). *Windows into science classrooms: problems associated with higher-level cognitive learning.* London: The Falmer Press.

Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K. Tobin (Ed.). (1993). *The practice of constructivism in science education* (pp. 3–21). United Kingdom: Lawrence Erlbaum Associates.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, 10 (2), 159–169.

Treagust, D. (1995). Enhancing students' understanding of science using analogies. In B. Hand & V. Prain (Eds.). *Teaching and learning in science: the constructivist classroom.* Australia: Harcourt Brace.

Treagust, D., Duit, R., & Fraser, B. (1996). Research on students' preinstructional conceptions - the driving force for improving teaching and learning in science and mathematics. In D. Treagust, R. Duit, & B. Fraser (Eds.). *Improving teaching and learning in science and mathematics.* New York: Teachers College Press, Columbia University.

von Glasersfeld, E. (1984). An introduction to radical constructivism. In P. Watzlawick (Ed.). The Invented Reality. New York: Norton, pp. 18–40.

von Glasersfeld, E. (1990). An exposition of constructivism: why some like it radical. In R. B. Davis, C. A. Maher, & N. Noddings (Eds.). *Constructivist views on the teaching and learning of mathematics. Journal for Research in Mathematics Education Monograph*, 4, 19–29.

Vygotsky, L. S. (1978). *Mind in Society. The development of higher psychological processes.* In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.). Cambridge, MA: Harvard University Press.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.). *Handbook of research on science teaching and learning*, (pp. 177–210). New York: Macmillan.

Watson, J. M., Campbell, K. J., & Collis, K. F. (1993). Multimodal functioning in understanding fractions. *Journal of Mathematical Behaviour*, 12, 45–62.

Watson, J. M., Collis, K. F., & Campbell, K. J. (1995). Developmental structure in the understanding of common and decimal fractions. *Focus on Learning Problems in Mathematics*, 17 (1), 1–24.

Watson, J. M., & Mulligan, J. (1990). Mapping solutions to an early multiplication word problem. *Mathematics Education Research Journal*, 2 (2), 28–44.

Watt, D., & Russell, T. (1990). *Primary SPACE Research Report on Sound*: Centre for Research in Primary Science and Technology, Liverpool University.

Weber, M. (1949). 'Objectivity' in social science and social policy. In E. A. Shils & H. A. Finch (Eds.). *The methodology of the social sciences.* The Free Press.

Wellington, J. J. (1984). *Sounds, selected topics: Extending science 4.* England: Stanley Thornes Ltd.

White, R. (1994). In P. Fensham, R. Gunstone, & R. White (Eds.). *The content of science. A constructivist approach to its teaching and learning.* London: Falmer Press.

White, R. T., & Gunstone, R. F. (1989). Metalearning and conceptual change. *International Journal of Science Education*, 11, 577–586.

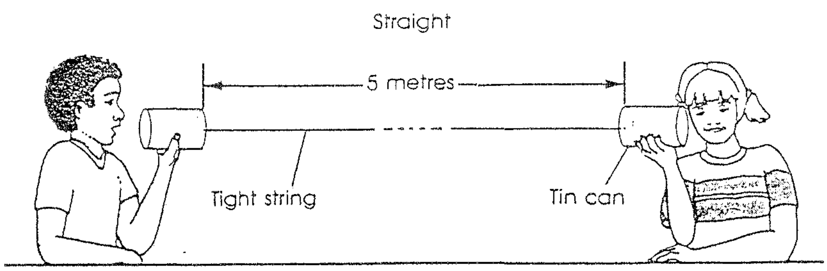
Wilson, J., & Jan, L. W. (1994). Ways of questioning. *Primary Education*, 25 (5), 34–35.

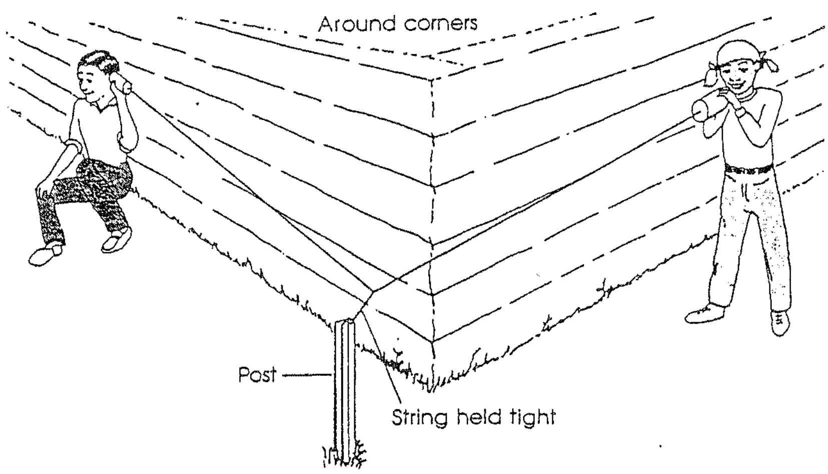
Wittrock, M. C. (1974). Learning as a generative process. *Educational Psychology*, 11, 86–95.

Appendices

Appendix 1 Description of the string telephone

The string telephone is constructed by joining two empty tin cans by a length (approximately 5 metres) of string threaded through a hole in the base of each can. One person speaks into the first can while the other person holds the second can to his/her ear. If the string is kept taut, this device can be used as a 'telephone' in which the sound travels along the string.





Drawings taken from Wellington, J. J. (1984), p. 28.

Appendix 2 The teaching unit on 'light and seeing'

Light and Seeing

The aim of this curriculum module is to create a classroom environment in which the students are more likely to understand the currently accepted scientific view of this topic as a result of interactions mediated through discussion and negotiation with their peers and with the teacher. The teaching strategy involves practical activities and teacher- or student-stimulated discussion designed around a series of questions. The sequence of questions is structured in such a way as to successively introduce and link together elements of the theoretical pathway, the 'Development Map for the Standard Seeing Framework' (abbreviated Development Map for Seeing), proposed by Collis, Jones, Sprod, Watson, and Fraser (1998) for the development of an understanding of 'light and seeing'. The desired outcome is that all students demonstrate a scientific understanding of 'light and seeing' and possess the Standard Seeing Framework (Collis et al., 1998) at the completion of the Teaching Unit.

In the following unit, questions to be investigated by the students are written in Italics, and instructions for the teacher in normal font. Additional information for the teacher is placed in brackets [ ].

The time allowed for the Teaching Unit is approximately four 50-minute lessons.

During the implementation of the unit encourage the students to express their own ideas on 'light' and to make predictions as to what would happen under certain circumstances.

1. <u>Introduction:</u> Orientation Stage

Introduce the topic by asking students to suggest as many words as possible which come to mind when they think of **light** and **seeing**. Write all the words on the whiteboard. Then ask the students to work in groups of four to arrange the words into a **concept map** using the sheets of butchers' paper provided. Put all these maps on display for review and modification if necessary at the conclusion of the topic. You may need to explain what a concept map is.

[Some of the words which students may suggest are discussed here in terms of the Development Map for Seeing. The words 'light', 'sun' (as a source of light), 'eyes', 'pupil' (part of eye) and 'object' are the unistructural elements of the Development Map for Seeing in the Ikonic mode. Other words such as 'reflection', 'image', and 'vision' may indicate a linking together of these unistructural elements and an understanding of 'how the eye sees'. Alternatively, they may simply be terms acquired by the student from external sources. The use of these words, unless linked with others indicating or clarifying their meaning, will not give any indication of whether the students understand the processes of reflection, vision, and image formation. The word 'rays' may imply that light travels, but again the level of understanding cannot be determined.]

The Orientation stage has served to bring to the fore the elements involved in 'seeing'. The following stages should assist the students to develop a clear understanding of 'light and seeing' by progressively linking the elements together.

2. Student Investigations: Elicitation and Restructuring Stage

Ask the students to work in small groups to investigate the following questions which address the basic concepts of light and how we see, and to report back to the class with their findings. Encourage them to make predictions and to put these to the test.

[The sequence of questions is designed to identify the unistructural elements of the Development Map for Seeing, as the concept map has done, and, progressively, to link these elements together.]

Question 1: ***Have you ever been in a place where there is no light at all?***

Do you think that you would be able to see, eg. my diamond ring, this sheet of silver foil, this book, this mirror?

Can you suggest what you would see if you went into the school darkroom?

Shall we try it out?

Divide the students into two groups to investigate the school darkroom. Very few students will have experienced total darkness such as in a cave or a photographic darkroom. This activity is designed to make students aware of the importance of light for seeing.

Place a variety of objects on the bench in the dark room, e.g. diamond ring, sheet of silver foil, book, mirror.

Accompany each group into the dark room and ensure that the room is dark.

Ask the students to stand for a few moments with their eyes shut and then to open their eyes and allow them to become accustomed to the darkness.

Both groups are to report to the rest of the class:

What could you see in the dark room? Was it completely dark?

Yes! Could you still see the objects inside; your own hand?

No! What could you see? f

Was there any light in the room? I so, where was it coming from?

As a result of this activity, the students should conclude that 'light' is necessary for seeing.

<u>Question 2:</u> *How do we see? What do we require to be able to see ?*

[possible responses '**light**' and '**eyes**']

Why can't you see if you shut your eyes?

What if your eyes are open but you are wearing a blindfold?

Can cats see in the dark?

Does eating carrots help us to see in the dark?

How do bats see in a dark cave?

[As the students discuss the first question, it should prompt them to ask some of the other questions. The first two questions address the issue that light must enter the eyes in order to see. The students should discuss the idea that if their eyes are closed, or if they are wearing a blindfold, then light cannot enter their eyes and, as a result, they cannot see. This discussion links together the elements 'light' and 'eye' as designated in the Development Map by L/E.1 'light + eye: we see'. As the students become aware that they are able to see something, that is, an object, they should also link together the notions of 'light' and 'object' as given by L/O.1 'light + object: seeable' and E/O.1 'eye + object: look'. The final conclusion should be that light is required in order to be able to see an object with the eyes. Even cats, which can see at a lower light intensity than humans, are unable to see in total darkness. The questions about carrots and bats are of general interest to the students and not relevant to an understanding of vision, but if they do raise them then they make interesting discussion.]

The next part of the discussion deals with the nature of light and is centred around the following questions:

<u>**Question 3:**</u> ***What is light?***

Where does it come from?

What are its properties?

Ask students for their ideas - write these on the board.

[Students may say that light comes from the sun or from a light globe, that is, it travels from a source to illuminate an object, but they will be less clear about what light is. Some students may say it is brightness but with no understanding of what this means; others may say it is energy; some may even mention wavelengths, although they may not appear to understand the significance of this.]

The students also may not be able to state the properties of light so extend this discussion by posing the questions:

What path does the light follow in coming to us - curved, straight, zig-zag?

Can you suggest how you would test this?

Can you shine a torch beam around a corner?

Divide the students into groups of three or four to investigate the properties of light.

In each case ask the students to suggest how they would do this before you give them any ideas.

[The path of light can be demonstrated using lasers, spotlights, projector beams, torch beams. You could perhaps remind the students of the pin-hole camera (which they may have made in lower grades). Mention sunbeams if the students don't.

Students could also test this using three sheets of cardboard with a single pin-hole the same distance from the bottom in each and a thin torch beam. If the students shine the torch beam through all three holes onto a screen and then run a string line through the holes, the string will be straight].

The students could also try to shine a torch beam around the corner of the doorway from one room to another. This should reinforce the notion that light travels in straight lines.]

[The students should thus have established the Concrete Symbolic notions of the Development Map for Seeing, L/O.2 'light travels to illuminate objects', and L/E.2 'eye and light interact to see', although they may not yet have established the nature of this interaction. Also, they probably will not yet have established the notion E/O.2 'eye-object involves light travel', although they should be aware that 'eye-object involves light']

Once the students have established that seeing an object involves eyes and a source of light, and that light travels to illuminate an object, the class should then move on to consider what is thought to be the most difficult concept to illustrate and the key to many of the students' difficulties with the scientific understanding of 'seeing'.

Pose the question

<u>Question 4:</u> **How do we know whether it is light entering our eyes or our eyes looking at the object?**

Discuss this question with the whole class. Encourage the students to think about the other senses of touch, taste, hearing and smell. Can they see an analogy between the other senses and the eyes. They may find this difficult.

[Each of these senses involves the stimulation of receptors in the particular organ responsible for that sense. By analogy, the receptors for seeing must be within the eyes and are activated by the light entering the eyes and stimulating the receptors at the back of the eye (the retina) which sends a message to the brain.]

[This addresses the notion L/E.2 'eye and light interact to see', and moves further along the pathway of developing understanding to establish the notions L/E.3 'seeing involves light entering the eye', and E/O.3 'light travels from object to eye', and the extension of this notion that light is reflected off the object in order to travel to the eye, the notion L/O.3 'light reflects off objects']

[A number of students may say that it is not necessary to 'look at' the object, the connection E/O.1, that they can see objects out of the corners of their eyes. For these students 'look at' means turning their head and eyes in the direction of the object. Encourage the students to discuss this. It may be necessary to point out to these students that the light still had to come to the eye, even if from the side.]

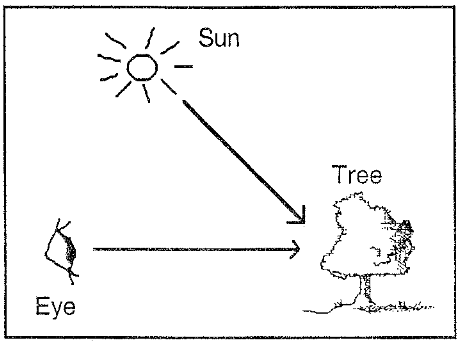
<u>Question 5:</u> ***How does light enable us to see?***

Ask the students, working in groups of three or four, to draw a diagram to illustrate how they believe they can see the book placed on the table in front of them.

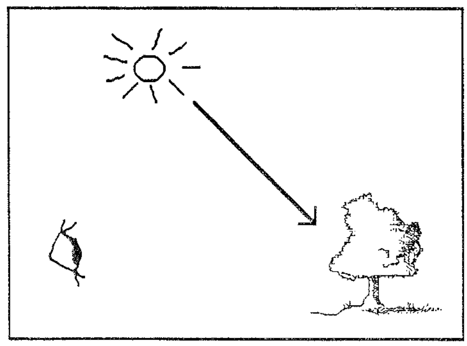
Ask each group to put its diagram on display for discussion, with a spokesperson from each group standing by to answer questions or to explain the ideas of the group.

[It is hoped that in their diagrams the students will have demonstrated an understanding that 'light travels to illuminate objects' (L/O.2) and, more importantly, that 'light reflects off objects' (L/O.3), that 'light travels from object to eye' (E/O.3), and that 'seeing involves light entering the eye' (L/E.3). Once each of these three connections, L/E.3, L/O.3, and E/O.3, have been constructed, then students have acquired the Standard Seeing Framework postulated by Collis et al. (1998)]

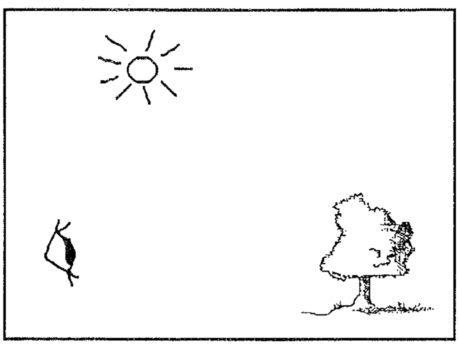
[There are 5 options which have been suggested by researchers as representative of the beliefs of students concerning the role of light in seeing. Diagrams of each of these have been provided. Place on display with the class diagrams any of these which are not mentioned by the class. Encourage the class to consider the evidence for and against each option.]



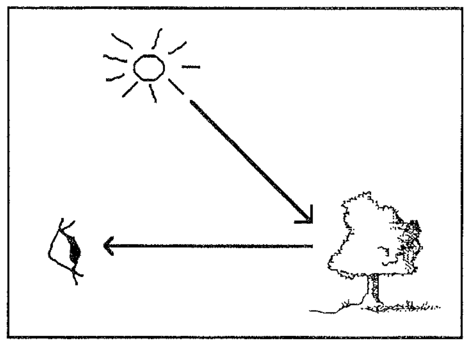
1. Light goes to the tree and
we <u>look</u> at the tree.



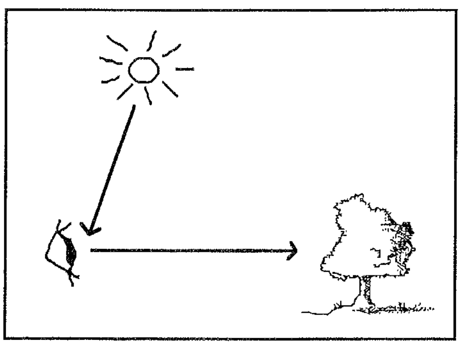
2. Light shines on the tree
and we can see it.



3. Light is everywhere in a well lit area
and we can see the tree.



4. Light goes to the tree and
bounces to our eye.



5. Light comes to the eye and
we <u>look</u> at the tree.

[Thus the sequence of questions, activities, and discussion has 'led' students along the pathway defined in the Development Map for Seeing according to Vygotsky's notion of 'assisted discovery' (see Section 2.2 in Thesis). The elements involved in developing a scientific understanding of 'light and seeing' have been introduced and linked in a hierarchical sequence as the Teaching Unit progressed.]

3. <u>Conclusion:</u> Review Stage

Ask the students to look at the concept maps drawn at the commencement of the unit.

<u>Question 6:</u> ***If we have come to the conclusion that we can only see an object if light reflected from it enters our eyes, then which of the concept maps correctly illustrates how you would see an object?***

Appendix 3 Responses of year 9/95 students to questionnaire on light and seeing at each phase of the investigation

Appendix 3.1 Pre-instruction responses

Student Number	Question Number	Response
2	1	We can see the tree from the other things around it as the tree may be a lighter colour than other things behind it or a darker shade. Also the eyes can see the object it then sends the message to the brain which recognises the object as a tree. The light is on the tree from the sky, which reflects into our eyes. This must be right as, if there was a very dark light on this page I wouldn't be able to see it as there is light on the page I can see it, and the same would apply to a tree.
	2	Seeing Conception selected: 4 1. This is possible but that doesn't explain why we see it only why we look at it. 2. Light would shine on everything then making it unable to difine [sic] the tree from something behind it. 3. no comment. 4. The light must go onto the tree to be able to see it. For example you can't see a tree at night outside when it is dark as there is no light but we can see it if someone was to put a torch light onto it. 5. If this was right we wouldn't be able to see anything if the light is coming into our eyes.
4	1	We can see things with our eyes. In colours, in shades and in this way: Light from the sun, or wherever it gets its source, goes to the object and bounces to our eye. Therefore, we can see the object.

	2	Seeing Conception selected: 4 1. Light isn't just on the tree. Light is also on us and everywhere in a well lit area. 2. no comment. 3. Light needs to have a source, it can't just be everywhere. 4. We can see this because .... [sic]. 5. no comment.
5	1	We can see objects because of the light waves comming [sic] from the sun. The waves hit the object then go into our eyes so we can see its colour.
	2	Seeing Conception selected: 4 1. no comment. 2. This is wrong because light needs to go in our eyes. 3. If no light hits our eyes then we probably won't be able to see it. 4. I think this one is right because the light bounces off object and reflect onto others. 5. This one is wrong because the light hits an object then goes into our eyes.
6	1	We need light to see. Without light we are unable to see any sort of object. That is why we cannot see in the dark. The light reflects off the object and comes to our eyes.
	2	Seeing Conception selected: 4 1. It is allright for the light to go to the tree, but we then need it to reflect off the tree to our eyes, otherwise we cannot see it. We are able to look at something without actually being able to see it which is what would happen here. 2. The same applies to here. If the light doesn't then come to our eyes from the tree, then we cannot see it. 3. If there is light everywhere, then we can see an object but it still means that the light must reflect from an object to our eyes. 4. no comment. 5. no comment.
7	1	Light from the sun is reflected onto the objects which is then reflected to our eyes.

	2	Seeing Conception selected: 4 1. Same as in Q. 2. 2. Because something has to hit our eyes so we know colours, shapes, etc. 3. Same as in Q. 2. 4. Because it is logical. 5. Because our eyes only recieve [sic] light from the sun. We are unable to determine shape, colour, etc.
10	1	The light is, um [sic], put onto the tree and the colour then either reflects some colours such as green and brown and absorbs other colours from the light. The reflecting light then is recieved [sic] by the eye and is reflected on the back of the retina (drawing), upside down. The brain then turns the image around and recieves [sic] it - so we can 'see' a tree.
	2	Seeing Conception selected: 4 1. No, light goes to the tree but the light on the tree is reflected into the eye. 2. No, the eye needs the reflection from the tree to see it. 3. No, because light reflects and the tree absorbs some colours and reflects others to create colours. 4. I believe this is how we see trees because, how else? 5. No, we would be blinded if the light came from the sun to our eye.
11	1	The light rays are reflected by the object according to the type of pigment it has in it. Our eyes receive the light rays and because the pigment will only reflect one perticular [sic] colour we see what colour the object is.
	2	Seeing Conception selected: 4 1. The light must bounce from the tree to our eye for us to see it. If we look at it and no light rays enter our eyes we wouldn't see it. 2. The light must be reflected to our eyes for us to see it. 3. There must be light rays travelling from object to object. 4. I believe this is how you see a tree because that is what I have been taught. 5. If it happened this way we would probably see a tree the colour of our eyes. The rays must be reflected by the tree.
12	1	Light reflects off the object and the reflection travels to our eyes. Sort of like this: [student drawing].

	2	Seeing Conception selected: 4 1. This cannot be true because we need light to be reflected off an object that reflects back to our eyes so we can see. 2. To see, we need light to be reflected on it. At night there is no bright light shining on an object, yet we can still see it. 3. This cannot be true as we need a reflection to see the tree. We can also see objects at night and I don't actually call night 'well-lit'. 4. In order to see, we need light reflected off other objects that reflect back to our eyes. 5. If light came straight to our eyes, we would go blind.
13	1	The suns rays hit an object and reflect to us but upside down. Then something inside our eyes turns it up the right way. If there was no sun we wouldn't be able to see an object.
	2	Seeing Conception selected: 4 1. There is no image for our eyes to pick up because the light is not reflecting/bouncing off the tree. 2. There is no image because the light is not reflecting to our eye. 3. If the light doesn't reflect off the tree the image has no way of getting to our eyes. 4. If the light goes to the tree it picks up the image and it is reflected to our eyes. 5. If the light comes to our eye <u>first</u> there is no image for it to pick up.
14	1	Light is exposed and we then see the object through our eyes. The light travels to our little black dot in the centre of our eye (pupil).
	2	Seeing Conception selected: 5 1. Light does not just go to the tree light is everywhere. 2. no comment. 3. no comment. 4. no comment. 5. Because light first goes to the pupil then we see the tree.
15	1	The sun/light shines on the object and the colour particles in that object give off a certain colour. There is only one colour given off or a mixture of colours. Our eye sees this colour/picture and turns it upside down there [sic] the picture is sent to the brain where in turn the brain says this is a tree (or object).

	2	Seeing Conception selected: 4 1. Light needs to bounce off the colour particles for us to see the tree. 2. The light needs to bounce into our eyes for us to see it. 3. There needs to be lighted colour particles for us to see. 4. no comment. 5. The light needs to bounce off the colour particles of the tree enabling us to see.
16	1	We can see a tree by the light which reflects off it to our eyes. With the green of a tree, we can see the green because the light is full of different colours, when the light hits it, every other colour is absorbed into the tree but green which is the green we can see.
	2	Seeing Conception selected: 4 1. I think this is wrong because the light bounces off the tree and the [sic] to our eyes. 2. The light from the tree needs ..... to bounce off to our eyes before we may see it. 3. If there are no light rayes [sic] directed at the tree we cannot see it. 4. no comment. 5. The light needs to go to the tree first and not to the eye so we can see it.
17	1	Light rays reflect from objects and when they reach our eyes our eyes percieve [sic] the different lights and pigments and transmit a signal to our brain and we see.
	2	Seeing Conception selected: 4 1. This is incorrect because our eyes don't send out or transmit anything as indicated by the arrow in this picture. 2. This picture is incorrect because our eyes cannot see anything just by looking in a certain direction - light rays have to be reflected to our eyes. 3. no comment. 4. no comment. 5. Incorrect because our eyes don't see just by looking. The image has to come to the eyes not vice versa.

18	1	The light rays from the sun bounce of [sic] the object and into your eyes which gives you the image upsidown [sic], then something in your eye turns it the right way up and sends the image to your brain.
	2	Seeing Conception selected: 4 1. We can not see without things being reflected into our eyes. 2. Because light shines everywhere so the tree needs to bounce the light into our eyes to make it visible. 3. There are no light rays reflecting of anything which means nothing stands out. 4. Because the light from the sun reflects off the tree into your eyes, so the sun actually highlights the tree. 5. There is no light on the tree so it would not be visible.
19	1	We look at the object with our eye - and the nerves in our eyes - rectors [sic], respond to the object. Our eye interpets [sic] the colour and shape of object and puts it into porpotion [sic]. Light is shone on the object and reflexes [sic] back into your eye.
	2	Seeing Conception selected: 5 1. The sun is just giving light on the tree, and your eye is seeing it, the rectors [sic] need to reflect but in your eye. 2. If the light is on the tree, and nothing is happening about your eye, nothing reflexting [sic] back in your eye. 3. Light isn't everywhere something has to reflect back in to your eye. 4. Light can't bounce from the tree to our eye your eye has to be looking at the tree in the first place. 5. I think this is a good example because light is coming to your eye and throughfore [sic] you can see the tree because of the light.
20	1	The reason why it is or how we can see any object for example a tree. Nerve endings in our eyes react to our surroundings. The objects we see everyday are not always the same things. The brain sends messages to the nerve endings in the eyes which gives us the information to interpret what each object is. When it is dark it is impossible to see much so we do need light to enable us to see objects.

	2	Seeing Conception selected: 3 1. Light does shine on the tree but even if the light was just shining on the tree you can still see things which are partially in the dark. 2. Light shining on one particular object does not stop us looking at other things surrounding or near the tree. 3. This explains that when you are in a well lit area you basically can see everything if it is dark you can not. 4. The only way light can bounce to a certain place is by a mirror reflection if light bounces to our eye it would impare [sic] our vision. 5. If light shines onto our eye or when it does it affects our eyesight. Our eyesight becomes blurry so this would make it harder to see objects.
21	1	The light goes into the eyes and reflects off something at the back of the eyes. As well, the light aluminates [sic] the object which is being look [sic] at enabling us to see it.
	2	Seeing Conception selected: 5 1. It's wrong because you are still able to see the tree when it's dark. 2. It's wrong because the light has to go into the eye to be able to see. 3. It's wrong because the eye has to have light behind it to be able to see. 4. It's wrong because the light has to go to the eye before coming from the tree. 5. Because the light enables the eye to see the tree and then the brain processes the information.
23	1	The light from the sun or any other source shines onto the object. This reflection is reflected into our eyes, where our brain decides what colour the object is going to be. The colours are displayed in our eyes and this is what we see.

	2	Seeing Conception selected: 4 1. There is not light supply from the sun dirrectly [sic]to the eye, so the tree would not be seen. 2. There is not supply of light from the sun or tree to the eye, so the eye would not see anything. 3. There is no direction of light in this picture. 4. The sun light is reflected from the tree and we see the tree in our eyes. 5. There is no direct light source to the tree, and the light comes from the tree to the eye anyway.
24	1	Light from the sun is reflected off objects to our eyes. This is also how we guage [sic] distance, texture and shape - by the distribution of the light waves that are reflected to our eyes.
	2	Seeing Conception selected: 4 1. I don't think we look at the tree because we don't have a choice as to whether we see things or not. 2. There is no passage of light to the eye. 3. Although light is everywhere, we can still see things in a not so well lit area. 4. Light from the sun reflects off objects to our eyes. 5. I don't think we have a choice as to whether we see things or not, so we can't look at the tree.
25	1	We can see because when light hits an object it bounces off it and the light that bounces off it we see. e.g. in a dark room that has a spotlight on an object our eyes acting like mirrors reflect the picture of that on to the back of our eyes and our optic nerves collect it and our brain interprets it.
	2	Seeing Conception selected: 4 1. This is wrong because what leaves our eyes to see the tree? 2. e.g. in a dark room we can see the bright spot because our eyes have mirrors or something to focus it onto the back of them (our cornea I think) where our brain can interpret it. 3. What happens when you are in a dark room, why can you see something bright? 4. Yes because light all the other ways are unlikely. 5. I know this is not true because when you are on a stage under bright lights you can't see the audience.

27	1	The light from the sun comes into our eyes which enables us to see the tree or any other object.
	2	Seeing Conception selected: 5 1. You need light in your eyes to be able to see an object. 2. Just because light shines on an object, it doesn't mean we will look at it. 3. no comment. 4. no comment. 5. I think this is how you see a tree because you need light in your eyes to actually see an object.
28	1	Light waves that are not absorbed by the tree are reflected of [sic]. Our eye intercepts these reflected light waves and converts the light energy into electrical energy which is then transmitted to the brain through nerves.
	2	Seeing Conception selected: 4 1. Light rays bounce off the tree coming towards the eye. The reflected light does not just stay near the tree. 2. We do not just simply see the tree light waves are reflected off it. 3. Light does not just brighten things so we can see them it is reflected off objects. 4. no comment. 5. We do not see because our eyes are lit but because some light waves are reflected off the tree.
29	1	I'm not sure but perhaps it's because of the light rays that we see. When something blocks the light rays to your vision it becomes a definable shape and colour - or - the light rays bound [sic] off the tree and form a shape.

	2	Seeing Conception selected: 4 1. Looking is an action that is not compulsary [sic]. So if you look at a tree you look at it voluntarily - not because of the sun. 2. If a light shines on something - we can see it better. But in this case it doesn't have much relevance. 3. There are light rays everywhere and there is not enough rays bounding [sic] off to form a shape. 4. The formation of the light rays bouncing off the tree form the shape of the tree. So we see it. 5. I don't think that the light from the sun would cause you to look at a tree.
30	1	Our eyes pick up the shape of the object upsidedown sent back to the eye turned the right way up and sent to the brain.
	2	Seeing Conception selected: 4 1. The reflection of light from the sun on the tree needs to hit our eyes. 2. We need to see the tree more than the light. 3. We need direct light on the tree to see the image properly. 4. Because our eye can pick up objects that are in the sun more easily than at night. 5. The light will stop us seeing the tree because it is in our eyes.
31	1	You look at tree which is reflected in the back of your eye upside down but we see it as the right way.
	2	Seeing Conception selected: 3 1. no comment. 2. If the light shone on the tree would be in shadow. 3. Light needs be everywhere or we couldn't see much. 4. no comment. 5. If the light came to our eye we couldn't see as it would be to [sic] bright.
32	1	We see a tree or any other object with the naked eye. There are special little things at the back of our eyes that make us see things. Then a message goes to the brain to tell us to do something.

	2	Seeing Conception selected: 4 1. I don't believe this because to me it doesn't make sense. 2. But how does light get to our eyes. 3. I can go along with this but I still think No. 4 is correct. 4. We see the tree light bounces to our eyes and we see tree and light. I believe this because I don't believe in any other way. 5. Well if your looking at the tree and light comes to the eye wouldn't light already be at the eye?

Appendix 3.2 Immediate post-instruction responses

Student Number	Question Number	Response
2	1	We can see the tree from the light which is bouncing off the tree into our eyes. The light is coming from the sun. The light which bounces off the tree goes into the pupil of the eye.
	2	Seeing Conception selected: 4 1. Because there is light on the tree we will not look at it. Looking at something is different to seeing it. 2. More needs to happen that [sic] this as there is light on everything. 3. Something needs to pick up your [sic] to see it other wise everything would look alike. 4. The light rays need to bounce into the eye for it to be sent to the back so it can be recognised as being 3Dimensional and an object. 5. Because light goes into your eye it doesn't mean you are going to look at the tree, also with light in your eye you can't see much anyway.
4	1	Light waves from the sun hits an object. The chemicals absorb the lightwaves. The light bounces back to our eye so that we can see an image.

	2	Seeing Conception selected: 4 1. We cannot just look at the tree, we need the light waves to bounce back in order to produce an image. 2. There is no way we can just see it when there is no light coming to our eye. The light must bounce back from the tree. 3. In order for us to see, the light has to hit a tree. In this picture, there is no evidence of the light going to the tree. 4. The light has to hit the tree before we can see it. The light then bounces back to our eye to bring back the image. 5. The light must go to the tree before it comes to our eye.
5	1	When the light rays come down, the light rays reflect off an object and goes into our eyes. To see different colours, the objects absorb certain light rays and the others reflect. When the light goes into our eyes, it triggers off the cones inside the eye. It then goes through the optical nerve which goes into the brain. The brain makes you see the objects and its colours.
	2	Seeing Conception selected: 4 1. We can only see the object if the light comes into our eyes off the object it had reflected from. 2. I think this is wrong because no light rays come into the eye. 3. If not [sic] light hits an objects and no light comes into the eye then we would not be able to see. 4. When the light rays hit the trees, the light is reflected off the tree and goes into the eye, which enables us to see the object. 5. To see an object, the light has to reflect of [sic] an object, not the eye.
6	1	We open our eyes and light shines onto an object which reflects into our eyes and we see the object. We must have light to see!
	2	Seeing Conception selected: 4 1. The light must also come to our eyes. 2. The light must then come to our eyes. 3. In a well lit area we can see the tree, but this diagram doesn't explain how we see it with the light. 4. The light reflects off the tree to our eyes giving us an image, enabling us to see the tree - like a mirror sees an object. 5. Light must also go to the tree if we want to see it.

7	1	With our eyes! - The light shines from the sun or other light source onto all objects - We then look at the objects and the light reflects from them onto our eyes.
	2	Seeing Conception selected: 4 1. Something must come back to our eyes or else we couldn't see it. 2. The light has to reach our eyes. 3. The light has to travel from the sun to object to eye in order so we can see it. 4. Because the light from the tree goes to our eyes enabling us to see the tree. 5. The image of the tree has no way of getting back to our eye.
10	1	We see a tree when light rays from the sun reach the tree and then reflect from the tree to our eyes. To see the colour some light rays are absorbed and some are reflected.
	2	Seeing Conception selected: 4 1. If we look to the image then the light does not go to the brain. 2. Again we need the image to go to our eyes. It is like how a camera works. 3. Light isn't just everywhere. Light travels in rays. If light was everywhere there would be no shadows. 4. It is how a pinhole camera works. The light must go onto the tree and then into the eye, and in the camera to get the image it must be reflected onto the piece of paper or film in the camera. 5. If this happened we would be blinded. The image must come to our eye for us to see it.
11	1	The light rays from the sun hit the tree. Some are absorbed but some (green ones) are reflected back. The ones that are reflected back travel in a straight line. Some will hit your eye. The ones that hit your eye go in through the iris and are turned to electric impulses by rods. The impulses travel along the optic nerve to your brain and you see.

	2	Seeing Conception selected: 4 1. The light from the tree must be reflected to the eye. 2. Light from the tree must be reflected to the eye. 3. Light must travel from the sun to the tree. It then must be reflect [sic] to the eye. 4. no comment. 5. Light comes to the tree and is reflected to our eye.
12	1	We can see trees and other objects due to light. Light coming from a source like the sun reflects off the tree or other object, the reflection of light reflecting to our eyes.
	2	Seeing Conception selected: 4 1. There is no light going to our eyes, the image is therefore not converted into electric impulses so the brain can't tell you what you're seeing. 2. Again, no light reflection so we would not be able to see. 3. No light reflection. In a non-well-lit area, how come we can still see slightly. 4. I believe this is the right one as it is exactly how I explained on the page before. Light reflects from object, reflections go to our eyes, image converted into electric impulses and we see in our brain, the image. 5. If this really happened we'd be blinded. If light came straight to the eye, all we'd see is brightness and nothing else.
13	1	There are light waves from the sun and they hit the tree. Some of the colours are absorbed by the tree, but others are reflected off it. Such as green for example. These rays are bounced off the object into our eyes.
	2	Seeing Conception selected: 4 1. We need sun to come to our eyes as well as the object. 2. No image can be reflected if the suns rays just go to the tree. 3. We need the sun's rays to come to our eye + the object, so the image can be reflected. 4. The image of the tree is reflected into our eyes as the sun's rays hit it and are reflected off. 5. If the tree had eyes it would be able to see an image of us. The sun's rays need to be reflected off the object so an image can be picked up by our eyes!

14	1	Because light goes to the tree and every other object that is around us, and bounces to our eyes, which allows us to see.
	2	Seeing Conception selected: 4 1. It can't both happen at the same time. 2. Light does not just shine on the tree. 3. Light is not everywhere. 4. Light does go to the object before we can see it, and then it does bounce to our eye. 5. Light does not come to the eye and we don't automatically look at the tree.
15	1	Light rays hit an object and the reflected light rays hit our eyes. The reflected light rays go into the eye's nerves system and are then sent to the brain.
	2	Seeing Conception selected: 4 1. The only way we see something is when light rays hit our eyes. 2. no comment. 3. Light travels in straight lines. 4. Because some light rays are reflected off the tree and hit our eyes 5. no comment.
16	1	The light comes from the sun - or other light sorce [sic] such as a light globe - and hits the tree or other object, the light is then reflected to the eye and we can see the tree.
	2	Seeing Conception selected: 4 1. This is wrong because some light reflected from the tree needs to come to our eye before we can see. 2. This is wrong because some light reflected from the tree needs to come to our eye before we can see the tree. 3. This is wrong because light needs to go to the tree thus reflected to our eye. 4. This is correct because the light from the sun is reflected by the tree and so we can see. 5. The light needs to go to the tree FIRST because the light must be reflected from it.

17	1	A light source (eg the sun, a lamp, etc) sends out rays of light. Some of these rays strike the object. Some of the rays are absorbed into the pigments and so the rays that bounce off the object are the correct colour. Some of these rays strike the eye which transmits an electrical signal to the brain which interprets the information recieved [sic] and we see the object.
	2	Seeing Conception selected: 4 1. Wrong because the eye can't just look light rays have to reach the eye after reflecting off the object. 2. Wrong because light rays reflected from the tree must reach the eye. 3. Wrong because it doesn't show that rays reflected from the tree have reached the eye. Also wrong because we can also see in a poorly lit area. 4. This is correct because light rays reach the tree, reflect off it and reach the eye. 5. This is wrong because it looks as if the eye is projecting something towards the tree, whereas actually light bounces off the tree to the eye.
18	1	The rays of light from the sun bounce off the tree and into your eye, the eye then sends messages to the brain which tell the brain what it is that you see.
	2	Seeing Conception selected: 4 1. No light enters the eye so no message is sent to the brain because the eye responds to the light which enters it. 2. Because no light enters the eye for us to see. 3. Because if light is everywhere then you could not see the tree because it would look no different and no message would go to the brain because nothing (light rays) would be bounced into the eye. 4. Because the light is partly absorbed and partly reflected and the bit that is reflected bounces into your eye, which sends messages to the brain about the colour and shape of the tree. 5. Because the tree would not be able to be seen because there would be nothing going into the eye.
19	1	Light is shone on an object and the object is reflexed [sic] into your eye and so then we see the object.

	2	Seeing Conception selected: 4 1. We don't look at the tree the flexation [sic] is bounced into our eyes. 2. If there is only light going to the tree nothing is bouncing to our eye. 3. This is true that we can see things in a well lit area but nothing is bouncing to eye and so no reflexation [sic] is occuring. 4. Because seeing has to occur with light when the object has light on it bounces to our eyes. 5. Light has to come to the object and then bounce eyes so we can see the object. We just don't look at the tree.
20	1	The reason why we can see anything is that light focuses on an object which we then see. The light goes to the tree and the light then bounces off the tree and into our eye the pupil dilates and we see an object. The light is all around yes but in need for us to see it has to focus on a particular object, our eye does not give out anything in aid of us to see.
	2	Seeing Conception selected: 4 1. The diagram is wrong because nothing comes out of our eye to aid us in seeing. 2. We need the light to focus on our eye not just on the object. 3. Light is everywhere yes but when we see something the light has to focus on that object with our eyes. 4. Because this is how we see an object we need the light to focus on one object and the light to see it. 5. Light cannot bounce off our eye to aid us to see object the light needs to be focused on the object first.
21	1	Light from a source, such as the sun, makes an object visible by sending light rays to the object. The object then reflecs [sic] the light rays off its self to the eye.

	2	Seeing Conception selected: 4 1. The light needs to be reflected from the object to the eye. 2. This is wrong because the light is reflected to the eye from the tree. 3. There is no reflection of the light. 4. Because the light rays are being reflected from the tree to the eye. 5. This implies that if the tree had eyes it would be able to see the other eye. The light is going to the eye and reflecting to the tree.
23	1	The light from the sun (rays) go to the object. They then bounce from it back to our eye. Here it goes into and through our eyes.
	2	Seeing Conception selected: 4 1. Nothing comes out of our eye for us to see the image. 2. We still need light and the reflection coming to our eye. 3. The image isn't being sent to our eyes and light travels in waves; not just being everywhere. 4. Our eyes must have the image coming to them, with light, for us to see it. 5. There must be light going to the tree, or we can't see it. Once again, nothing comes from our eye.
24	1	Light from a source, eg the sun, is reflected off objects and into your eyes, where either the rods or cones in your eye are stimulated and transfer messages to the brain via the optic nerve.
	2	Seeing Conception selected: 4 1. No light has entered the eye, and with no light entering the eye nothing is visible. 2. Light has to enter an eye for the receptors to be stimulated. 3. If this were true we would be able to see <u>everything</u>, including things we cannot normally see. 4. Light is reflected off objects to our eyes. 5. Although light goes to the eye, we do not have a choice what we see, so we cannot 'look' at an object.
25	1	The light coming from the sun in this case hits the object and because that object (the tree) is opaque it bounces off. The light that has bounced off the object and reaches our eye goes through the pupil.

	2	Seeing Conception selected: 4 1. How are we supposed to 'look' at the tree? What gives the message that our nerves interpret and give the brain? 2. What gives us the message? Some intangible force we don't know about? How do we see it? 3. If that is so why in a dark room where something is spotlighted can we see it even though we're in the dark? 4. That's better. As I said before, something has to come to the eye off the object so the nerves at the back of our eye can recieve [sic] it. This something must be light as there is nothing else. 5. If this is true why, when we are under the spotlight in a darkened room can we not see around us?
27	1	The light goes onto the object that we see and the object is then reflected into our eyes.
	2	Seeing Conception selected: 4 1. The light is reflected. We don't just look at an object and see it. 2. The light just doesn't shine on the tree. It shines everywhere. The object is reflected into our eyes by the light. 3. Objects are reflected into our eyes by light. 4. Because objects are reflected into our eyes by the light. 5.Because the light that is comming [sic] into our eyes isn't reflecting any object. The light has to be on the object first.
28	1	Light rays from the sun are reflected off the tree in all directions, some of these rays hit our eye. The receptors in the back of the eye are activated by the light rays and they send out an electrical signal to the brain which then changes the electrical pulses back into an image.
	2	Seeing Conception selected: 4 1. We do not look at the tree. The light rays are reflected to our eyes. 2. You do not just see the tree because it is lighted. 3. You do not see because it is light but rather because of specific light rays. 4. Light rays are reflected off the tree and some of these hit the eye. 5. The light rays do not light your eyes so you can see the tree but rather reflect off the tree.

29	1	We can see something due to light rays from a light source (in this case the sun). These go through the air and when they hit an object they are reflected to our eyes so that we can see them. There are many light rays that hit this tree or go straight past but due to the reflection we can make out the shape.
	2	Seeing Conception selected: 4 1. We can't do this as there is no indication of where we should look. 2. It's really the same as drawing 1 except that we're 'seeing' not 'looking'. 3. There are no light rays being reflected to the eye - the eye wouldn't be able to make out the tree. 4. The light rays reflect off the tree and go to our eyes so that we can see. 5. This is the wrong way round. The light ray cannot be reflected off the eye to the tree. In this case it would be thought that the eye would be blinded.
30	1	Light from the sun shines on and around an object and our eyes see the object and the image is sent to the back of our eye.
	2	Seeing Conception selected: 4 1. The sun needs to reflect off the object to our eye to see. 2. Needs to be light coming from the tree as well. 3. Sun needs to directly hit the tree. 4. Because the sun is needed to reflect onto the tree and then to our eye to see it. 5. There needs to be light on the tree and reflecting off the tree for us to see it.
31	1	The light is all around and on the tree then we see the tree and that then is shown on the retina and transported to the brain.
	2	Seeing Conception selected: 4 1. We don't <u>look</u> at things we <u>see</u> them. 2. Light needs to be near our eyes otherwise we can't see properly. 3. The light is everwhere but the tree. 4. The tree is bounced back to our eye by the light because of the reflections. 5. The light needs to be also on the tree so we can see properly.

32	1	We can see other objects because light rays land on the objects that our eyes focus on. We can only see objects in a well lit area otherwise we wouldn't be able to see properly.
	2	Seeing Conception selected: 3 1. This is impossible light does not shine on the tree and then into our eyes. 2. Light (daylight) is everywhere for us to see and focus on objects. Light doesn't shine on a tree and we only look at things with light on them. 3. To see something eg a tree it would have to be in a well light area for the eyes to focus. 4. This is basically saying the same thing the other 3 pictures show. 5. Same thing again light doesn't come to the eye and then we look at the tree.

Appendix 3.3 Delayed post-instruction responses

Student Number	Question Number	Response
2	1	We are able to see any object by light reflecting off it into our eyes. The object that is seen is then transmitted to the brain. If there is no light we are unable to see.
	2	Seeing Conception selected: 4 1. Because the light is on the tree it doesn't mean we will <u>look</u> at it and see it. 2. no comment. 3. If the same amount of light was everywhere then wouldn't be able to pick up different objects in what we see. 4. Light must reflect off the object into the eye to be able to see it so it can be sent to the brain and identified. 5. If the light came straight to our eyes we would be unable to see anything in front of us.

4	1	The objects ultra rays bounce out and into our eye. This is how we know its colour. The image passes through the retina and into our brain where it is distinguished and we know what it is ie. Light goes to the object and bounces to our eye and we can see the image.
	2	Seeing Conception selected: 4 1. Our eye is not getting any ultra rays bouncing back, so we can see the object. 2. The light must then bounce to our eye, before we see it. 3. Light travels to the object and absorbs in it, so it can bounce back to our eye so we can see it. 4. Because the light has to go to the object, so as we can see it, because if the light went to our eye first, we wouldn't get the ultra-rays that are coming from the object in order for us to see. 5. Light must go to the tree ifrst. The light must bounce off the tree and then to our eye, in order for us to capture the picture.
5	1	The light rays come from the sun and hits the objects and then the light reflects into our eyes. When the light hits the objects, they absorb certain light rays while the others reflect off, and it shows the colour of the object.
	2	Seeing Conception selected: 4 1. I think this is wrong because the light does not go to the tree as soon as we look there unless light is reflected from the tree into our eyes. 2. If light shines on something, but the light does not come to our eyes, then we would not be able to see the objects. 3. When light shines everywhere, it has light rays moving around everywhere, we see the objects when the rays enter our eyes. 4. When the light rays hit the tree, it reflects off and enters our eyes, then messages are sent to the brain so we can see it. 5. If light just comes to our eyes and does not reflect off the tree then we would not be able to see it.
6	1	With our eyes and LIGHT. We cannot see an object if there is no light. Light travels to the tree where it is reflected (bounces off the tree) to our eyes enabling us to see it.

	2	Seeing Conception selected: 4 1. This doesn't explain anything. The light does go to the tree to enable us to see it, but the light must also travel to our eyes. 2. This is correct, but it doesn't explain how we see the tree. Like the first picture, it doesn't just happen. 3. If light is everywhere then we can see objects, but once again this picture doesn't explain how we see it. 4. We need light to be able to see & the light goes to the tree where it then travels to our eyes and we are able to see the image. 5. We cannot see an object if there is no light on it.
7	1	We can see the tree or any other object because of light. We need light to penetrate our eyes and therefore allow us to see. The light must hit the tree and depending on the amount of light absorbed will vary the colour we see.
	2	Seeing Conception selected: 4 1. no comment. 2. no comment. 3. no comment. 4. Because the light is reflected. 5. no comment.
10	1	We see the tree when light strikes the tree and then reflects into our eye.
	2	Seeing Conception selected: 4 1. How do we look at the tree? answer - we don't the light reflects to our eye. 2. No, we must have some light reflecting off the tree into our eye to see it. If no light reflects where does it go? 3. No, light must travel to the tree and then be reflected into the eye. 4. Because 1. we have been taught this and 2. the other ways are stupid. 5. If this happened we would go blind as too much light would be in the eye.
11	1	Light rays from the sun are reflected or absorbed by the tree. The ones reflected by the tree travel to our eyes.

	2	Seeing Conception selected: 4 1. The light rays must come to our eyes. 2. The light rays must travel to the eye. 3. Light isn't everwhere. It travels in rays which are reflected by the tree to our eye. 4. This is what I've been told is how we see. 5. Light must first go to the tree and be reflected to our eyes. Otherwise we couldn't see it.
12	1	We can see because the light from the sun shines upon an object such as a tree and the light is bounced off or reflected back to our eyes.
	2	Seeing Conception selected: 4 1. This is wrong because even though there is a little light in dark places, we still look at them. 2. To see anything we need light, just like a camera. 3. Again, the light must be reflected from the object to our eyes. 4. As I said on the previous page, light needs to be reflected from an object to our eyes in order for our eyes to send messages to our brain to register what we're seeing. 5. If light went to the eye, we would be blinded.
13	1	The light from the sun hits the object and reflects into our eyes.
	2	Seeing Conception selected: 4 1. There is no image being projected into our eyes <u>FROM</u> the tree, so we can't see it. 2. Once again, there is no image reflecting into our eyes. 3. The sun's light is not going to the tree or our eye. 4. The light goes from the tree, hits it, bounces back into our eyes and we see it. 5. If the tree had eyes it would see a person, but it doesn't!! No image <u>from</u> the tree to us.
14	1	We can see trees and other objects by the tiny pupil in our eyes. The light hits our pupil, which then allows us to see.

	2	Seeing Conception selected: 5 1. Light is not like a spotlight and shine on one object, light is everywhere. 2. no comment. 3. Just because there is light everywhere, it doesn't mean that we are able to see it. 4. no comment. 5. no comment.
15	1	Light is radiated out by the sun in light rays. They hit the tree and the light is reflected off the tree in straight lines. Some of these rays may hit our eye and enter it.
	2	Seeing Conception selected: 4 1. Light needs to be reflected off an object for us to see it. 2. Light needs to be reflected off an object for us to see it. 3. Light travels in straight rays. 4. Light bounces off an object absorbing colour shade and shape. As these rays hit our eye the retna [sic] and brain distinguishes what the object is. 5. Light needs to be reflected off an object for us to see it.
16	1	The light from the sun shines on the tree and reflects to our eyes and our eyes see it.
	2	Seeing Conception selected: 4 1. Because no light reflects to the actual eye. 2. No light goes off the tree and into the eye. 3. There is no reflection occuring [sic]. 4. The reflection of the light bouncing off the tree enables us to see it. 5. There is no light shining onto the actual tree, therefore we cannot see it.
17	1	We see because light, (which must be present in order for us to see) travelling as light rays, strikes objects, such as a tree, and reflects off the objects. Some of these reflected rays can strike our eyes and from there the optic nerves relay a message to the brain and the vision is interpreted.

	2	Seeing Conception selected: 4 1. This is wrong because we can't see unless reflected light from the tree 'bounces' to our eyes. 2. This is wrong because reflected light from the tree must strike our eyes in order for us to see. 3. Wrong because rays need to strike the tree and reflect to our eyes. 4. Right because the light rays do strike the tree and some reflected rays are 'bounced' to the eye. 5. This is wrong because our eyes do not project any thing, they just receive reflected light from the tree.
18	1	Light from the sun bounces off the object & back into your eyes. This enables you to see things.
	2	Seeing Conception selected: 4 1. Because our eyes do not project light or have magic powers. We need a reflection of light to enable us to see an object. 2. Because it doesn't work like that. 3. Because if light does not bounce off things then you would see the air as well as the tree & the sun. 4. Because that is what the teacher told us in class. 5. If there is no light going to the tree then the pigment does not reflect it so we could not see it.
19	1	Light shines on an object and it is reflected back into our eyes.
	2	Seeing Conception selected: 4 1. In this picture nothing is bouncing off the tree into our eye so how can we see the object. 2. In this picture nothing is reflectioning [sic] into the eye light is just on the tree, therefore nothing is happening. 3. No, because nothing is reflecting back into our eye and no light is shining onto the tree. 4. This is correct because light is shinning [sic] on the tree and this is bounced to our eye. 5. Light is not coming to the object that we are looking at so nothing is happening light has to be on the tree for us to look at it.
20	1	How we can see a tree or any other object is that our pupils in our eyes respond to light. Without light our pupils become very small and if not pitch black dark we can see some things.

	2	Seeing Conception selected: 4 1. Light has to been [sic] available to our eyes it does not just shine on the object. 2. Light needs to shine on our eye. 3. Light is not really everywhere and with our eyes they do not always see in a well lit room. 4. This is the correct one because the light is concentrated on the object but also on the eye. 5. Light doesn't just have to be on our eye it needs to be concentrated on our eye but also on the area.
21	1	Light enters the eye and the image we look at is sent to the brain.
	2	Seeing Conception selected: 5 1. There is no light going to the eye. 2. There is no light going to the eye. 3. There is no light going to the eye. 4. Light must go to the eye before seeing the tree ie the light doesn't come from the tree. 5. This is right because the light goes to the eye and then we look at something.
23	1	The image is directed to our eyes by light rays. It is received by our eyes. It is by light that we see anything. Light bounces from the object to our eye. Light bounces from an object and transports that image to our eye.
	2	Seeing Conception selected: 4 1. Nothing comes out of the eye. We don't 'look' the image comes to our eye by light. 2. We need the image to be reflected into our eye. 3. This does not explain how an image can actually be picked up by the eye. 4. This makes sense as light bounces from the tree & holds the image then is reflected to our eye. 5. There needs to be light on the tree. The image must come to the eye. Nothing comes out of the eye that allows us to see.
24	1	Light goes from the sun to any object and is reflected off that object. Some of these reflected rays hit our eyes and so we can see that object.

	2	Seeing Conception selected: 4 1. We can't actually choose to look at the tree, and I don't think our eyes can emit something to gather the necessary information to see the tree! 2. There is nothing to show how the information (the rays) are getting to our eyes. 3. If this were the case, we would be able to see everything, even things hidden by something else. 4. This pattern of light rays is necessary. Light reflects off the tree so we can see it from a certain angle. When we move our heads our eyes pick up diferent rays reflected off the same object and we see the object from a different angle. 5. How do we gather the necessary information to tell our brains there is a tree there? There is nothing going from the tree to the eye.
25	1	The light from the sun or any other source hits the object in question, bounces off it and straight away in any direction. The photons that come off the tree in our direction pass through the front part of our eyes.
	2	Seeing Conception selected: 4 1. How do we look at a tree? What travels been [sic] the tree and us, some sort of mental energy? 2. How do we see things if there is a completely empty gap, a vacuum without light energy in it between two things. 3. Why then can you see something under a spotlight when you are in complete darkness? 4. Because something has to give our brain the impression of the tree. None of the other drawings show this. 5. Same as no.3. How, if you are in a darkened room and not under the spotlight, can you see the object?
27	1	We can see a tree or any other object because light goes to any object and bounces, or reflects into the eye when we look at the object.

	2	Seeing Conception selected: 4 1. If no light goes to the tree, that means that we would be unable to see it. At night you can see trees quite easily. 2. You have to look at the object. You don't just automatically see it. 3. This is wrong because the light needs to be reflected into the eye. 4. Because if you look at an object the colour is being reflected into the eye. If you close your eye, you are unable to see the object because there is something blocking the light. 5.There is no light to reflect off the tree in the first place. The object needs to be reflected to see it.
28	1	Light beams/rays hit the tree some are absorbed and some are reflected off in all directions. Some of these reflected rays hit our eye.
	2	Seeing Conception selected: 4 1. The light rays are reflected off the tree towards our eyes we do not simply see it. 2. We do not just simply see it. 3. Light is not everywhere. 4. no comment. 5. We see reflected light from the tree. All the light hitting our eyes does is allow others to see their colour.
29	1	We can see a tree by light rays hitting an object and coming to our eyes.
	2	Seeing Conception selected: 4 1. I don't think this is right as - I'm not sure about this, but perhaps the eye would not be aware of the object unless some light had been deflected. 2. You need some flow of current back and forth. There's no movement of rays here to the eye. 3. There's no shown movement of the rays here so it cannot be assumed if the eye can see or not. 4. The sun gives out light rays which are deflected in all directions by an object and some hit our eye enabling us to see the object. 5. This can not be so as light shining in our eyes does not mean we decide to look at something.

30	1	Light is reflected on every object in the picture. Our eyes pick up those objects when we look at them. They are sent back into our eyes.
	2	Seeing Conception selected: 1 1. Because you need light to see things clearly. 2. You need to be looking at the tree to see it. 3. The rays need to be going onto the tree to see them. We also must be looking at the tree to see it. 4. We have to look at the tree to see it. 5. The light needs to be on the tree not in our eyes.
31	1	We look at an object and it is reflected back onto our eyes so then we can recognise and identify the object.
	2	Seeing Conception selected: 4 1. We can look at it but don't necessarily see it. 2. Light would be too much in your eye. 3. It doesn't have to be light everywhere eg if a lit room, dark outside, you can see in. 4. no comment. 5. As for Q.1 and 2.
32	1	no response.
	2	Seeing Conception selected: 5 1. This is wrong because if light goes to tree and we look at, that means that it would be not so light around the area of tree. 2. This is nearly the same as No.1. If there was no sun we wouldn't see as well, but we can. 3. Light can't be in a well light [sic] area because otherwise we wouldn't be able to see in not so well lit areas. 4. no comment. 5. I believe that this is how you see a tree because light is everywhere but light needs to be on the tree so that we can see it.

Appendix 4 Responses of year 9/96 students to questionnaire on light and seeing at each phase of the investigation

Appendix 4.1 Pre-instruction responses

Student Number	Question Number	Response
2	1	We can see a tree or any other object because the light and colours of the tree are reflected back to our eyes which are convect [sic]. The convect [sic] lens then directs the light rays to our focus [sic].
	2	Seeing Conception selected: 4 1. no comment. 2. no comment. 3. no comment. 4. Light hits the tree and is reflected back to our eye, through the convect [sic] lens which directs the rays to the focus. 5. no comment.
3	1	Light from a source reflects off an object. The reflected light travels through the air and enters our eyes. The image is received at the back of the eye.
	2	Seeing Conception selected: 4 1. Light must enter our eye for us to be able to see something. 2. Light must enter our own eyes for us to be able to see something. 3. Light must be reflected off something for us to be able to see it. 4. Light from the sun is reflected off the tree. The reflected light enters our eyes. 5. In this picture there is no light being reflected from the tree.
4	1	We can see objects because of light. The light reflected off an object enters the eye, bounces off the back and then back out again. Different lights reflect different colours and objects.

	2	Seeing Conception selected: 4 1. Without the light going into our eyes we cannot see anything. 2. The light rays go towards the tree but there isn't an arrow showing the light going towards the eye. 3. There are no arrows to indicate where the light is going. 4. The sun produces light which then goes towards the tree and then the light is reflected into our eyes. 5. If the sun goes directly towards the eye, it would therefore be too bright for us to see anything.
5	1	We see when light is shone onto an object, the light then reflects back to our eyes and into our irises.
	2	Seeing Conception selected: 4 1. We don't look at the tree, the image is reflected into our eyes. 2. Light needs to reflect off the tree. 3. no comment. 4. Because the light reflects off the tree. 5. It is the other way round.
6	1	We can see a tree or any other object because when the light is everywhere our eyes are able to focus on images.
	2	Seeing Conception selected: 2 1. I think this could almost be correct as we do look at the tree. 2. I think this way the light shines on a tree, therefore we are able to focus on a lit image. 3. If light is everywhere, then no certain areas are highlighted. 4. Light doesn't reflect off trees! 5. The light wouldn't travel from our eye to the tree.
7	1	The image we see is firstly picked up by our eyes and then is reversed upside down by our eyes.
	2	Seeing Conception selected: 1 1. Everything must have light to be seen and when the sun strikes the tree, it shows its colours and you see it. 2. You have to look at something to see it. 3. Light isn't everywhere because otherwise there wouldn't be shadows. 4. Light doesn't bounce around, otherwise we would see very strangely. 5. The eye doesn't need much light to operate but the tree has to have light around to be seen.

8	1	We can see a tree or any other object as long as there is light - any amount of light. If it is too bright we cannot see and if there is no light we cannot see. The light reflects off the object we are looking [sic] and into the eye.
	2	Seeing Conception selected: 4 1. This is incorrect because the light needs to enter our eye not just the image. 2. This is incorrect because the light does not have to be on an object to see it the light has to reflect into the eye. 3. Once again this is incorrect because the light is shining all around us but not reflecting into the eye. 4. This is correct because the light is hitting the object and reflecting the image into our eyes and our eyes send a message to the brain to identify the object. 5. This is incorrect because if the light comes to the eye thats all we will see. The light needs to be shining on the object and reflecting back to us.
9	1	The light enters our eye and then we look at the tree. We are able to see the tree because the light bounces off the tree as well, and then it enters our eye upside-down.
	2	Seeing Conception selected: 4 1. This is wrong because the light has to bounce off the tree before we see it. 2. Same as Q.1. 3. Same as Q.1. 4. The light bounces off the tree and into our eye so that we can see the tree. 5. The light enters the eye and bounces off the back of it and to the tree, but it doesn't bounce back and so we can't see it.
11	1	Light rays from the tree go through your eye and the picture is turned upside down.When the picture reaches your brain it is turned back up the right way and you see the picture as it is.

	2	Seeing Conception selected: 4 1. You don't look at something when light shines on it. 2. There is no way that the brain can determine the shape of the object because there is nothing going towards the eye. 3. There are no rays going to the eye so that the brain can see the object. 4. Light rays bounce off a solid object so when we look at something the rays bounce off the tree to our eye. 5. There may not be any light around the tree so if this diagram was true you would be able to see air as well as the tree.
12	1	We can see a tree or any other object by the light from the sun shining on the tree or object and being bounced off to our eyes. Therefore we can see. Therefore if there was no light we would not be able to see any thing. So we need light in order for us to see.
	2	Seeing Conception selected: 4 1. I think this is wrong because we don't just look at a tree we need light to help us see it. 2. I think this is wrong as the light is only on the tree and it is not reflected back to the person's eye. 3. I think this is wrong because the light needs to come to our eyes from the tree in order for us to see. 4. I think this is correct because the rays of the sun hit the tree and are reflected to our eye. Thus causing us to see. 5. I think this is wrong because the light needs to be also focusing on the tree.

Appendix 4.2 Immediate post-instruction responses

Student Number	Question Number	Response
2	1	We can see a tree or any other object because the light rays from the sun hit the tree and are reflected back to our eyes through our convex lens that then converge to our focal point.

	2	Seeing Conception selected: 4 1. no comment. 2. no comment. 3. no comment. 4. Go to front page! 5. no comment.
3	1	Light from the sun strikes the tree (or other object). The light is then reflected and some of it enters our eye.
	2	Seeing Conception selected: 4 1. We don't look at something. Light enters eye from object. 2. Light must travel from the tree to the eye. 3. Light from the sun is reflected off many things but it must enter our eye to 'see'. 4. no comment. 5. Light enters the eye from the object we 'see'.
4	1	The light rays are focused on an object eg a tree. The rays are then absorbed towards the eye and then met [sic] the lens
	2	Seeing Conception selected: 4 1. There is no light ray directed to the eye. The eye does not produce light. 2. There isn't a light ray going towards the eye. 3. There are no light rays provided. 4. The rays go to the tree, from the tree in towards the eye. 5. The light rays are going towards the eye first and then the tree. It should be the other way round.
5	1	We can see objects because light from the sun reflects off them and reaches our eyes. Light rays go in through the iris.
	2	Seeing Conception selected: 4 1. Because the light rays need to reach our eyes for us to see. 2. Because light rays need to hit our eyes for us to see. 3. But specific rays hit the tree and are reflected. 4. Because the light hits the tree and travels towards our eye. 5. Because the light has got to be reflected by the tree not our eye.
6	1	The light travels to our eyes and our eyes see an image.

	2	Seeing Conception selected: 3 1. There still needs to be light coming to the eye and the eye could look but it may not see anything without light. 2. Light also needs to come to the eye to enable us to focus. 3. Because the light is everywhere there is light coming to both eye and tree enabling us to focus on the tree. 4. Light does not reflect off trees. 5. This would probably hurt the eye not allow it to see the tree.
7	1	The sun radiates rays which hit objects which filter out all colours but what they are. Light rays then enter our eyes.
	2	Seeing Conception selected: 2 1. This could be true but it doesn't describe the process quite right. 2. Because in the absence of light, there is darkness and you cannot see. Therefore if there is light shining on the tree, you can see it. 3. This can't be right because there is no direction of rays in the diagram. 4. I don't know if light rays do bounce except off of [sic] mirrors. 5. This could also be true because if no light came to the eye it would be shrouded in darkness and unable to see.
8	1	We can see a tree or any other object as long as there is light. If there is no light we can't see anything. To be able to see an object the light shines on the tree and reflects an image to our eye.
	2	Seeing Conception selected: 4 1. We cannot look at the tree if no reflection is coming off it. 2. Can't see it unless light reflects off it. 3. no comment. 4. This enables us to see by reflecting an image into the eye for the brain to interpret. 5. If the light were to come to our eye first we wouldn't be able to see, because the light would blind us.
9	1	Light rays from the sun hit the object (in this case a tree) and reflect into our eyes.

	2	Seeing Conception selected: 4 1. No light or reflection is coming to our eye, the arrow should go from the tree to the eye (not vice versa) 2. No light is entering the eye or bouncing off the tree. 3. There is no reflection of light to the tree and then into the eye. 4. Light hits the tree and then bounces off into our eye. 5. There is no light hitting the tree or reflecting off the tree.
11	1	Light rays from the sun are reflected onto the object and out into the eye of a person.
	2	Seeing Conception selected: 4 1. The image has no way of getting to the eye. 2. The eye is not able to see the image because there are no light rays going into the eye. 3. The eye is unable to see the image because no light rays are going to the tree or the eye. 4. The sun's light rays go to the tree and pick up an image which is then reflected into the eye. 5. In this diagram if the tree had eyes it would be seeing the image of the eye.
12	1	We can see a tree as light rays go to the tree then the light reflects the image into the retina of the eye.
	2	Seeing Conception selected: 4 1. This is incorrect as the sun does hit the tree, however, nobody could see it as the light is not being reflected off it to the eye. 2. This is wrong as there is no light being reflected from the tree to the eye. 3. This is wrong as the light rays have to hit an object and be reflected to an eye otherwise nothing can be seen. 4. I think this is correct as the light is reflected off the tree into the retina of the eye. 5. This wrong as the sun is going to the eye and there is no reflection off the tree to the eye.

Appendix 4.3 Delayed Post-Instruction Responses

Student Number	Question Number	Response
2	1	We can see a tree or any other object because the sun or any other form of light hits the tree which makes it visible. The light from the tree is then reflected back to our eyes enabling us to see the tree.
	2	Seeing Conception selected: 4 1. You cannot see the tree because you look at it. We can still see objects even if we don't look at them. 2. The light rays need to travel to the eye to be able to see the tree. 3. We would not be able to see the tree because the light needs to be reflected from the tree into our eyes. 4. The light goes to the tree and is reflected to our eye and an image is formed. 5. If the light comes to our eye, then the tree would be in darkness and no reflection produced therefore tree not visible.
3	1	Light from the sun travels in rays and some of these strike the tree. They are reflected in all directions and some of them travel to the people. The light rays are received in the eye and an image is formed.
	2	Seeing Conception selected: 4 1. Light travels from the tree to the eye. 2. Light must travel to our eye. 3. Light travels to the tree and is reflected. 4. Light travels in rays to the tree. It must then be reflected so that it can enter the eye. 5. We receive images from an object. Light must travel to it and be reflected to us.
4	1	We can see an object because the light rays from the sun go towards the object. These light rays bounce off the object in all different directions. Thousands of these light rays enter the eyes of people. These rays are reflected onto the retina and an image is fromed.

	2	Seeing Conception selected: 4 1. Light rays aren't produced from the eye. 2. No arrow showing rays towards the eye. 3. No arrows showing light rays. 4. It shows the lines of light rays and they are going in the right direction. 5. It would be too painful for light to go straight into the eye. It would be so blinding that you wouldn't see a thing.
5	1	Light rays strike the tree and some are absorbed but the green and brown colours are rebounded and travel to our eyes and onto the retina.
	2	Seeing Conception selected: 4 1. To look at the tree the light needs to bounce off the tree to our eye. 2. Light must also go from the tree to our eye for us to see. 3. no comment. 4. no comment. 5. The light must go to the tree not our eye for us to see.
6	1	The light from the sun comes into our eyes and the light creates an image of the tree on the retina.
	2	Seeing Conception selected: 5 1. Light wouldn't reflect off the tree, so we couldn't see it. 2. Light needs to be reflected into our eyes to enable us to see an object. 3. Light needs to be directly reflected in one place. 4. Light won't reflect off a tree. 5. Light must come into our eye, to enable us to see an object.
7	1	Light travels from the light source to the tree which screens out all colours that aren't involved in the appearance of the tree. These (green) light rays travel to the eye.

	2	Seeing Conception selected: 4 1. This isn't right because you can see even when you don't consciously look at anything in particular. 2. This could be right because you couldn't see the tree if light didn't shine on it. 3. Even if light isn't everywhere, you can still se where the light is. 4. This I think is the most right because it makes the most sense. 5. This is the wrong order.
8	1	We are only able to see if there is light. Light reflects off the object we are looking at and into the area at the back of our eye.
	2	Seeing Conception selected: 4 1. The light has to come from the tree to our eyes. We don't just look at the tree and see it. 2. Light may shine on the tree but we have to look to see it. A reflection travels off the tree into our eyes. 3. Once again light has to be reflected off the object for our eyes to see it. 4. The light is reflected off the tree and into our eyewhere the brain interprets it and turns the image up the right way. 5. If light came to the eye we would be unable to see as the light would blind us.
9	1	The light rays from the sun hit the tree and then reflect off the tree into the eye.
	2	Seeing Conception selected: 4 1. Light must enter the eye so we can see. 2. Light must go into the eye for us to see. 3. The light must reflect from the tree into the eye. 4. The light rays hit the tree and then reflect into your eye and travel to the brain via the optic nerve. 5. Light must reflect off the tree for us to see.
11	1	Light rays from the sun go to the tree.The light rays bounce off the tree and go into our eye as an upside down picture.

	2	Seeing Conception selected: 4 1. This would be the same as looking at a tree in darkness. You cannot see it. 2. There are no light rays going to the eye enabling us to see the tree. 3. There are no light rays going to the tree or to the eye. 4. The light rays pick up the image of the tree and then go through our eye to the brain. 5. This is not possible becasuse there is no light going to the tree enabling us to see it.
12	1	The light rays from the sun shine on everything including the tree. The light rays on the tree reflects to our eyes and then we can see the tree as the light is reflecting off it.
	2	Seeing Conception selected: 4 1. This is not correct as the light has to come from the tree to our eyes to enable us to see it. 2. You can not just see a tree if the sun is on it, the rays of light have to come from the tree to the eye. 3. This is not true as the rays of the sun have to reach the tree and the tree has to reflect those rays to our eyes. 4. This is correct as the tree reflects the rays to our eyes so we can see. 5. This is not true, light can not just come to your eyes. The light rays come from the tree to the eye.

Appendix 5 Transcript of interview with year 4 students on sound and hearing

Question: *The topic I want to talk to you about is 'sound' and how you think you hear things.*

If I say to you "What is sound or What do you think of when I mention the word 'sound'. Think about it, what does it bring into your mind when I talk about 'sound?"

Responses: noise vibration sound waves music sound animal sound strong wind bird sounds computer games tree outside the window television noises waterfall coffee blender (grinder) cochlea, nerves (in your ear) building noises traffic jams wind chimes cuckoo and grandfather clock hail CD player shuffling echo (when my dog barks it echos) clock ticking laughing washing machine fire alarm dogs barking thunderstorms lightening pencil (squeaking when you write) scraping fingernails on board duck quacking talking shouting tummy rumbling pages of a book blowing in the wind machinery in a factory dishwasher

Question: *How do you hear?*

Responses: with your ears eardrum (in your ear)

sound waves enter ear and go to the little bones in the ear and then carry up to the cochlea and set hairs in the cochlea moving - if you listen to loud noise the hairs break and if you loose all the hairs you'll be deaf

Question: *How does the sound get to your ears?*

Response: Travels from where the sound comes from (source) to your ears

Question: *Do you know how it travels?*

Response: In sound waves

Question: *OK then do you know how those sound waves get there?*

Response: They travel through the air

The speed is about 2000 km/s

Question: *Can you hear under water?*

Response: Yes, but sounds different, sort of squeaky

Can't hear very well

Question: *Some animals communicate under water by squeaks. Have you heard of this? Do you know any animals that do this?*

Response: Yes

Dolphins, whales

Question: *If these animals are communicating under water, what is between them?*

Response: Water

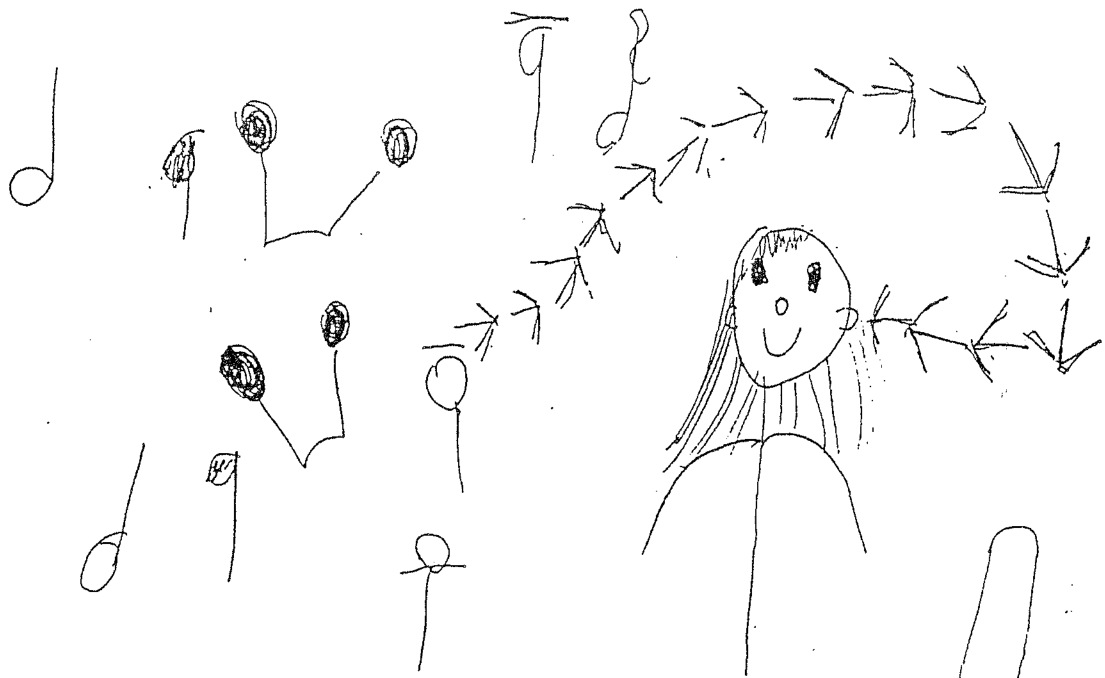
Question: *OK, what about us then? We are not underwater. What is between e.g this bell and your ears?*

Response: Air.

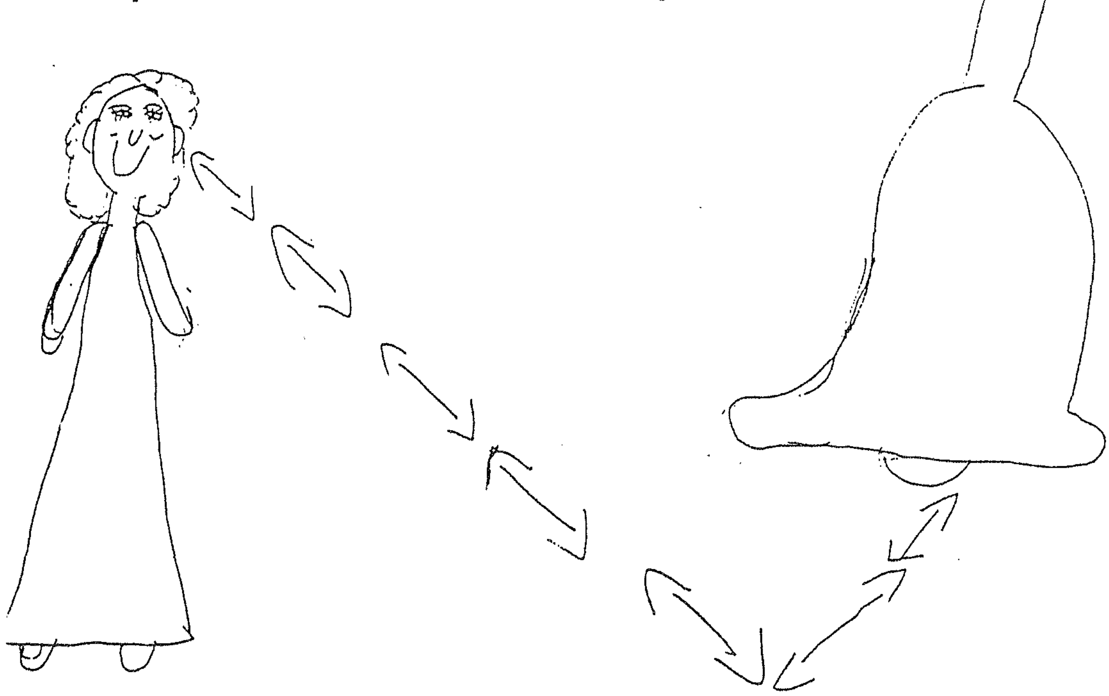
Appendix 6 Samples of drawings of year 4 students on sound and hearing

Students were asked to draw a picture showing how a person could hear a sound, e.g. a clock ticking or a bell ringing. The drawings were subsequently divided into groups on the basis of the connections (if any) between the ear and the sound source and whether or not those connections indicated a direction of transmission.

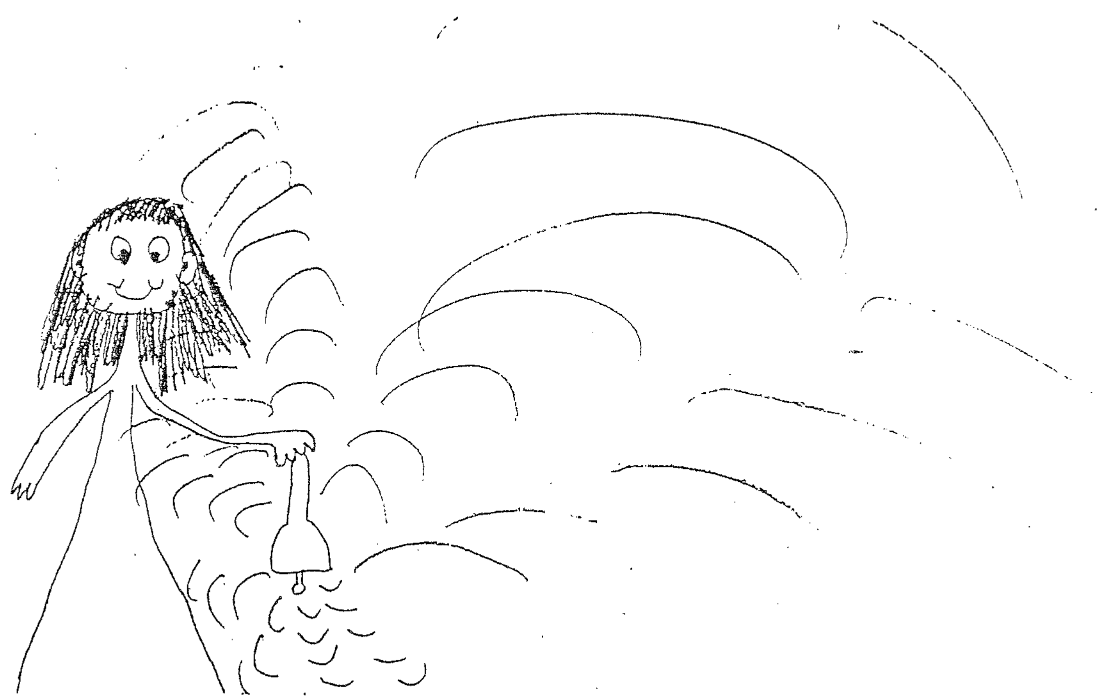
Group 1 Single-headed arrows from source to ear



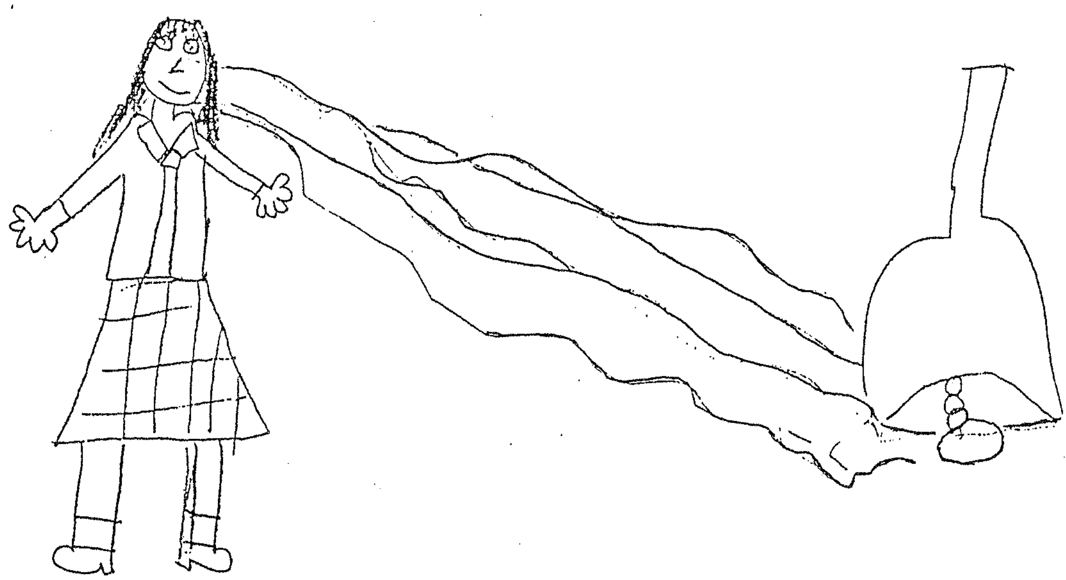
Group 2 Double-headed arrows linking source to ear



Group 3 Curved lines radiating out from source, some going to ear



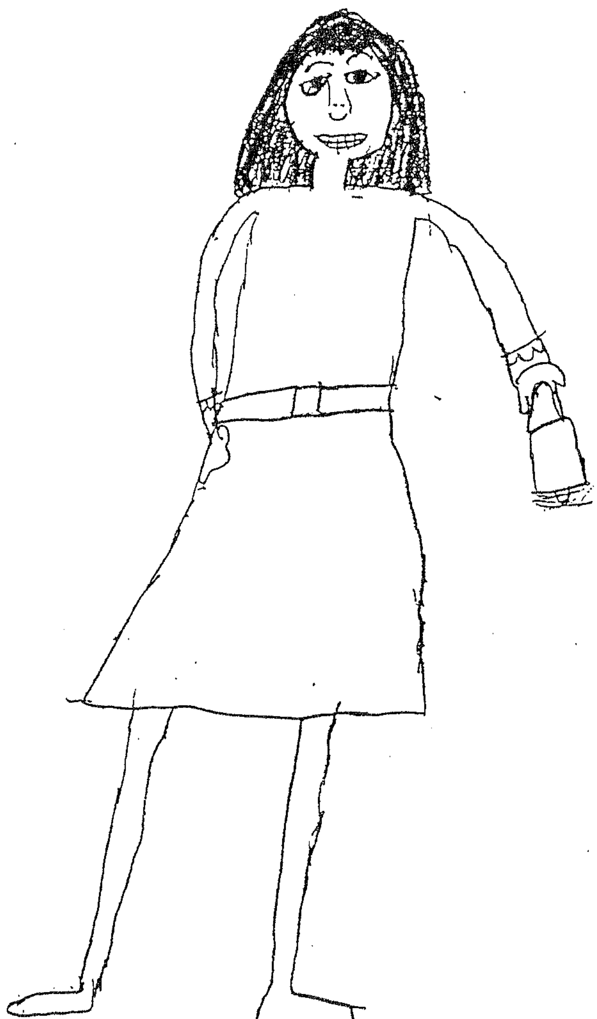
Group 4 Link (for example, wavy lines) between source and ear



Group 5 Words to indicate sound travel

No Year 4 students in this group.

Group 6 No link drawn between source and ear



Appendix 7 Transcript of interview with year 7 students on sound and hearing

Question: *I want you to tell me what the word 'sound' means to you or what you think of when I mention the word 'sound'.*

Responses: noise talking music my sisters (e.g. music, crying) voices rhythm loud hearing animal noises soft slow noise (e.g. whispering, wind) traffic footsteps letting out the bath thunder rain tummy rumbling rivers paper rustling and pencils writing whistling car horn taps birds chirping school bell trees rustling waves at the beach gas (e.g. out of a tap) telephone alarm clock smoke alarm doorbell kettle chairs moving(e.g scraping on the floor) aeroplanes taking off snoring motor in the car roaring conversation radio sirens (e.g. fire-engine, ambulance) people eating words ears volume listening movement (e.g. bumping producing sound) people (talking or moving) television or radio **vibrations** [this student was asked what vibrates and she said the air that makes the sound]

Question: *What do you use to hear?*

Response: your ears

Question: *How do you hear or How do those 'sounds' reach your ear?*

Responses: sound waves - if it's silent and something breaks the silence
echos
vibrations in the air
air into the ears
sound bouncing off ear drum
ear drum vibrating when sound wave hits it

Question: *How does the sound of my voice or this tuning fork get to your ears?*

Responses: by listening
concentrating
sound waves - by the vibration of the air

Question: *If the tuning fork is vibrating, how does that vibration get to your ear?*

Response: movement of the air

Question: *How is the air moving?*

Responses: in waves

air currents
bouncing off things in the room

Question: *Can you hear under water?*

Responses: Yes sometimes
vibrations in the water
sound is muffled
out here (in the air) you can tell which direction the sound is coming from, under water you can't

Question: *Do you know of any animals that communicate under water?*

Responses: dolphins, whales

Question: *How do they communicate?*

Responses: communicate by song squeaking blow bubbles
send out sound waves and they know when they might bang into something because it (the sound wave) bounces back to them and they can tell how far they are away from it echo location

Question: *If these animals are communicating under water, what medium (material) is between them?*

Response: water

Question: *If I'm talking to you, what material is between me and you?*

Response: air

Question: *Do you know of any other animals that communicate or detect things by a high-pitched signal or sound?*

Response: Bats

Question: *Would you be able to hear if you were in a place where there was no air?*

Responses: No

there would be nothing to carry it (the sound) with air is missing

Question: *If you put a clock in a bell jar on the bench and you used a vacuum pump to suck all the air out of the jar, would you still be able to hear the clock ?*

Response: No

Question: *Would the alarm still go off?*

Response: Yes

Appendix 8 Samples of drawings of year 7 students on sound and hearing

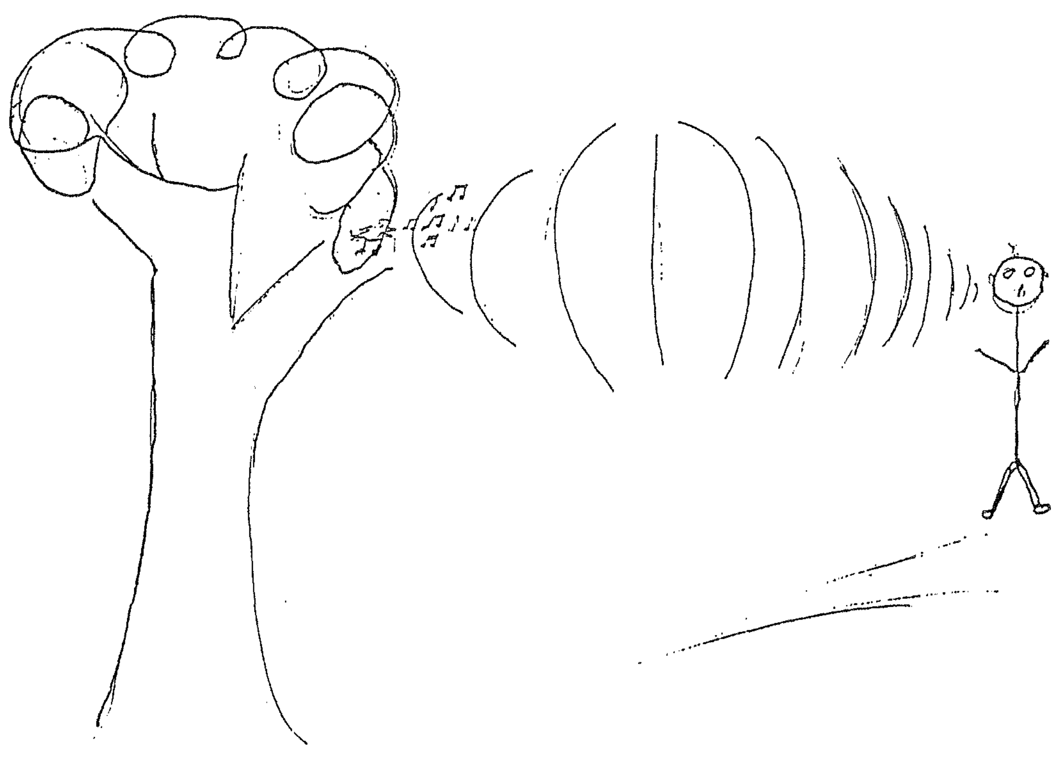
Students were asked to draw a picture showing how a person could hear a sound, e.g. a clock ticking or a bell ringing. The drawings were subsequently divided into groups on the basis of the connections (if any) between the ear and the sound source and whether or not those connections indicated a direction of transmission.

Group 1 Single-headed arrows from source to ear

No Year 7 students in this group.

Group 2 Double-headed arrows linking source to ear

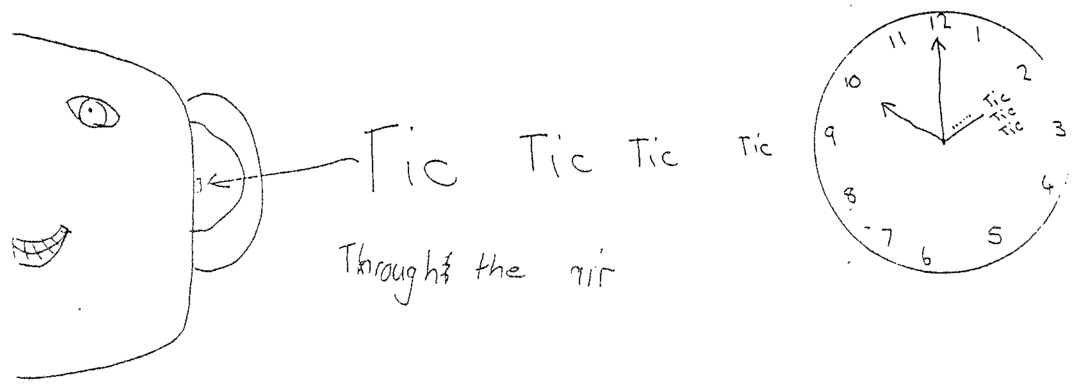
No Year 7 students drew double-headed arrows but one drew curves going in both directions from source to ear.



Group 3 Curved lines radiating out from source, some going to ear

Group 4 Link (for example, wavy lines) between source and ear

Group 5 Words to indicate sound travel



Group 6 No link drawn between source and ear

Appendix 9 Responses of year 10 students to questionnaire on sound and hearing

Researcher's notations are written in [ ].

Student Number	Question Number	Response
1	1	The child can hear the sound of the bird singing in the tree because the sound waves produced by the bird travel in a straight line to the boy's ears. The air is constantly compressing and stretching producing vibrations called sound waves. No. of key elements present: 3.5
	2	Option selected: (iv) (i) This is incorrect because sound does not echo around the room and your outer ears could not channel this echo to produce sound. (ii) You cannot hear sound by concentrating. No vibrations of air occur, therefore it is impossible to hear sound. (iii) The sound waves cannot travel through the air from your ears. The sound waves come from the gong and travel towards your ears. (v) The air is not vibrating, therefore cannot hear any sound. (vi) The gong does not vibrate for you to be able to hear the sound, the air has to.
	3 (i)	Yes, because sound waves can travel through air and liquid although it would not be as clear or as loud.
	(ii)	No, sound cannot travel through dense materials such as brick.
	(iii)	Yes, because the sound waves are vibrated along the string and the amplitude is increased when it reaches the tin.
	(iv)	No, because sound waves travel in a straight line. Therefore would hit wall and echo.
	(v)	Yes, because there is no air to stretch or compress the vibrations. [student may have meant to write 'No']
	(vi)	No, because-------[sic]

2	1	The bird uses its voice to create vibrations of the air. These vibrations travel in waves in all directions. Some of these waves travel to the person's ear. The sound enters the ear and sets the eardrum vibrating. No. of key elements present: 4
	2	Option selected: (iv) (i) The gong does not make a sound, it sets air vibrating around it. (ii) Sound waves travel all around the room and you cannot avoid 'hearing' something. (iii) Sound waves travel from the gong where the vibrations are created to your ear. (v) Your ears receive the vibrations and change them into messages sent to the brain. (vi) Vibrations travel to your ear and are received inside.
	3 (i)	Yes, vibrations can be transmitted through water.
	(ii)	Yes, vibrations travel through the metal, into the air then your ear.
	(iii)	Yes, the string carries the vibration.
	(iv)	Yes, very faintly. Vibrations travel in all directions.
	(v)	No, there is nothing (no air) through which vibrations can be passed.
	(vi)	Yes, the siren produces vibrations in the air which travel in all directions.
3	1	The child can hear the bird because when the bird makes a sound vibrations are given off. These vibrations enter the child's ear. No. of key elements present: 2.5 [student has not specifically said vibrations travel but has said they are given off and enter the ear]
	2	Option selected: (iv) (i) The sound is actually the vibrations so you must say 'sound vibrations'. (ii) This is what you do to listen, it doesn't say anything about the sound vibrations. (iii) The sound waves don't come from the ear, they come from the gong. (v) Nothing mentioned about sound waves. (vi) Doesn't say how you hear it.
	3 (i)	No, because water is denser than air.

	(ii)	Yes, the wall can pass sound waves through it.
	(iii)	Yes, because vibrations are sent down the string.
	(iv)	Yes, the sound waves could go over the wall.
	(v)	No, because the air is compact in the bell jar and is very dense.
	(vi)	Yes, because the air is not very dense and the vibrations have a lot of space.
4	1	When the bird sings, sound waves in the form of vibrations travel through the air and down the ear canal of the child. The ear drum vibrates. No. of key elements present: 3.5 [does not say medium vibrates]
	2	Option selected: (iv) (i) The sound does not echo around the room, it travels in sound waves - vibrations in the air. (ii) You do not have to concentrate to listen - it happens automatically. (iii) The sound waves travel from the gong to your ear not the other way around. (v) You do not automatically hear it - the vibrations have to reach your ears. (vi) no response.
	3 (i)	Yes, because sound can travel well through water.
	(ii)	Yes, because the steel girder would conduct the vibrations to your ear.
	(iii)	Yes, because the vibrations would travel through the string.
	(iv)	No, because sound cannot travel through dense substances such as brick.
	(v)	No, because sound waves cannot travel through a vacuum - there's no air to set vibrating.
	(vi)	Yes, because light travels faster than sound, therefore the car will reach you before the sound. [student appears to mean that you can see the car before you can hear it]
5	1	When the bird sings in the tree it causes the air to start vibrating, therefore causing the ear of the boy to start vibrating. No.of key elements present: 3 [student has not specifically said vibrations travel but has said ear starts vibrating]

	2	Option selected: (iv) (i) The sound doesn't echo around the room, it sets the air in the room vibrating to help you hear a sound. (ii) You would not hear the sound any more easily if you concentrated. (iii) The sound waves would not travel from your ear to the gong, the waves would travel from the gong to your ear. (v) The sound waves must travel to your ears and set your ears vibrating, you wouldn't just magically hear it. (vi) That is correct but sentence 4 accurately explains how you hear the sound.
	3 (i)	Yes, because the water would vibrate as air does but much slower.
	(ii)	Yes, because the hammer would set the steel vibrating causing your ear to vibrate and you to hear the sound.
	(iii)	Yes, she might be able to hear because the tin and string would vibrate causing the other girl's ear to vibrate.
	(iv)	No, because the voice would not make the wall vibrate and the other person does not have her ear against the wall.
	(v)	No, because there is no air in the vacuum and the vibrations could not get out.
	(v)	Yes, because the air would still be vibrating just after the air [student means car] had passed.
6	1	He can hear the sound of the bird singing in the tree because the sound is travelling in sound waves. No. of key elements present: 1.5 [mentions sound waves but not vibrations, hence 0.5]
	2	Option selected: (iii) [but also says (iv) could be logical] (i) This sentence doesn't actually involve you hearing the sound, just describes what happens to the excess sound waves. (ii) You don't have to concentrate to hear, it comes naturally. (iv) This one could be logical but I didn't see these alternative answers on this page. (v) Does not go into details of sound waves. (vi) Does not mention sound waves.
	3 (i)	Yes, because sound can travel through water.
	(ii)	Yes, because that is a very noisy sound and would be able to travel through the wall.

	(iii)	Yes, because the first tin amplifies it, the string quietens it and the 2nd tin amplifies it again.
	(iv)	No, because the wall would block the sound waves.
	(v)	No, sound cannot travel in a vacuum.
	(vi)	Yes, it would be quietened but you could still hear it. Would be quieter because of the Doppler effect.
7	1	The sound that the bird makes is actually made up of small vibrations which make sound waves. These sound waves vibrate through a medium (in this case air) all around the bird. The ear picks up the vibrations with the ear pinnae. No. of key elements present: 4
	2	Option selected: (iv) (i) A sound cannot echo around a room by itself. As sound is vibrations, it is actually vibrations in the air that surround the gong and fill the room and then those vibrations echo. (ii) If you concentrate or not does not hugely affect whether you hear a sound. It only affects you determining the sound. When the clapper strikes you hear the sound not listen for it. (iii) Your ear cannot produce sound waves as it is not making the sound. The sound waves come from where the sound is coming from - that is the gong. (v) This is almost right but what you receive is vibrations which travel to ears and your brain makes you hear it as it transforms the vibrations to impulses to sound. (vi) You receive the vibrations and your brain changes them to sound. You don't actually hear the sound.
	3 (i)	Yes, the vibrations travel through the water to your ear.
	(ii)	Yes, vibrations travel through girder to your ear.
	(iii)	Yes, the vibrations travel along the taut string.
	(iv)	Yes, vibrations travel through the two different mediums - the air and the wall.
	(v)	No, if it is a true vacuum no sound will be heard because there are no particles for the sound waves to travel along.
	(vi)	Yes, there are still vibrations in the air after car passes you and siren is still going.
8	1	Sound vibrations from the bird travel through the air and vibrate until they reach the ear drum inside the child's ear. No. of key elements present: 3.5 [does not say air vibrates]

	2	Option selected: (iv) (i) The vibrations from the gong need to enter your ear so that you can hear them, not just echo around the room. (ii) There must be vibrations for you to hear the sound. (iii) Sound waves don't travel from your ear, they travel to your ear. (v) There must be vibrations for you to hear. (vi) The vibrations must travel to your ears.
	3 (i)	Yes, (just) because sound vibrations also travel through water but you could only just hear it (water has a greater density than air)
	(ii)	No, vibrations can't travel through a wall (it is too dense)
	(iii)	Yes, the vibrations would travel along the string.
	(iv)	Yes, vibrations can travel over the wall.
	(v)	No, sound waves can't travel through a vacuum as there is no medium to vibrate.
	(vi)	No, because the car pushes the sound waves along as it travels, therefore sound is at its loudest before the car passes by.
9	1	The child can hear the sound of the bird singing in the tree because the bird makes a noise sending sound waves through the air. These sound waves travel in all directions and some will reach the child's ear causing the vibrations to travel to a nerve. No. of key elements present: 3
	2	Option selected: (iv) (i) I think this sentence is wrong because the sound doesn't just echo around the room. (ii) This is wrong because you need the vibrations in the air to travel to your brain so the sound can be recognised. (iii) This cannot be possible as the gong causes the vibrations (sound waves) not the ear. (v) This is wrong because you do not really hear through your ears - they receive the sound waves and then pass the information on to your brain. (vi) This is not quite right because there is more to sound than just hearing - the vibrations need to be received by your ears.
	3 (i)	Yes, you would be able to hear the sound of the engine but not as well as in air. The sound waves travel at a similar speed as in air.
	(ii)	Yes, because the vibrations would travel down the steel girder. It would be quieter.
	(iii)	Yes, because the sound waves would travel down the string.

	(iv)	No, because the wall (if brick) would absorb the sound waves.
	(v)	No, because there is no air for the sound waves to travel through.
	(vi)	Yes, slightly because you are going in opposite directions and the sound would hit you when you passed and then for a moment afterwards.
10	1	The sound of the bird singing vibrates through the air to the child's ear. No. of key elements present: 3.5
	2	Option selected: (iv) (i) The sound of the gong will only echo if the gong is loud enough or if it is in the right type of room. (ii) This is wrong because you are able to hear sounds without concentrating on them. (iii) This is written around the wrong way because sound waves travel through the air to your ear when the gong is struck. (v) The clapper does strike the gong but vibrations must travel through the air before you can hear the sound. (vi) It is not the gong which vibrates but the sound waves which make vibrations through the air.
	3 (i)	No, because it is harder for sound to travel through dense mediums.
	(ii)	No, because again the mediums are too dense.
	(iii)	Yes, the sound vibrations are able to travel along the string.
	(iv)	No, because sound cannot travel through a brick wall, unless it was very loud you couldn't hear it.
	(v)	No, sound cannot travel through a vacuum.
	(vi)	Yes, because this is when the sound would be travelling to your ear drum.
11	1	The child can hear the sound of the bird singing as sound waves from the bird's mouth are travelling through the air. These sound waves set the air vibrating and the vibrations travel to your ear. No. of key elements present: 3.5 [student says sound waves set air vibrating instead that vibrations are the sound wave]

	2	Option selected: (iv) This is correct as the gong sets up ?sound waves which cause the air to vibrate and your ear picks up these vibrations. (i) The sound appears to echo but this is not what you hear. It is the sound waves produced from the gong not the echoes. (ii) You cannot concentrate and listen to a sound. The sound waves have to travel through the air to your ear. (iii) Sound waves do not travel from the ear but they are produced from the gong which is making the sound. (v) This is incorrect as you cannot just hear something, it has to produce sound waves which set the air vibrating. (vi) This is also wrong as you cannot hear the vibrations of the actual gong.
	3 (i)	Yes, sound travels through water.
	(ii)	Yes, sound travels through metal and brick.
	(iii)	No, as the sound produced by the girls is a very low pitch.
	(iv)	No, the sound waves are not heard as the sound is too quiet.
	(v)	No, because there is no air to vibrate to produce the sound.
	(vi)	Yes, as the air vibrations from the sound are still lingering in the air and can be heard.
12	1	Sound is transmitted through sound waves. The high pitched frequency made by the bird is transmitted into the ear. The air is set vibrating and vibrations travel to your ear. No. of key elements present: 4
	2	Option selected: (iv) (i) Although the sound echoes, it is the vibrations that were set at the first instant that travel to your ear. (ii) In order for the air to start vibrating the gong must be struck. It is the vibrations that are converted that gives identification to the sound. (iii) The sound waves travel through the air from the gong to your ear. Sound waves are not produced by your ear, the ear receives the vibrations. (v) In order for your ear to hear the sound, vibrations travel through the air and travel to your ears. (vi) no comment.
	3 (i)	Yes, vibrations are converted into sound waves and can still pass through water due to the oxygen content.

	(ii)	Yes, the vibrations would be blocked slightly, they will still penetrate sound. [what does student mean?]
	(iii)	Yes, the sound vibrates the string and is converted into a message.
	(iv)	Yes, although there is an obstacle in the way, sound can still travel through the air.
	(v)	No, no air is present, therefore vibrations/sound waves cannot be heard [doesn't say cannot be transmitted]
	(vi)	Yes, sound can stil be heard as it passes you, the vibrations would be stronger.
1 3	1	The sound of the bird singing travels through the air as vibrations. When the vibrations reach the child's ears they go inside. No. of key elements present: 3.5
	2	Option selected: (iv) (i) The sound that you hear comes from the vibrations not an echo. (ii) You don't have to be concentrating to hear the sound. (iii) The sound waves do not travel from your ear but to it. (v) The ear receives the sound but you hear it in your brain. (vi) The gong vibrates the air around it and that is what you hear.
	3 (i)	Yes, because the vibrations would reach your ear through the water.
	(ii)	Yes, because the vibrations would travel to your ear [no mention of how - girder, wall, air?]
	(iii)	Yes, because the vibrations would travel along the string.
	(iv)	No, because the vibrations would not be able to pass the wall.
	(v)	No, because the vibrations would not be able to pass through the glass.
	(vi)	Yes, because the sound would still reach your ears.
1 4	1	The child can pick up the sound the bird is making by sound waves being carried by the wind. No. of key elements present: 1 [student says sound waves but there is nothing to show she understands what they are]

	2	Option selected: (i) This makes it easy for someone to hear because they hear the actual strike and they then hear it for sometime after. (ii) You don't have to concentrate in order to hear a sound. (iii) The sound waves may travel but your ear isn't making the sound so the sound waves can't travel from your ear to the gong. (iv) Doesn't tell you how the gong sets the air vibrating. (v) This sentence doesn't tell you how you hear it with your ears. (vi) This sentence doesn't tell you that the gong makes a sound.
	3 (i)	No, because you can't hear things very clearly under water.
	(ii)	Yes, because of the vibrations.
	(iii)	Yes, because the sound would echo inside the tins.
	(iv)	No, because the sound can't go through the wall.
	(v)	No, because it would be hard for the sound to get out of the glass.
	(vi)	Yes, because it's very loud and you can hear it for quite some time after the car has passed you.
1 5	1	The bird makes a noise which causes vibrations which travel through the air. These vibrations travel to the boy making an impact in his ear drum. No.of key elements present: 3.5
	2	Option selected: (iv) (i) The sound if it echoed around the room would end up making a louder noise and would come from the wrong direction. (ii) You don't have to concentrate to hear something. (iii) This is right except that the sound waves travel from the gong to the ear not the other way round. (v) You hear things with your brain. Your ear just collects the signal. (vi) If the air didn't vibrate the sound wouldn't reach you.
	3 (i)	Yes, the vibrations can still travel through water.
	(ii)	No, the vibrations would be cut off by the bricks.
	(iii)	Yes, the vibrations can travel along the string.
	(iv)	No, depends on what kind of wall. The vibrations can't get through the wall unless it is wire or something else which can move.
	(v)	No, the vibrations can't get through the vacuum [student appears to see a vacuum as a barrier like a wall]

	(vi)	Yes, even after the car has passed you can still hear it.
16	1	The child can hear the sound of the bird singing in the tree because when the bird makes a noise the air vibrates. The vibrations in the air move along the air until they reach the child's ear and goes in. No. of key elements present: 3.5
	2	Option selected: (iv) (i) If the gong makes a sound then there must be vibrations. If there are no vibrations then it cannot be heard. (ii) You cannot concentrate sound waves. There are no vibrations. There must be vibrations. (iii) The sound waves must come from the gong to your ear not from your ear to the gong. (v) You do not just hear the sound with your ears. There must be vibrations in the air. (vi) The gong's vibrations must not only be there but they must travel to the ears. There must be vibrations.
	3 (i)	Yes, the vibrations would travel through the water.
	(ii)	No, the vibrations wouldn't carry through the brick. It would stop them.
	(iii)	Yes, the noise would vibrate on the string and carry to your ear.
	(iv)	No, the brick wall would stop any vibrations trying to reach you.
	(v)	No, in a vacuum there is no air so there are no noise vibrations. Without vibrations you cannot hear.
	(vi)	Yes, the noise vibrations are still in the air even after the car has passed.
17	1	This is because the ear drum vibrates and sends out sound waves so that the sound of the bird carries from the tree into child's ears. It sends vibrations running through the ear. When the bird is singing its voice vibrates in the air and travels to your ear. [In 1st sentence student may mean 'voice' vibrates rather than 'eardrum 'as she says 'voice' in last sentence] No. of key elements present: 3.5 [see note]

	2	Option selected: (iv) This is correct because the gong does make the air vibrate and so the vibrations can carry to your ears. (i) This is wrong because the gong makes the air vibrate and it has to go to your ears not around the room. (ii) You can't concentrate and listen because even if you don't the sound is still going to be carried to your ear. (iii) No, because the sound waves have to travel from the thing that is making the sound ie the gong, not the other way round. (v) You actually don't because it's the vibrations that travel to your ears. (vi) You do, but first the vibrations have to be carried to your ears.
	3 (i)	Yes, because the boat vibrates the water and so you can hear.
	(ii)	Yes, because --------[sic]
	(iii)	No, because the sound will not be able to travel through string.
	(iv)	No, because the sound cannot carry over the wall unless she talks louder.
	(v)	No, you shouldn't be able to hear the ringing through the vacuum because the sound cannot get out.
	(vi)	Yes, because the sound of the siren travels back through the air to you.
18	1	The child can hear the bird because when it opens its beak and lets out the sound what is actually happening is there are vibrations that travel through the air and end up in the child's ear which converts it into sound. This happens even though the bird is in the treee as the vibrations go through the gaps in the leaves and branches. No. of key elements present: 3.5
	2	Option selected: (iv) (i) This is true but in order for the sound to come from the gong it must make the air vibrate around it. (ii) You don't have to concentrate to hear the sound as it is very loud and would make no difference. (iii) The sound begins at the gong as it is the one causing the vibrations that the ear can hear. (v) When the clapper strikes the gong you do hear it with your ears but it is the vibrations the ear picks up. (vi) The gong does vibrate when struck but it is the vibrations that cause the air to vibrate that makes the sound travel.

	3 (i)	Yes, because it is making the water vibrate and the ear will pick it up.
	(ii)	No, the sound waves would get stopped at the wall.
	(iii)	Yes, because it still makes the string vibrate and the message travel.
	(iv)	No, the sound waves wouldn't travel over the wall if only a slight sound was made - they would only go straight ahead [this last comment indicates student does not fully understand the nature of sound waves]
	(v)	No, the foam would absorb the vibrations bounding off the sides causing none to get out.
	(vi)	Yes, it has a very loud high pitch sound which would send the vibrations back even from a distance away.
19	1	This is because the sound that the bird makes sends signals in sound waves through the air to the child. These sound waves vibrate the inside of the ear. No. of key elements present: 3 [student says sound waves make ear vibrate but does not say that sound waves are vibrations. Does she understand the nature of the 'signal' ?]
	2	Option selected: (iv) (i) The gong when it is struck sends sound waves, they don't necessarily echo around the room. (ii) This sentence is wrong because you don't have to concentrate to hear a gong. (iii) This is wrong because the sound waves would travel through the air from the gong to the ear not the other way round. (v) The clapper strikes the gong. You don't just hear it with your ears. Signals have to be sent so you can hear it. (vi) The gong does vibrate but it also sends out sound waves so it can be heard.
	3 (i)	Yes, the sound from the engine would travel through water.
	(ii)	Yes, the sound would vibrate along the steel girder.
	(iii)	Yes, the sound waves travel along the string to the tin and noise can be heard.
	(iv)	No, sound waves travel in straight lines so they can't be heard through a wall.
	(v)	No, the sound has nowhere to travel so it can't be heard.
	(vi)	Yes, the sound waves go in every direction so it can be heard.

20	1	The bird makes a chirping sound which travels in sound waves and the child picks up those sound waves and the sound hits the ear drum. No. of key elements present: 1.5 [no mention of vibrations or medium]
	2	Option selected: (iv) (i) This doesn't explain how I hear the sound. (ii) You don't need to concentrate to hear. (iii) The sound waves don't travel from your ear to the gong, the sound waves travel from the gong. (v) We don't actually hear the gong being struck. The sound waves travel after it has been struck. (vi) The gong does vibrate, but -----[sic]
	3 (i)	Yes, but not very clearly. Sound waves can still travel underwater.
	(ii)	Yes, the sound travels through the steel.
	(iii)	No, you have to speak loudly so the string picks up the vibrations.
	(iv)	No, sound waves can't travel through walls.
	(v)	no response
	(vi)	Yes, because the siren is so loud.
21	1	The air vibrates and hits the ear drum. No. of key elements present: 3 [no mention of how vibration reaches ear drum or that ear drum is set vibrating]
	2	Option selected: (iv) (i) Does not say what the sound is. (ii) Does not explain how the sound gets to you. (iii) No they don't. (v) How What do you hear? (vi) How does the sound get to you?
	3 (i)	No, the water does not carry sound like air.
	(ii)	Yes, the sound travels through the air.
	(iii)	Yes, the string vibrates the air.
	(iv)	Yes, the sound waves travel in all directions.
	(v)	No, There is no air to carry the sound.
	(vi)	Yes, it would be loud enough for you to hear.
22	1	The bird sings and sound waves travel through the air to the child's ear. No. of key elements present: 2.5 [no mention of vibrations]

	2	Option selected: (iv) (i) It doesn't say that you hear the gong. (ii) You don't have to concentrate to listen to the sound. (iii) The sound waves travel from the gong to your ear not the other way around. (v) It doesn't explain <u>how</u> your ears hear the sound.
		(vi) Again, it doesn't explain how (or why) you hear the sound.
	3 (i)	Yes, it would be muffled but the sound waves would still reach you slowly.
	(ii)	No, the steel girder would vibrate but to you would be silent because the sound waves can't get through the wall.
	(iii)	Yes, the sound waves travel on the tight string to your ear.
	(iv)	No, the sound waves can't get to you because the wall is in the way.
	(v)	no response.
	(vi)	Yes, there are still some lingering sound waves to reach your ears.
2 3	1	The person that can hear the bird has ears and the sound that the bird has made has travelled to the person's ear which ables him to hear what the bird sound is. No. of key elements present: 1.5 [no mention of vibrations or medium]
	2	Option selected: (iv) (i) The gong can make a sound and the sound echoes around the room but this is not why we can hear the sound. (ii) This one is wrong to me because if the gong is striked [<u>sic</u>] I do not think I would concentrate on the sound. (iii) The sound waves do not travel from my ear to the gong, the sound travels from the gong to my ear. (v) The sound has to travel to our ear for us to hear it. (vi) The gong vibrating will not make a sound but it does when it has hit something.
	3 (i)	Yes, the boat engine is half under the water and the sound that the engine has made the water vibrates and you are able to hear it.
	(ii)	Yes, the sound is very loud so you will be able to hear it and it is vibrating and echoes.

	(iii)	Yes, because the sound through a tin through a piece of string able [sic] you to hear the sound vibrates.
	(iv)	Yes, because the person would not be on the other side
	(v)	Yes, because the alarm clocks are very loud and able [sic] you to hear it and the vibrations travel through the vacuum cleaner and this ables [sic] you to hear it. [student does not understand the meaning of 'vacuum'].
	(vi)	Yes, because this sound is very loud because it is an emergence [sic] car.
2 4	1	The sound vibrations travel through the air and are picked up by the ear where these waves are turned into an identifiable sound. No.of key elements present: 3 [does not say ear vibrates].
	2	Option selected: (iv) (i) The gong makes sound waves. (ii) You don't really have to concentrate to hear a loud sound. (iii) The sound waves travel from the gong to the ear and not vice versa. (v) You hear the air vibrations not the actual gong. (vi) You don't hear the gong vibrations, you hear the air vibrations the gong causes.
	3 (i)	Yes, some sound waves (vibrations) travel through the water, but not as easily as above water.
	(ii)	Yes, you would hear the vibrations through the steel girder.
	(iii)	no response.
	(iv)	No, quiet sound waves would not be able to pass through the high wall.
	(v)	No, because there is no air in the vacuum for the vibrations to travel through.
	(vi)	Yes, the loud siren can still be heard from a great distance.
2 5	1	The sound waves coming from the bird's voice travels through the air towards the ears of the child. No. of key elements present: 2.5 [no mention of vibrations]

	2	Option selected: (iv) (i) This is true, but the ears have to pick up the sound waves from the gong. (ii) You do not need to concentrate most of the time when a loud noise is set off. (iii) The sound waves do not travel through the air from your ear to the gong. It is the other way around. Sound waves come from the gong. (v) This is true however the vibrations from the gong are amplified once in your ear. (vi) In order to hear the sound sound waves must travel through the air from the gong to your ears.
	3 (i)	Yes, the sound of the motor would be in a way amplified and the vibrations from the engine would travel through the water.
	(ii)	Yes, the ear is touching the steel girder and therefore the sound waves can be transferred from the hammer to the ear.
	(iii)	Yes, the sound waves can travel through the cups and on the string from one to another.
	(iv)	No, the brick wall is blocking most, if not all, of the sound waves.
	(v)	No, you could not hear this because the alarm clock is tightly in a vacuum cutting off all available connection.
	(vi)	Yes, sound waves do not travel as fast as light however sound can travel in all directions.
2 6	1	The sound waves travel from the bird to the child and the sound waves vibrate through the ear. No. of key elements present: 2 [no mention of vibration of medium]
	2	Option selected: (vi) This is the best way because it is exactly what happens. (i) It is better to mention that the sound is heard by you than the sound just echoing around the room. (ii) When a sound is made it is impossible to concentrate because it comes naturally. (iii) Sound waves don't travel from your ear to the gong, only from the gong to the ear when the gong makes the sound. (iv) The air doesn't vibrate, the sound does. (v) The sound travels through your ears, the sound is not automatically heard with your ears.

	3 (i)	No, water stops the vibrations from reaching your ears.
	(ii)	Yes, it can vibrate through the wall.
	(iii)	Yes, the sound can travel through string.
	(iv)	Yes, walls cannot stop sound from reaching another person.
	(v)	Yes, very faintly it can be heard.
	(vi)	Yes, the sound continues to vibrate after it leaves from a distance.

Appendix 10 Responses of physics 1 students to questionnaire on sound and hearing

Researcher's notations are written in [ ].

Student Number	Question Number	Response
1	1	The birds vocal chords vibrate causing air molecules to vibrate in resonance. The energy of this vibration travels in a wavelike fashion in all directions. When the vibrating molecules strike the childs eardrum this vibrates (resonates) too. No. of key elements present: 4
	2	Option selected: (iv) (i) This doesn't describe how you hear the gong just what happens to the sound waves when they strike a reflective surface. (ii) When the gong is struck the sound waves will strike your eardrums whether you concentrate on them or not. You don't need to concentrate to hear. (iii) The sound waves don't travel from your ear, they travel to your ear from the gong. (v) Again this doesn't describe how you hear it. You only hear the clapper strike the gong when the vibrating air molecules hit your ear drum. (vi) This is true but doesn't explain what carries the sound to your ear.
	3 (i)	Yes, in this case the water molecules are vibrating not air but the principle is similar.
	(ii)	Yes, the hammer causes the girder to vibrate which causes the air to vibrate which reaches your ear, etc.
	(iii)	Yes, the can reflects and concentrates the vibrations from your voice which are transferred through the string, causing the other can to vibrate, reaching your ears via air molecules, etc.
	(iv)	No, the wall blocks the travel of the wave in vibrating air molecules, therefore it doesn't reach your ear.
	(v)	No, there is no air to vibrate, therefore nothing to carry the sound to your ear.

	(vi)	Yes, the sound is "projected" in all directions even behind the car.
2	1	Sound is propagated via pressure vibrations in the air. The birds vocal chords vibrate and produce a corresponding vibration in the surrounding air. The vibrations radiate in a spherical pattern where possible and eventually reach the ears of the child. The pressure vibrations in the air then cause corresponding vibrations in the eardrum. No. of key elements present: 4
	2	Option selected: (iv) (i) What is the sound? (ii) Doesn't explain how the sound gets to your ear. There must be some physical sensation. (iii) The sound waves travel from the gong to your ear not the other way round. (v) See No. 2. (vi) See Nos. 2 and 5.
	3 (i)	Yes, in this case the water vibrates to cause the sound.
	(ii)	Yes, in this case its the steel girder vibrating.
	(iii)	Yes, in this case its the string and cans.
	(iv)	No, probably not, the air vibrations are unlikely to cause corresponding vibrations in the wall.
	(v)	No, in a vacuum there is nothing at all to propagate the sound.
	(vi)	Yes, although at a different frequency to when it travels towards you.
3	1	Sound travels in waves. For a sound wave to travel from one place to another it needs a medium to travel through. (In space, for example, sound is not possible as space is a vacuum and thus there is no medium). When the bird tweets, it creates compressional disturbances in the air (sound waves). These waves travel through the air (the medium) and reach the childs ear. The childs ear receives these waves as sound. No. of key elements present: 3.5 [no mention of vibrations, student has not said how the ear receives the sound wave]

	2	Option selected: (iv) (i) This sentence makes no mention of the air - the medium through which the sound travels. (ii) As for No.1. (iii) The sound waves travel from the gong to your ear - not the other way around. This sentence does, however, mention the medium. (iv) This is the closest explanation of what actually happens. (v) As for No.1. (vi) As for No.1.
	3 (i)	Yes, the medium is water - sound travels through the water.
	(ii)	Yes, the medium is the girder - sound travels through the girder.
	(iii)	Yes, the medium is the string - sound travels through the string.
	(iv)	No, sound waves are weak (little disturbance in the air) by the time they pass through the wall they are too weak to hear.
	(v)	No, there is no medium for the sound to travel through.
	(vi)	Yes, sound travels radially outwards from the source - it doesn't matter where the car is.
4	1	The bird exhales air through its vocal chords which produce sound waves of varying frequencies. The sound waves proceed through the air as a group of compression waves with air molecules transferring the waves through eachother. The waves then vibrate the eardrum at the various frequencies allowing the child to hear the birds song. No. of key elements present: 3.5 [doesn't say air vibrates]
	2	Option selected: (iv) (i) The sound may echo around the room but it does not tell how you hear them. (ii) You do not need to concentrate to hear the sound you will most likely hear it anyway. (iii) Sound does not travel from your ear to the gong. (v) You do not hear it with your ears you collect the vibrations with your ears. (vi) How does the sound travel to the ear.
	3 (i)	Yes, the sound will travel by the water molecules vibrating.
	(ii)	Yes, the vibrations will make the air vibrate making a hum.
	(iii)	Yes, the sound will travel along the vibrating string.
	(iv)	No, the sound will just bounce off the wall.

	(v)	No, there is nothing to transport the soundwaves.
	(vi)	Yes, the sound will still be able to reach you through the air.
5	1	Using air in its lungs, the bird vibrates its vocal chords in such a way the passing air is given a frequency to match a certain pitch - sound wave. This sound wave leaves the birds beak and travels through the air to the childs ear where the ear drum vibrates No.of key elements present: 3.5 [doesn't say sound wave travels by vibration of air]
	2	Option selected: (iv) (i) If it echoes you get more than one sound. (ii) The striking doesn't make the sound, the reverberations in the gong do. (iii) Sound waves cannot originate from something silent. (v) The clapper doesn't make the sound. (vi) You feel the air vibrations not the gong vibrations.
	3 (i)	Yes, vibrations in the water.
	(ii)	Yes, vibration through the steel.
	(iii)	Yes, vibration in the string.
	(iv)	No, too many obstacles for the sound waves.
	(v)	No, no air to vibrate.
	(v)	Yes, Doppler effect. [doesn't explain how]
6	1	The singing bird causes air to vibrate. These vibrations propagate through the air as longitudinal waves. The childs eardrums resonate sympathetically with the waves and this is interpreted by the childs brain as sound. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound waves echo around the room. This sentence doesn't explain why/how you hear the sound. (ii) This sentence does not explain how the sound gets to you. (iii) Sound waves travel through the air to your ears not vice versa. (iv) It doesn't explain that you "hear" the vibrations. (v) This does not explain how the sound gets to your ears. (vi) This doesn't explain the connection between sound and vibration nor how either got to your ears.
	3 (i)	Yes, sound waves can travel through water.
	(ii)	Yes, sound waves can travel through steel.

	(iii)	Yes, sound waves can travel along a medium such as string very quickly so the sound doesn't dissipate too quickly and become inaudible.
	(iv)	No, the sound dissipates too quickly and becomes inaudible.
	(v)	No, there is no medium to carry the sound waves.
	(vi)	Yes, sound propagates in all directions so it should be audible just after the car passes.
7	1	The birds song sets up a series of waves in the air, compression alternating with rarefaction. These waves hit the ear drum and it vibrates in [kind?] No. of key elements present: 3 [no mention of travel through air or how, doesn't actually say air vibrates]
	2	Option selected: (iv) (i) The sound is what we perceive as vibration. (ii) This implies that you must see the clapper hit the gong in order to hear it. (iii) The sound waves travel <u>from</u> the gong <u>to</u> your ear. (v) Doesn't mention vibration or a medium for these vibrations to travel in. (vi) Same as No. 5, needs air to be vibrating to travel to your ear.
	3 (i)	Yes, water is a very good conductor of sound.
	(ii)	Yes, steel is an excellent conductor of sound.
	(iii)	Yes, a tight string will conduct sound.
	(iv)	No, the vibration would dissipate too much for you to hear her.
	(v)	No, no medium to conduct the vibration of the alarm.
	(vi)	Yes, the speed of the car is much less than that of sound, though the frequency would be lower.
8	1	Sound travels as longitudinal waves, consequently the birds "voice" box vibrates producing sound waves. The sound waves travel through the air and reach the ear of the child. When the sound waves enter the ear canal they cause the ear drum to vibrate. Sound travels through a medium, if there was a vacuum the child wouldn't hear the sound. No. of key elements present: 3.5 [doesn't actually say the air vibrates]

	2	Option selected: (iv) (i) The gong doesn't really 'make' a sound, it vibrates and sets up waves. The 'sound' doesn't need to echo for you to hear it. (ii) Striking the gong doesn't do anything other than cause it to vibrate. Define listen - you don't just 'listen' to sound, your ear drum must vibrate. (iii) The sound waves come from the gong, not your ear! (The gong vibrates) (v) Well yes, but this says nothing about the technicalities - vibrations, sound waves, etc. (vi) Yes, but your ear drum vibrates to turn the vibrations into an interpretable sound for the brain.
	3 (i)	Yes, the sound has a medium to travel through, and it travels through water fairly easily - same as air in some respects.
	(ii)	Yes, travels through the steel - vibrates longitudinally through the steel and then through the air.
	(iii)	Yes, the string carries the wave and the tin amplifies the sound.
	(iv)	No, sound is travelling through air but is dampened by the brick wall - the sound is not intense enough to make the wall vibrate and hence carry the sound.
	(v)	No, sound requires a medium through which to travel - no medium, no sound.
	(vi)	Yes, the waves travel outwards through the air so you can hear it for quite a while after it has passed - Doppler effect also applies.
9	1	The bird sings. The sound uses air as a medium to carry the vibrations to the child ear where the vibrations are converted from air vibrations to fluid vibrations to bone vibrations all within the childs ear. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound echoing around the room is not necessary for me to hear it. (ii) This does not <u>best</u> describe how I hear the sound of the gong. (iii) The sound waves would not travel from my ear to the gong if I was to listen to the gong as it is travelling the wrong way. (v) Does not <u>best</u> describe it. (vi) Does not best describe it.

	3 (i)	Yes, maybe faintly but the engine noise would be muffled as sound does not travel as well through water.
	(ii)	Yes, a 'tink' would probably be heard as the vibrations would be muffled by the brick.
	(iii)	Yes, the sound vibrations are carried by the string.
	(iv)	No, the brick wall interferes with the sound vibrations.
	(v)	No, no medium for the sound waves to travel.
	(vi)	Yes (no explanation)
10	1	The singing of the bird via vibrations of organs sets up air pressure waves in the surrounding air. These waves travel through the air until they run out of energy. When these waves meet an object they will cause it to vibrate. Such an object might be the small bones in the ear. No. of key elements present: 3.5 [no mention of vibration of air]
	2	Option selected:(iv) (i) No ------? to propagation or reception [response illegible] (ii) Irrelevant. Concentration is not a process in [transmission?]of sound. (iii) Wrong propagation direction. (v) No [reference?] to mechanism (vi) No ----- to ------- - [transmission?] by [air?] [response illegible]
	3 (i)	Yes, water efficiently transmits sound waves.
	(ii)	Yes, vibrations travel through steel into the air and to [the ear?]
	(iii)	Yes, probably the vibrations are transmitted by the string.
	(iv)	Yes, probably - sound waves can travel around corners but if very quiet may not be [sufficient?] to hear.
	(v)	No, sound waves cannot propagate through a vacuum.
	(vi)	Yes, sound is transmitted normally - slightly doppler [------?]
11	1	The sound the bird makes travels as a wave - the atmosphere being the medium in which this wave travels. This sound wave travels as gas molecules colliding with one another. These molecules (carrying the sound wave) eventually meet with the ear drum of the child where the sound is detected by the movement of air oscillating the childs ear drum. No. of key elements present: 4

	2	Option selected: (iv) (i) Sound is not a pure form of energy. It is based on moving sound waves/gas molecules etc. (ii) This explains your awareness of the sound, not how you hear it. (iii) No the reverse occurs, gong to ear. (v) There must be something occurring between the gong being striked [sic] and your listening. (vi) This is a true statement - it makes more sense than some things I have learnt, but it doesn't explain how the sound is heard.
	3 (i)	No, the water stops most of the sound wave transmission.
	(ii)	Yes, the sound waves would vibrate and a big sound would be heard.
	(iii)	Yes, sound wave transmission would occur through the length of the string.
	(iv)	No, the sound waves would be stopped as they travel through the air by the brick wall.
	(v)	No, sound waves do not exist in a vacuum.
	(vi)	Yes, the sound waves are still travelling through the air.
12	1	The bird singing creates compression waves in the air by the vibrating action of its vocal chords. The childs ear senses these compression waves. No. of key elements present: 2.5 [no mention of travel through the air or vibration of the ear drum]
	2	Option selected: (iv) (i) This statement is correct but makes no reference to how you actually hear the gong. (ii) There is no need to concentrate and listen in order to hear and again it makes no reference to how you actually hear the gong. (iii) This statement is almost correct except that the waves travel in the opposite direction ie from the gong to your ear. (v) This statement says what you hear the sound with not how you hear the sound. (vi) This is part of what is happening and again not how you hear the sound.
	3 (i)	Yes, because sound waves travel through water.
	(ii)	Yes, sound waves travel through steel.
	(iii)	Yes, sound can travel along the string.

	(iv)	Maybe, depending on how quietly, how high and how good your hearing is.
	(v)	No, sound doesn't travel through a vacuum.
	(vi)	Yes, obvious. [student hasn't explained why]
1 3	1	Sound from a bird travels to the child in the form of a wave - a 3-dimensional longitudinal wave to be exact. The motion of this wave consists of the vibration of the air particles, otherwise known as oscillation. No. of key elements present: 3 [no mention of how the child receives the sound]
	2	Option selected: (iv) (i) This is true but it does not explain why the sound echoes or why you hear the echoes. (ii) This is true but it does not explain the reason why you hear the sound. (iii) This would be correct except for the fact that it is round the wrong way. (v) Once again a very elementary description - does not explain why, would expect this from a 5 year old. (vi) Yes, the gong vibrates, yes you hear it but still this does not explain how/why the sound travels to you.
	3 (i)	No, unlikely - depends on wave frequency, high pitched sounds only.
	(ii)	Yes, the girder vibrates and hence the sound will travel.
	(iii)	Yes, sound vibrates through string to other person.
	(iv)	Yes, sound waves oscillate through air and wall.
	(v)	No, sound waves must have some kind of substance to pass through otherwise they will not exist.
	(vi)	Yes, sound will behave according to Doppler effect.
1 4	1	First assume the childs hearing good and bird is close enough by. The birds singing is transmitted to the boys ear through the air in sound waves. These sound waves carry the tune and energy. The boys ear changes or interprets the sound waves into electrical impulses. No. of key elements present: 2.5 [no mention of vibration of air nor how ear receives the sound wave]

	2	Option selected: (iv) (i) No complete on explaining how echoes [response unintelligible] (ii) This is a part of hearing the sound, not explaining how sound travels or received by person. Gives impression only can hear when concentrate and listen. (iii) Wrong direction of transmission of sound waves. (v) Not mentioning how - air (medium) or sound waves (vi) No how.
	3 (i)	Yes, sound waves travel well through water.
	(ii)	Yes, sound wave travel through the steel girder.
	(iii)	Yes, as the string weakly transmits the sound.
	(iv)	No, as the wall acts as a barrier to travelling sound waves.
	(v)	no response.
	(vi)	no response.
15	1	As the bird sings the air particles are moved out of the mouth of the bird. These in turn hit the particles next to them and so the sound energy is transferred in a wave to the boys ear. No.of key elements present: 2.5 [no mention of vibration of air or ear]
	2	Option selected: (iv) (i) This sentence says nothing about <u>how you</u> hear the sound. (ii) You do not need to 'concentrate', the sound will reach your ears no matter what you are doing (unless it is wearing very good earmuffs) (iii) The waves do not travel 'from' your ear. They travel from the gong to your ear when it is struck. (v) You do hear something but this sentence does not say what. (vi) You do hear the sound when it (the gong) vibrates but this sentence does not say <u>why</u>.
	3 (i)	Yes, the water molecules are easily able to vibrate and sound travels well in water because of this.
	(ii)	Possibly, as the vibrations from the hammer are very loud the wall may not be thick/high enough to completely stop the metal from vibrating.
	(iii)	No, as it is quiet there is not enough force to make the string vibrate over that distance.

	(iv)	No, if the friend were 'quietly' talking, the waves would have to pass over the wall and back down, but if the friend shouts or talks louder then yes.
	(v)	No, there are no molecules to pass the wave along so the sound cannot get out of the bell jar.
	(vi)	Yes, the siren is very loud and high pitched so you can hear it from a distance, even when the car is travelling fast away from you as sound travels very fast.
1 6	1	The vibrations made when the bird sings cause the air to compress then rarefact which then causes the air in front of it to do the same, thus forming a sound wave. This wave then reaches the childs ear and thus the child can hear it. No. of key elements present: 3.5 [no mention of how ear receives sound wave]
	2	Option selected: (iv) (i) This is true but you also hear the sound from when it is initially struck. (ii) You don't have to concentrate as the sound will reach you through the vibrating air. (iii) The sound waves travel in the other direction. (v) You don't hear the clapper strike, you hear the sound made by the gong as a result of the clapper striking it and causing the air to vibrate and travel to you. (vi) You don't hear the vibrating gong, you hear the noise when it is struck, which consequently makes it vibrate.
	3 (i)	Yes, the motor causes the sound waves to travel through the water to your ears.
	(ii)	Yes, the molecules in the steel vibrate thus the sound waves reach your ear.
	(iii)	Yes, the sound waves move down the string and the can acts as a resonator.
	(iv)	No, as the sound waves don't pass through the wall to your ears.
	(v)	No, because there is no medium for the sound waves to travel through to reach you.
	(vi)	Yes, the vibrating air caused by the siren will reach you and you will hear it.

17	1	The bird creates the sound by vibrating its vocal chords, these become the source of longitudinal waves in the air. When these waves reach the child they in turn vibrate in his ear. The waves could not travel in a vacuum therefore if there was no matter the child could not hear the bird. No. of key elements present: 4
	2	Option selected: (iv) (i) Does not state the presence of a medium, does not define the sound or the method of its creation. (ii) Does not state the presence of a medium, does not define the sound or its creation. (iii) Sound waves travelling the wrong way! (v) This implies that the gong could be heard even without a medium for the sound to travel through. (vi) Again this does not state the presence of a medium.
	3 (i)	Yes, reasonably dense medium for the sound to travel through.
	(ii)	Yes, there is a dense medium for the sound to travel through. [student has not said to what medium he is referring -steel or brick]
	(iii)	Yes, dense medium for sound to travel through.
	(iv)	No, quiet voices, low density medium (air).
	(v)	No, no medium for sound to travel through.
	(vi)	Yes, loud sound with dense enough medium.
18	1	The child has ears that pick up the sound the bird makes. The bird singing sets the air vibrating and these vibrations travel to the childs ear No. of key elements present: 3.5 [no mention of vibration of ear]
	2	Option selected: (iv) (i) Sound waves echo around the room. (ii) You listen to sound vibrations in the air. (iii) The sound waves travel from the gong to your ear. (v) You hear the air vibrating. (vi) You hear the sound because the air is vibrating.
	3 (i)	No, the sound waves don't pass through the water.
	(ii)	Yes, the sound waves vibrate through the steel.
	(iii)	Yes, the sound vibrates along the string.
	(iv)	No, depends on how quietly and the size of the wall.
	(v)	No, sound waves don't pass through a vacuum.

	(vi)	Yes, if it is still within range of the sound waves.
19	1	The sound waves that the bird generates travel through the air and will hit the boys ears which gather the sound and process it. The sound waves travel through the air by moving the air particles thus transporting the energy. No. of key elements present: 3 [no mention of vibrations]
	2	Option selected: (iv) (i) The sound travels throughout the room, not necessarily echoing. (ii) It isn't the concentrating that makes the sound 'reach' the ear. Sound waves travel from the gong to the ear. (iii) Sound waves have to go to the ear from the source, otherwise my ear would be making a noise and the gong listening. (v) Doesn't have any sort of explanation. (vi) Not enough explanation either.
	3 (i)	Yes, sound waves move in water, so the swimmer would hear them.
	(ii)	Yes, the steel carries the sound even though the wall doesn't.
	(iii)	Yes, the string takes the sound from one tin to the other.
	(iv)	No, the wall would stop the sound waves from reaching the listener.
	(v)	No, the vibrations from the clock have no medium in which to move.
	(vi)	Yes, the sound is 'sent' in all directions from the siren, so you can hear it.
20	1	The childs ears are used to pick up the frequency (ies) [sic] of the birds singing. When the bird sings its vocal chords move and it pushes air out of its mouth. This moving air causes a disturbance which is the vibration of the molecules of air. These air molecules vibrate the molecules adjacent to them and so on. The sound of the bird singing is dispersed through the air via the vibrating air molecules. The ear picks up this disturbance and recognises it as a bird singing. No. of key elements present: 3.5 [does not say how ear picks up disturbance]

	2	Option selected: (iv) (i) The sound travels by movement of air ie sound [wave?] when struck travels by movement echoes are movement. (ii) In a situation such as this, you would not need to concentrate to hear the sound - the sound is dispersed and travels to you. (iii) The sound waves travel from the gong to the ear, not ear to gong. (v) You don't hear strike, hear vibrations. (vi) Vibrations travel to you and hence you hear the sound.
	3 (i)	Yes, sound travels underwater.
	(ii)	Yes, steel vibrates then vibrates air (can hear a train on track)
	(iii)	Yes, string vibrates.
	(iv)	Possibly, probably not though as vibrations of air aren't great enough to move wall then air again.
	(v)	No, alarm clock cannot move any particles.
	(vi)	Yes, as sound travels in all directions.
2 1	1	The bird will vibrate chords (equivalent of vocal chords in humans) with air from lungs. The vibration of these chords will in turn vibrate the surrounding air. This process will continue ie air vibrates neighbouring air molecules, thus the initial vibration of the birds vocal chords will be transferred through space by this 'propagation'. The childs eardrum will interpret these vibrations as sound. No. of key elements present: 3.5 [student has not said eardrum vibrates]
	2	Option selected: (iv) Vibrations constitute a wave. (i) This is not accurate as it does not give a reason for the 'sound' to be heard, echo is a vague term. (ii) Whether you concentrate or not the sound wave will 'invade' your ear and you will inevitably hear it . (iii) The reverse of this is true, ie sound waves travel from a vibrating object to your ear not vice versa. (v) Yes, but this is very unspecific and not useful in terms of physical explanations. (vi) Yes, the sound travels as a result of the vibrations of the gong.
	3 (i)	Yes, sound waves will propagate quite well through water.

	(ii)	Yes, if your ear is close enough to the steel girder as it will have a low amplitude.
	(iii)	Yes, the sound waves will be propagated through the wire and 'amplified' by the tin.
	(iv)	How quietly? No, probably not even though waves diffract around obstacles.
	(v)	No, the vibrations will have no means of propagating through space.
	(vi)	Yes, for longer than when it approaches because of the Doppler effect [student drew diagram to illustrate Doppler effect]
22	1	The birds singing is a disturbance (vibration) in the air, this disturbance runs through the air in a process where one air molecule which has been disturbed disturbs the adjacent air molecule and so on until it reaches the childs ear which then converts these vibrations of the air into sound. No. of key elements present: 3.5 [student has not said ear vibrates]
	2	Option selected: (iv) (i) The gong does not make a sound but causes air vibrations which can be heard as sound. (ii) The sound travels to you, therefore you do not have to concentrate to hear it. (iii) The sound waves do not travel from your ear, but from the gong where the air disturbance first occurs. (v) You do not hear the strike but the vibrations. (vi)The gong does vibrate, but it is the vibrating air that you hear.
	3 (i)	Yes, as sound waves can travel underwater.
	(ii)	Yes, I'm not sure.
	(iii)	Yes, as the vibrations travel down the string (an easier path than air), therefore can be heard.
	(iv)	No, as the vibrationbs in the air would be reflected off the wall.
	(v)	No, as no air to vibrate.
	(vi)	Yes, as the air vibrations you will hear.
23	1	The birds voice box vibrates in and out thus displacing the air around it. This in turn sets up longitudinal waves. Thus the sound of the bird is transported through the air in the form of waves called "sound waves" where it is intercepted by the ear. No. of key elements present: 3.5 [no mention of vibration of ear]

	2	Option selected: (iv) (i) no comment. (ii) You do not have to concentrate on the sound, you will hear it whether you want to or not. (iii) The sound waves travel through the air from the gong to your ear, not from your ears to the gong. (v) No mention of the air vibrating. (vi) No mention of the air vibrating.
	3 (i)	Yes, the water is a good medium for sound to travel through.
	(ii)	No, sound waves do not travel through steel or brick.
	(iii)	Yes, vibrations (sound waves) can easily travel along the tight string.
	(iv)	No, brick is not a good medium for sound to travel through.
	(v)	No, there is no air to transport the sound waves, ie no medium with which the vibrations can move.
	(vi)	Yes, the sound waves can still reach your hear [sic] [ear?], through the medium (air).
2 4	1	Vibration of the birds vocal chords ----? vibrating air particles (waves) that travel through the air and are received by the childs ear. The sound wave has the ability to refract through the tree. No.of key elements present: 3.5 [does not say ear vibrates].
	2	Option selected: (iv) (i) The gong does make a sound when it is struck and could possibly echo but you would hear the sound before the echo. (ii) When the clapper hits the gong vibration must occur for you to be able to concentrate and listen to the soumd. (iii) It is impossible for the sound waves to travel from your ear to the gong - the sound would not be audible as they are going in the wrong direction. (v) Nothing wrong except lack of precise information, ie vibrating air. (vi) Nothing wrong except vibrating air travels to your ear.
	3 (i)	Yes, rotating propeller vibrates water particles to ear.
	(ii)	Yes, the vibration would travel from particle to particle along steel girder and then vibrating air to ear.
	(iii)	Yes, sound travels along string particle to particle and resonates air to can.
	(iv)	No, sound waves are unable to refract around/over wall.

	(v)	No, there is no medium for the sound waves to travel along.
	(vi)	Yes, sound waves travel in many directions.
2 5	1	The bird somehow through a voice box vibrating gets the air to vibrate. These vibrations are radiated out from the bird in the form of longitudinal waves that have compressions and rarefactions. The waves travel through the air by passing the energy of the vibration of the birds call from one air particle to the next. When it passes the childs ear the childs ear interprets the sound and hears it. No. of key elements present: 3.5 [no mention of vibration of ear]
	2	Option selected: (iv) (i) How do you know the sound is echoing. (ii) Even if you didn't concentrate the sound would still be there. (iii) The sound is emitted <u>from</u> the gong and would travel <u>from</u> the gong <u>to</u> your ears. (v) Not very precise - the gong must vibrate for the sound to be heard, ie to make sound waves. (vi) How does the sound get to your ears ?
	3 (i)	Yes, sound waves make water particles vibrate and this vibrational wave passes through water.
	(ii)	Yes, vibrations would travel along steel as long as the steel rod wasn't [muted?] by wall.
	(iii)	Yes, vibrations travel down string and are emitted by can.
	(iv)	No, sound waves can't pass through the brick wall because atoms of bricks locked into a solid lattice and can't transfer energy vibrations of sound.
	(v)	No, vacuum, therefore energy can't be transferred because no medium to transfer it through.
	(vi)	Yes, allow for Doppler effect, ie sound will be heard because vibrational sound energy is passed through the air to ears but won't be the same 'original' frequency because car is moving away.

2 6	1	The bird produces a sound which travels through the air in all directions. When these waves come to an object the [they?] rebound (reflected, not sure if they can be refracted). Eventually these waves will reach the child (either directly or indirectly) and the childs brain picks up the sound. No. of key elements present: 2.5 [no mention of ear nor of vibration of medium]
	2	Option selected: (iv) (i) Yes the gong does echo around the room but these echoes travel as waves through the air. An echo is a sound. (ii) You do not need to be looking at or concentrating on something in order for it to be heard, eg a fire alarm waking you from your sleep. (iii)Your ear isn't producing the sound, the gong is. (v) You don't hear sound immediately it is made, therefore this is not true, eg watch a man kick a ball some distance away and listen for the sound. (vi) Yes the gong does vibrate and you hear the sound of the gong vibrating but the sound must travel from the vibrating gong to your ear.
	3 (i)	Yes, because the engine and the swimmers ears are in the same medium.
	(ii)	Yes, a steel girder will vibrate at both ends producing a sound on either side of the wall.
	(iii)	Yes, the sound travels along the string when it is pulled tight.
	(iv)	No, however if you yell the sound will travel over or around the wall.
	(v)	No, the sound can't vibrate through a medium.
	(vi)	Yes, sound travels in all directions with the siren as a point of origin.
2 7	1	Sound is a longitudinal wave formed by compressions and troughs of air particles. These are transmitted to the neighbouring air particles which also do the same to adjacent air particles and so on. This longitudinal wave is transmitted through its medium of air until it reaches the childs ear. Here the vibrations are detected by the sensitive eardrum. No. of key elements present: 4

	2	Option selected: (iv) (i) This doesn't tell us why the sound echoes around the room - by what method. (ii) This doesn't explain how the sound is transmitted from gong to ear. It also suggests that you can only hear a sound if you concentrate. (iii) The sound waves do not travel from your ear to gong. It is in fact the reverse. The waves travel from gong to ear. (iv) This doesn't tell us how the sound is transferred from gong to ear. (v) This is a fairly good explanation but it is not as good as (iv). This doesn't tell us that sound can be transmitted through the medium of air to the ears through vibration.
	3 (i)	Yes, the sound wave propagates through the medium of water by vibrating the water particles until they reach your ear.
	(ii)	Yes, the sound travels through steel girder by method of vibration.
	(iii)	no response
	(iv)	No, due to quiet voice, the low frequency sound waves will dissipate through wall as it is denser medium. Sound will echo back to small degree.
	(v)	No, there is no medium for sound to vibrate through within a vacuum.
	(vi)	Yes, sound is transmitted in 3 dimensions but will be of lower frequency due to Doppler effect.
2 8	1	There is a medium between the ear of a child and the vibrating of lungs (or equivalent for bird to chirp) by the bird in the tree. The medium is known to us as air, Thus the vibration at the source (ie bird) causes a wave to be propagated in three dimensional space as the vibrations in the medium influences other particles that continue on the longitudinal wave. This causes the air near our ear to vibrate hence we hear the sound on our eardrum. No. of key elements present: 3.5 [no mention of vibration of ear]

	2	Option selected: (iv) (i) The echo does not explain why we hear it. It may well be the room echoes but this describes the room's audio properties. (ii) Sound is not based on an individual's concentration. It is a longitudinal wave set up in a medium of 3D space, our ears tell us we hear the sound, not whether we concentrate on it. (iii) This implies that the wave travels away from us and thus the source must be our ear - when it is not. The gong is the source of vibration. (v) This is a general overview of what happens. Rather no explanation is given to why the sound is heard. (vi) Same as above. It does not say that the medium between vibrates.
	3 (i)	Yes, the medium is water and the sound travels through vibrating particles.
	(ii)	Yes, the medium is steel, this in turn will pass vibrations onto air then ear.
	(iii)	Yes, again string acts as a medium and passes on to air and ear.
	(iv)	No, the wall may cause a weak vibration to lose 'energy' to surrounding, ie will not carry.
	(v)	No, no medium.
	(vi)	Yes, medium is air and Doppler effect makes lower pitched sound.
29	1	Sound waves travel from the bird. The sound waves are travelling vibrations which move through the air. These travelling vibrations are varying in pitch due to the amplitude of the sound wave. These sound waves are received by the ear and a sound is heard. No. of key elements present: 3 [student doesn't say how vibrations travel through air nor how ear receives sound wave]
	2	Option selected: (vi) (i) Not all of the sound echoes around the room. (ii) This is saying that hearing is a voluntary effort, when it is involuntary. (iii) This is saying that your ears make the gong sound which is completely incorrect. (iv) Not all of the sound travels to your ears. (v) This does not explain what you hear with your ears.

	3 (i)	Yes, the sound waves cause vibrations in the water.
	(ii)	Yes, the steel girder has vibrations.
	(iii)	Yes, vibrations run down the string.
	(iv)	No, the sound waves are deflected.
	(v)	No, as no air molecules are able to vibrate.
	(vi)	Yes, sound waves are still travelling through the air.
3 0	1	Sound is a compression wave. Since the atmosphere exists the sound can compress and decompress in the atmosphere so that it travels to the child. So the sound travels through the atmosphere. No. of key elements present: 2.5 [no mention of vibration of medium or of ear]
	2	Option selected: (ii) Right how I heard it. (i) Who says you are in a room? --- it makes a sound though. (iii) Not from your ear to the gong -- the other way around. (iv) The air does not vibrate -- it compresses. You do not hear this happening. (v) You only hear the manifestation of the gong and clapper --- not the actual happening of it. (vi) You do not initially hear the gong because of the vibrations. An un-vibrating object can still make a noise.
	3 (i)	Yes, the sound compresses the water.
	(ii)	Yes, you can get the ringing (the sound travels through the steel)
	(iii)	Yes, the sound travels through the string.
	(iv)	No, the sound bounces off from the wall back to them.
	(v)	No, sound cannot travel in a vacuum as it has nothing to compress.
	(vi)	Yes, you can hear it as the sirens 'noise' goes out at 360^{o}.
3 1	1	The bird produces localised regions of high and low pressure which travel through the air. These are sound waves. When regions of different pressure are next to the eardrum the drum flexes. No. of key elements present: 2.5 [no mention of vibrations]

	2	Option selected: (iv) (i) That is true if the gong is in a room, but you can hear it in an open space. (ii) You don't have to concentrate to hear sound, the mechanics of your body register it whether you like it or not. (iii) The sound waves travel from the gong to your ear, not the other way round. (v) You don't hear the gong, you hear the vibrations it makes. (vi) You don't 'hear the sound' you register the vibrations the gong makes.
	3 (i)	Yes, the vibrations travel through the water to your ears.
	(ii)	Yes, the vibrations travel through the wall.
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, the wall is too dense to allow soft sounds to be transmitted at high enough amplitude to be registered by your ears.
	(v)	No, there is no medium for the waves to travel through.
	(vi)	Yes, unless the car is going faster than sound, the waves will travel backwards relative to the cars motion (the apparent frequency will be lower due to Doppler effect).
3 2	1	The bird forces the air coming out of its lungs to be compressed which gives the sound its frequency or pitch. The child receives the waves via the eardrum which vibrates in synch. with the original sound. No. of key elements present: 2.5 [no mention of vibration of medium or travel through medium]
	2	Option selected: (i), (iv), (v) and (vi) (ii) Sound waves are produced as a physical consequence of the gong being struck, not as a consequence of you concentrating. (iii) The sound is initially made by the gong, therefore it must travel from the gong to the ear.
	3 (i)	Yes (no explanation).
	(ii)	Yes (no explanation).
	(iii)	Yes (no explanation).
	(iv)	No (no explanation).
	(v)	No, sound needs a medium to carry the vibrations, a vacuum has no particles.
	(vi)	Yes (no explanation).

3 3	1	The birds vocal chords vibrate. The vibrations travel away from the bird like ripples in the water. When the vibrations reach the child they cause a very thin piece of skin down in the ear (the eardrum) to vibrate. No. of key elements present: 2.5 [no mention of medium]
	2	Option selected: (iv) I am implying that it is struck in here. If it is intended that it is not struck then I go for (vi). (i) This describes the behaviour of the sound not how it gets to you. (ii) Concentration is not essential in order for you to hear the gong. (iii) The sound waves come from the gong. (v) This is not as explicit as (iv). (vi) Not as explicit as (iv).
	3 (i)	Yes, sound needs to be quite loud.
	(ii)	Yes, steel transmits sound well.
	(iii)	No, string doesn't transmit sound very well.
	(iv)	No, bricks don't transmit sound well.
	(v)	No, air is needed to transmit the vibrations.
	(vi)	Yes, sound goes in all directions.
3 4	1	When the bird makes a sound it is creating a compression wave, ie a region of varying density in the medium through which it is travelling. These compression waves are interpreted by the ear. No. of key elements present: 2.5 [no mention of vibration of medium or of ear]
	2	Option selected: (iv) (i) Echoes occur when sound reverberates off a surface and reaches your ear after the sound of the gong reaches your ear. In other words, the above sentence doesn't make sense. (ii) I suppose if you were totally devoid of concentration you mightn't hear the gong but it's unlikely. (iii) Sound doesn't travel like normal transverse waves. (v) It doesn't explain anything, it just states the question. (vi) Doesn't explain enough.
	3 (i)	Yes, sound travels through most, if not all, mediums.
	(ii)	no response
	(iii)	no response
	(iv)	no response

	(v)	no response
	(vi)	no response
3 5	1	If the child is not deaf and is within the range of the waves on which sound travels of the birds chirping he should be able to hear the bird. The child can hear the bird because the sound from the bird resonates in waves and travels outward from the origin (the bird) eventually reaching the boy where the waves will penetrate his eardrums. No. of key elements present: 2 [no mention of medium or vibration or how ear receives sound waves]
	2	Option selected: (iv) (i) This is not how I would hear the sound, its how the sound echoes/travels. (ii) The clapper/gong produce the sound and if you are within range you will hear it regardless of whether you concentrate or not. (iii) The sound waves travel through the air from the gong not ear to your ear not gong when it is struck [response unintelligble] (v) True statement but not the best description as it doesn't describe how it reaches my ears. (vi) As for (v).
	3 (i)	Yes, vibration of sound greater hence louder, longer under/in water, ie sound does travel in water.
	(ii)	Yes/No, depends how hard hammer struck.
	(iii)	Yes, because I've tried this.
	(iv)	No, the sound waves will be blocked by wall if its high and sound low.
	(v)	No, nothing for sound to vibrate with.
	(vi)	Yes, if the siren continues you'll still hear it. Yes, as sound travels in waves it will reach you after.
3 6	1	The birds singing travels by sound waves the distance to the child. The child is hearing the singing some time after the bird actually sings. No. of key elements present: 1.5 [no mention of medium or vibration or how child hears the sound]

	2	Option selected: (i) (ii) no comment. (iii) The sound waves travel from the gong to your ear. (v) no comment. (vi) The sound must travel by sound waves, you can't just hear it.
	3 (i)	Yes, the sound waves travel through the water to your ears.
	(ii)	Yes, the sound vibrations travel through the steel.
	(iii)	Yes, sound travels through the string.
	(iv)	No, not loud enough.
	(v)	No, won't vibrate foam because the foam absorbs the vibrations.
	(vi)	Yes, sound waves echo around the street.
3 7	1	The vibrations made by the bird to produce the sound are converted into sound waves which travel through the air in all directions. The childs eardrums pick up these waves which cause vibrations within the ear and send messages to the brain so that the child recognises a sound. No. of key elements present: 3.5 [doesn't say how sound waves travel through the air]
	2	Option selected: (i) (ii) You don't need to concentrate to hear the sound as you will hear the sound from the sound waves reaching your ear regardless whether you are concentrating. (iii) This is wrong as the sound waves travel from the gong to your ear not from your ear to the gong. (iv) The vibrations cause sound waves but they don't travel through the air as vibrations as they are now sound waves. (v) This is true but you also hear the echoing of the gong as well as the actual striking of the gong. (vi) You don't hear the vibrations, you hear the sound waves caused by the vibrations.
	3 (i)	No, as the water is much denser than air, thus making it harder for the sound to travel to you.
	(ii)	Yes, as the sound will travel through the steel and you will be able to hear with your ear pressed against the steel.
	(iii)	Yes, as the wave motion can be transferred along the tight string.
	(iv)	No, as the sound waves would bounce off the wall back to you instead of travelling to the other person.
	(v)	Yes, as the waves will still be able to travel.

	(vi)	Yes, as the sound waves are still travelling around.
3 8	1	The bird sends vibrations as sound waves through the air. These waves reach the childs ears and vibrate the childs eardrum which sends signals via nerves to the brain. No. of key elements present: 3.5 [no mention of vibration of air]
	2	Option selected: (vi) (i) This makes no reference to sound waves and that the sound echoes has no bearing on how you hear it. (ii) This doesn't physically tell you how the sound reaches you, only how the sound is produced and what you do in response. (iii) The sound waves travel from the gong to your ear not from your ear to the gong. (iv) The air doesn't vibrate, oscillating sound waves vibrate through it. (v) This doesn't say how, only what happens.
	3 (i)	Yes/No, it depends on the frequency of the sound, only very high pitches can travel through water.
	(ii)	Yes, the girder is vibrating such that it makes sound, the wall does nothing.
	(iii)	Yes, the string vibrates varyingly depending on the sound waves from your friend it 'transmits' the sound to you.
	(iv)	Yes, because waves travel around corners.
	(v)	Yes, sound can travel through vacuums.
	(vi)	Yes, because of Dopplers effect.

Appendix 11 Responses of year 6 students to questionnaire on sound and hearing

Student Number	Question Number	Response
1	1	Through his ear the vibration from the bird travelled to the boys ear.
	2	Option selected: (iv) (i) no comment. (ii) you don't always have to concentrate to hear something. (iii) the sound waves don't travel from your ear to the gong the gong sound travels to your ear. (v) no comment. (vi) no comment
	3 (i)	No, because your ears would be blocked from the water.
	(ii)	Yes, because the bang on the wall would vibrate.
	(iii)	Yes, you could because the sound waves travel along the string.
	(iv)	no response.
	(v)	No, because there is no air.
	(vi)	Yes, because the siren is loud.
2	1	The bird makes a sound and invisible sound waves travel through the air and reach his ear.
	2	Option selected: (iv) (i) no comment. (ii) I don't have to concentrate very hard to hear the sound. If I am noisy I may have to be quiet but thats all. (iii) The sound waves don't go from your ear to the gong they go from the gong to the ear. (v) The sound travels to your ears in waves. (vi) no comment.
	3 (i)	Yes, because it is very loud and you can hear some things under water - but not talking.
	(ii)	Yes, because if you hit metal with something hard it makes a noise and I think you should be able to hear it.
	(iii)	Yes, because the vibrations travel through the string.
	(iv)	No, it depends how quietly and how high the wall is but probably not.

	(v)	Maybe, probably if you could only quietly.
	(vi)	Yes, ???????? [sic]
3	1	The boys ears are very sencitive [sic] to noise and can hear the birds sharp chirping.
	2	Option selected: (i) (ii) You don't need to concerntrate [sic] and listen to the sound because the sound is so loud. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, because the sound travels through the water.
	(ii)	Yes, because the sound is able to go through the wall.
	(iii)	Yes, because the sound vibrates between the two.
	(iv)	Yes, because any sound can be carried very far.
	(v)	Yes, because the sound would travel out the top of the jar.
	(vi)	Yes, because the sound would echo all around the area.
4	1	The ears hear a bird. Sound travels very fast so almost as soon as the bird sings the boy hears it even from a great distance the sound reaces [sic] him almost amediatly [sic].
	2	Option selected: (iv) or (vi) - student is not sure which one. (i) The sound has to eventualy [sic] reach your ears. (ii) Even if you don't concentrate you still hear the sound. (iii) It travels from the gong not your ear. (v) Dosent [sic] describe what happens eg how it gets to your ears. (vi) ? [sic]
	3 (i)	Yes, the vibration of the motor flows to our ears.
	(ii)	Maybe you could maybe not the hammer would let off vibrations.
	(iii)	Yes, the tount [sic] string lets your friends voice vibrate down.
	(iv)	Yes, noise vibratiant [sic] can float over a wall.
	(v)	No, there is no air for it to vibrate in.
	(vi)	Yes, the siren is a loud noise and even a great distance away it can be heard.
5	1	He can hear the bird in the tree because he has ears and he isn't death [sic]. He can also hear the bird because he is listening.

	2	Option selected: (iv) (i) When a gong is hit it dosen't [sic] echo. (ii) When the clapper strikes the gong it makes a sound and you don't have to listen to it, or concentrate. (iii) When you hit the gong it is surposed [sic] to travel through the air to your ear. Not from your ear to the gong. (v) When the clapper strikes the gong the gong needs to vibrate and make a sound. (vi) When the gong is hit by the clapper it vibrates but it needs to vibrate through the air.
	3 (i)	Yes, you would because the engine is loud and it would vibrate.
	(ii)	Yes, you would because it hit the wall and it would vibrate a lot.
	(iii)	Yes, because the tins are joined and the sound would vibrate along the string.
	(iv)	No, because a high and thick wall would stop the sound.
	(v)	No, because there is no air in the bell jar.
	(v)	Yes, because the siren is loud.
6	1	When the bird sings the sound rings around it when you go so close the sound waves travel to you and you listen.
	2	Option selected: (iii) (i) I [sic] didn't say it was going to your ear. (ii) You do concentrate and listen to the sound but it didn't say it made a noise. (iv) I think this one is partly right but number 3 is better. (v) ? [sic] (vi) The sound vibrates.
	3 (i)	Yes, sound is always louder under the water.
	(ii)	No, I don't think you would be able to hear it. Mabey [sic].
	(iii)	No, sound dosn't [sic] travel through plain string.
	(iv)	Yes, you would be able to hear it.
	(v)	Yes, comparing with mine defaletly [sic].
	(vi)	Yes, you would be able to hear it easly [sic].
7	1	With his ears and his brain and picturing and concentrating on the bird.

	2	Option selected: (i) there [sic] all right but the first one is the one that I would describe it as. (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	No, because your [sic] under water.
	(ii)	Yes, because it vibrates.
	(iii)	Yes, because the voice travells through the string.
	(iv)	Yes, because the sound goes over the brick wall.
	(v)	No if the vacuum was on and yes if it was on [sic].
	(vi)	Yes, because it is so loud.
8	1	The boy can hear from his ears.
	2	Option selected: (i) (ii) When the clapper strikes the gong you dont [sic] have to listen hard you can just hear because it is so loud. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	No, because you ears become cloged [sic] up when you are under the water.
	(ii)	Yes, because the sound through the wall will vibrat [sic].
	(iii)	Yes, because the sound will vibrat [sic] on the string.
	(iv)	No, because the sound wont vibrat [sic] enough because it's to [sic] quiet.
	(v)	no response.
	(vi)	Yes, because the sound will ecoh [sic].
9	1	no response.
	2	Option selected: (iii) and (v) (i) If you can only hear a sound when it echoes you wouldn't be able to hear the things outside that don't echoe [sic]. (ii) You don't always concentrate to listen. (iv) I don't think all things vibrate. (v) This may also be correct. (vi) What sound do you hear? I don't understand.

	3 (i)	Yes. (no explanation)
	(ii)	Yes, you can hear the vibration.
	(iii)	No, sound doesn't travel down string but it does in a pipe.
	(iv)	No, I don't know why because I think it depens [sic] on personality. Some people talk loud and others think they are shouting.
	(v)	no response.
	(vi)	Yes (no explanation)
10	1	The bird would sing and the sound would vibrate through the air and reach the childs ear. Also birds don't sing they whistle.
	2	Option selected:(iv) (i) This does not describe it that well. (ii) This sentence isn't right because you don't concentrate to hear the sound. (iii) This sentence doesn't work because the sound waves come from the gong not your ear. (v) This sentence does not describe this well. (vi) This sentence is not as good as 4 because it does not describe well.
	3 (i)	Yes, the sound would vibrate through the water.
	(ii)	Yes, the sound would vibrate along the girder?
	(iii)	Yes, the sound would vibrate along the string?
	(iv)	No, the sound would have no where to go.
	(v)	No, the sound would have nothing to be carried through.
	(vi)	Yes, the sound would still be in the air and the siren would be loud so you could hear it from far away.
11	1	The child can hear the bird because it makes a sound that can travel a long distant [sic] and so the child can hear it.

	2	Option selected: (iv) (i) I think that this sentence is wrong because it doesn't explain how the sound gets to the ear. (ii) I think that this sentence is wrong because it doesn't really explain much because sometimes you don't have to concentrate to listen. (iii) I think that this sentence is wrong because it doesn't travel from your ear it travels from gong to your ear. (v) I think that this sentence is wrong because it doesn't say that it vibrates in any way and it doesn't explain how the sound got to the ear. (vi) I think that this sentence is wrong because it doesn't say how you hear the sound.
	3 (i)	Yes, because the sound of the engine would vibrate.
	(ii)	Yes, because the sound would vibrate through the wall.
	(iii)	Yes, because it vibrates through the tin.
	(iv)	Yes, because the sound would bounce over the wall and also it would echo.
	(v)	You could probably not hear it it would just be a faint sound.
	(vi)	Yes, because the siren would be very loud. It would echo.
12	1	The child can hear the bird because he is listening hard. The bird is using its vocal cords to let the boy hear its beautiful music.
	2	Option selected: (iv) (i)This does happen but it doesn't explain how I would hear it. (ii) I don't think I would have to concentrate to a gong because it is very loud. (iii) The sound wave travel from the gong to my ear not from my ear to the gong. (v) A lot more things would happen for me to hear the gong. (vi) This also doesn't explain how I hear it.
	3 (i)	Yes, the engine would vibrate the water.
	(ii)	Yes, a hammer srucking [sic] a piece of steel is very loud.
	(iii)	Yes, her voice would vibrate along the string.
	(iv)	No, the wall would be to [sic] high for the sound to travel over.
	(v)	No, the air would need to be there for the bell to be heard.
	(vi)	Yes, the sound will travel through the air.

13	1	The sound is a vibration and can travel on air. The air carries the vibration to your ear.
	2	Option selected: (iv) (i) This means it is going round the room not in your ear. (ii) I do not have to concentrate to listen to the sound. (iii) I would think the sound travels from the gong to your ear not from your ear to the gong. (v) This does not describe very well. (vi) This does not say how you hear it.
	3 (i)	Yes, you would hear the engine with the sound carried by the bubbles.
	(ii)	no response.
	(iii)	Yes, the sound is carried on the tight string.
	(iv)	No, the wall would block a quiet sound but a loud sound could get over.
	(v)	No, the glass would block the way.
	(vi)	Yes, cause it says just after the car passed.
14	1	The child can hear the boy can hear the bird because the bird sends out sound waves which the boy can hear.
	2	Option selected: (i) (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes (no explanation)
	(ii)	Yes, just a little sound I think.
	(iii)	Yes, but I think you might have to talk in a normal voice.
	(iv)	No, because if you were talking quietly and the wall was very hight [sic] you would not hear the person talking.
	(v)	Yes=No. No not really but you might hear a faint sound.
	(vi)	Yes (no explanation)
15	1	The bird is making a sound so the boy can hear it through sound waves.

	2	Option selected: (iii) (i) I think it is wronge [sic] because the gong creates sound waves and it doesn't echo. (ii) It's wrong because we just automaticly [sic] hear the sound you don't really need to concerntrate [sic]. (iv) It doesn't really make the air vibrate it creates sound waves. (v) I think it's wrong because the gong creates sound waves. (vi) The gong will vibrate but it is the clapper hitting the gong that makes the sound.
	3 (i)	Yes, 'cause the engine creates sound waves that travel through the water.
	(ii)	No, because the sound waves can't get through.
	(iii)	Yes, 'cause the sound travels through the string.
	(iv)	Yes, 'cause the sound waves travel over the wall.
	(v)	No, because the sound waves can't get out.
	(vi)	Yes, because by the time the police car passes the other car is gone.
16	1	The child can hear the bird singing because the noise carries from the birds mouth into the persons ear because of the vibration. I really don't know much about it.
	2	Option selected: (iv) (i) I think that everyone really knows the when the gong is struck the noise echoes around the room. (ii) I don't think you need to concentrate to hear the gong. (iii) The bit that says from the ear to the gong sounds a bit strange. (v) I think you know in the first place you will hear it with your ears. (vi) I think I know that the gong would vibrate if you hit it.
	3 (i)	Yes, I think you could because the vibrations would probably travel through the water and get to your ears.
	(ii)	Yes, I think that you could hear a faint bang through the wall if you were that close to it.
	(iii)	No, I don't know, but I think if you were talking quietly it wouldn't work, but if you were rather loud you might be able to.
	(iv)	Yes, you could hear over the top of the wall, depending on how loudly they spoke.
	(v)	No, the sound would have to travel through too many things.

	(vi)	Yes, because the sound would still be close to you, but slowly it would fade away as the car got further away.
17	1	He can hear the bird singing because he can see it and he listened closely and he can hear the bird. He isn't very far away so the singing of the bird could be quite loud.
	2	Option selected: (iv) and (v) (i) The sound doesn't echo around the room. The gong echos. (ii) For people who have hearing problems that might be the case. (iii) The waves don't travel from your ear but from the gong. (vi) That is right.
	3 (i)	Yes, noises make things vibrate.
	(ii)	Yes, if you were close to the wall you could.
	(iii)	No, you need to talk loudly to make sure they hear your message.
	(iv)	Yes, if my friend was looking up at the wall. If looking down No.
	(v)	Yes, the noise would make things vibrate around it and I would hear it.
	(vi)	Yes, the sirens are designed to be loud so people know to clear the way for the police.
18	1	The child hears the bird through his ear after the sound has travelled.
	2	Option selected: (v) (i) It doesn't say were the sounds goes for you to see it [sic]. (ii) You don't need to concentrate. (iii) This one is totally silly because you don't send the sound waves. (iv) no comment. (vi) What do you hear it with.
	3 (i)	Yes, because it is quite a loud noise and the motors in the water.
	(ii)	Yes, because it vibrates it sends quite a strong and piercing sound.
	(iii)	Yes, because the sound travels somehow along the string and onto your side.
	(iv)	No, because their quite [sic] and the wall is stopping the sound.
	(v)	No, because there is no air for the sound waves to travel on.

	(vi)	Yes, because it is very loud and the sound only gets quieter the further away it is.
19	1	The sound of the bird would travel from the bird to his ear.
	2	Option selected: (vi) This is the best answer. (i) This allmost sound right [sic] but there is a better answer. (ii) You don't have to concentrate to hear the sound. Because the sound is loud. (iii) It happens the other way round. (iv) no comment. (v) not quite.
	3 (i)	Yes, you can hear a gergerly [sic] sound.
	(ii)	Yes, you could hear a claning [sic] sound.
	(iii)	No, but nearly.
	(iv)	No, the wall would be to [sic] high.
	(v)	? Don't anderstand [sic].
	(vi)	Yes, for sure.
20	1	With its ears.
	2	Option selected: (i) I don't know how to explain them because they sound the same. (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, because the sound travels if you are under water.
	(ii)	Yes, because it would vibrate as it went through.
	(iii)	No, because the tin things don't work.
	(iv)	It depens [sic] how high the wall is but I think you wouldn't be able to hear.
	(v)	No, because alarm clocks wake me up.
	(vi)	Yes, because you can hear the sound for a while.
21	1	The bird sings a tune and the noise gets carried into the boys ear.

	2	Option selected: (vi) (i) No comment. (ii)You don' really need to concentrat [sic] to hear the gong. (iii) I think about it the other way the sound waves travel through the air from the gong to your ear. (iv) I bit to much detail [sic]. (v) It does not explain how you hear it. (Does it vibrate or what) (vi) This explains it simply yet it tells you that the gong vibrates and things like that to mak [sic] it easy to understand.
	3 (i)	Yes, you would because of the vibrating engine.
	(ii)	Yes, it would vibrate.
	(iii)	Yes, you would probably hear your friend.
	(iv)	You could but you would have to listen pretty hard.
	(v)	You could but it would be muffled.
	(vi)	Yes, deffertly [sic].
22	1	Well the birds pretty close to him. The bird seems to have a higher voice than other creatures, so usually you could pick a bird from a dog for example. Also the sound is coming from a tree so you could also figure it out like that.
	2	Option selected: (i) (i) I think the sound echoes through the room because it is a low and powerful sound. (ii) I don't think you concentrate on the sound because the sound sort of gives you a fright, because you can know whats going to happen but you don't relise [sic] the effect really. (iii) no comment. (iv) no comment. (v) I think that's what sort of happens but number one is an easier way to think of it. (vi) no comment.
	3 (i)	Yes, you could probably hear it sort of echoeing.
	(ii)	Yes, I'm not sure but I thing [sic] it would probably vibrate and be an annoying sound.
	(iii)	Yes, I've tried it before and I can hear whoever it is whispering.
	(iv)	No, I don't think you could hear it because the wall blocks the sound.
	(v)	no response.

	(vi)	Yes, you could still hear the sound ringing in your head about 1 minute later.
23	1	Well the birds cherp [sic] is loud and the nerves in the boys ears can sence [sic] that it is the birds voice singing out loud.
	2	Option selected: (iv) (i) no comment. (ii) Concentration will not help you hear the sound but listnig [sic] will. (iii) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, because sound vibrations can be heard from under water.
	(ii)	Yes, because sound can be heard from away away.
	(iii)	Well not really.
	(iv)	No, because a soft sound can not travel as well.
	(v)	Yes and No, you could proberly [sic] hear a faint noise.
	(vi)	Yes, because it shure [sic] is a loud noise.
24	1	The bird sings and the sound waves travel through the air and the boy picks up the sound with his ear. He can now hear the bird singing!
	2	Option selected: (iv) (i) This is a good sentance [sic] except one of the other sentences describes it more clearly. (ii) I don't concentrate very hard when I am listening to a loud sound. (iii) I don't think that makes any sence [sic]!! (v) This is a good sentance [sic] but I think vibrating is an important word. (vi) This is a very good sentance [sic] except I think No.4 explains it more clearly.
	3 (i)	Yes, a motor can be very loud.
	(ii)	Yes, hammering is very loud.
	(iii)	Yes, I have tried it once.
	(iv)	No, the wall is too big.
	(v)	? [sic]
	(vi)	Yes, you seem to listen very hard when you hear a siron [sic].

Appendix 12 Transcripts of interviews with year 1 students on sound and hearing

Student 1

Interviewer: *I want you to tell me how you hear. If I talk to you how do you hear?*

Student: Out of my ears.

Interviewer: *If we were underwater and I spoke to you or if I made a noise, eg if I banged 2 blocks together, would you be able to hear that?*

Student: Yes.

Interviewer: *Very clearly?*

Student: Yes.

Interviewer: *What if we both went way out in space and I spoke to you would you be able to hear me?*

Student: Yes.

Interviewer: *If you and I are talking is there anything between us?*

Student: Yes, the floor.

Interviewer: *Anything else, something you can't see for example?*

Student: No response.

Interviewer: *What about air? There is air between us.*

Student: Yes.

Interviewer: *Do you think air helps you to hear? Would you hear if there wasn't any air there?*

Student: No

Interviewer: *Why not?*

Student: Don't know.

Student 2

Interviewer: *I want you to tell me how you hear a sound?*

Student: With my ears.

Interviewer: *If we were swimming underwater and I made a noise, would you be able to hear that?*

Student: Maybe

Interviewer *What do you think you would need to be able to hear it?*

Would it need to be very loud?

Student: Yes.

Interviewer: *What if we both went way out in space and I spoke to you would you be able to hear me?*

Student: No.

Interviewer: *Can you think why not? Why mightn't you be able to hear me talking?*

Student: Because it's far away.

Interviewer: *But if we're fairly close to eachother. I'm up there with you. Is there any air up there in space?*

Student: No.

Interviewer: *If you and I are talking how does the sound get to you?*

Student: It floats in the air.

Interviewer: *Would you be able to hear if there wasn't any air?*

Student: No.

<u>Student 3</u>

Interviewer: *I want you to tell me how do you hear something, e.g. how do you hear the sound of my voice?*

Student: With my ears.

Interviewer: *If we were swimming underwater and I made a noise, would you be able to hear that?*

Student: No

Interviewer: *What if we both went way out in space and I spoke to you would you be able to hear me?*

Student: Maybe. Probably.

Interviewer: *If you and I are talking how does the sound get to your ears?*

Is there anything between us? Anything between my voice and your ears?

Student: Air.

Interviewer: *Do you think if there wasn't any air there you'd still be able to hear?*

Student: No.

Interviewer: *Why not?*

Student: I think the air would send the sound of my voice to your ears.

Student 4

Interviewer: *How do you hear the sound of my voice?*

Student: With my ears.

Interviewer: *Do you have any idea how the sound of my voice gets to your ears?*

Student: No response.

Interviewer: *Well let's look at some other situations. What if you and I were swimming under the water and I made a noise under the water, I banged two stones together, would you be able to hear that sound?*

Student: Yes.

Interviewer: *Very well? Would you hear clearly?*

Student: Yes [very tentative and soft]

Interviewer: *What if you and I went right out in space, Right out where the rocketships go, would you be able to hear me talking to you out there?*

Student: No response.

Interviewer: *If we're talking, is there anything between us when we're talking?*

What's all round you, that you can't see?

Student: Air.

Interviewer: *Do you think air has anything to do with you hearing me?*

Do you think you'd hear if I took all the air away? Wouldn't it matter?

Student: No response.

Student 5

Interviewer: *How do you hear the sound of my voice? Do you know?*

Student: No.

Interviewer: *What do you use to hear?*

What do you hear with?

Student: My ears.

Interviewer: *What if you and I were swimming under the water and I made a sound under the water, I banged two stones together, do you think you might be able to hear me underwater?*

Student: I don't know.

Interviewer: *What if you and I went right out in space, Right out where the rocketships go, would you be able to hear me talking to you out there?*

Student: I don't know.

Interviewer: *If we're talking, is there anything between us when we're talking?*

What's all round you, that you can't see?

Student: Air.

Interviewer: *Do you think air has anything to do with you hearing me?*

Student: I don't know

Interviewer: *Do you think if I took all the air away you'd still be able to hear me?*

Student: I don't know.

<u>Student 6</u>

Interviewer: *How do you hear the sound of my voice?*

What do you hear with?

Student: Ears.

Interviewer: *What if you and I were swimming under the water and I made a sound under the water, I banged two stones together, do you think you might be able to hear me underwater?*

Student: Yes

Interviewer: *What if you and I went right out in space, Right out where the rocketships go, would you be able to hear me talking to you out there?*

Student: Yes

Interviewer: *If we're talking, is there anything between us when we're talking?*

What's all round you, that you can't see?

Student: The School.

Interviewer: *Something you can't see.*

What are you breathing?

Student: Air.

Interviewer: *Do you think air helps you to hear? Do you think its important?*

Student: Yes (tentative)

Interviewer: *Do you think if you took all the air away you'd still be able to hear?*

Student: No.

Interviewer: *Do you know why not?*

Student: Because the air is very important.

Interviewer: *Can you tell me why it's important?*

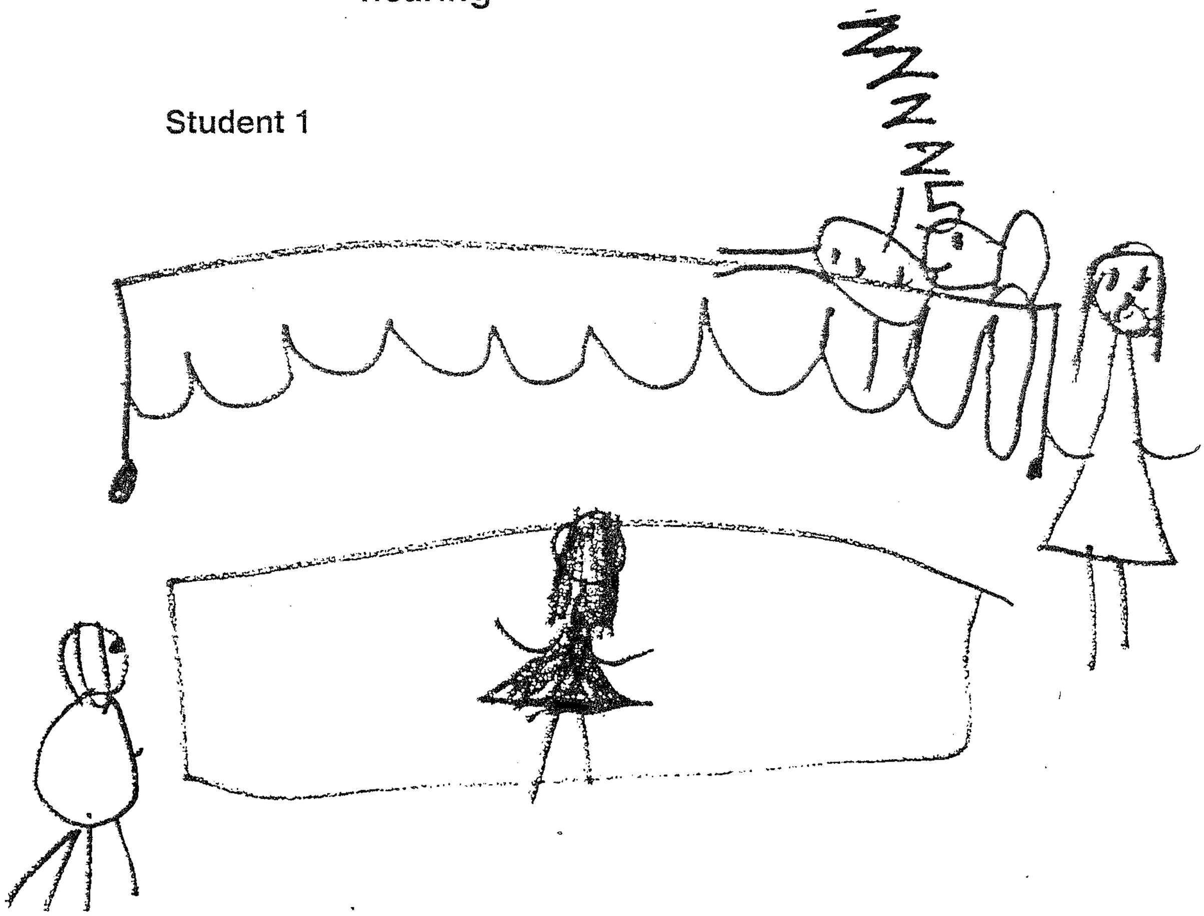
Student: Because it helps you hear?

Interviewer: *Do you know why? What's it do? How does it help?*

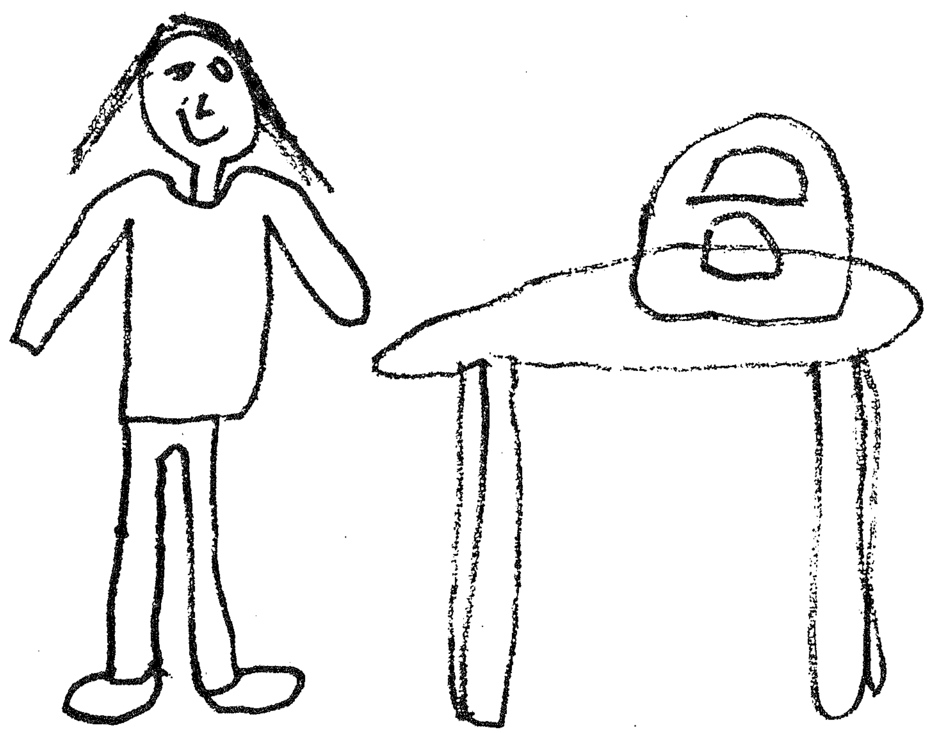
Student: Don't know.

Appendix 13 Drawings of year 1 students on sound and hearing

Student 1



Student 2



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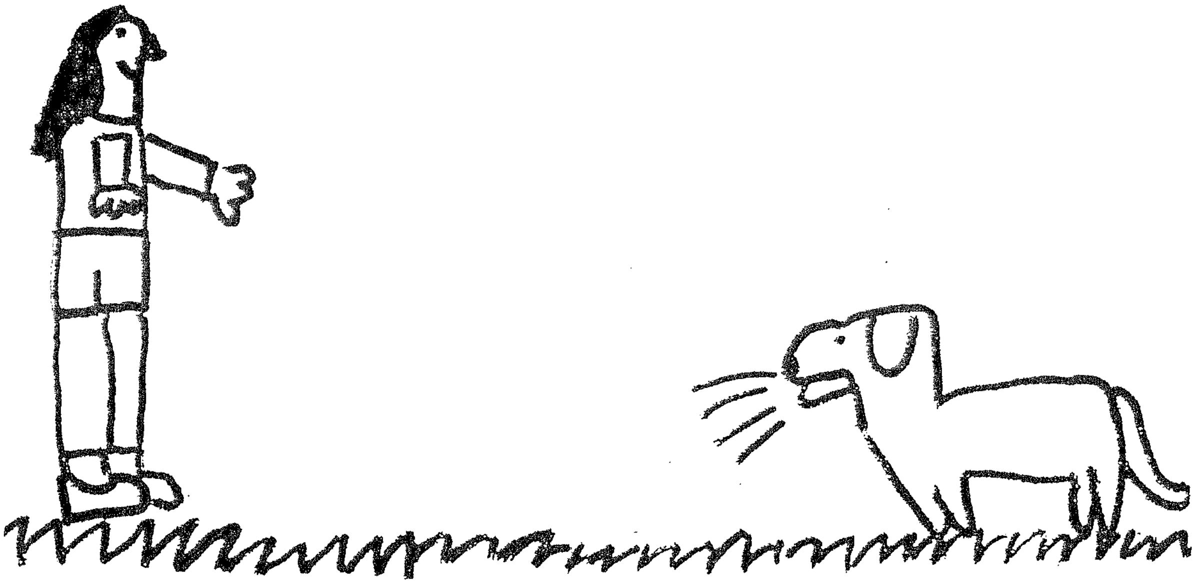
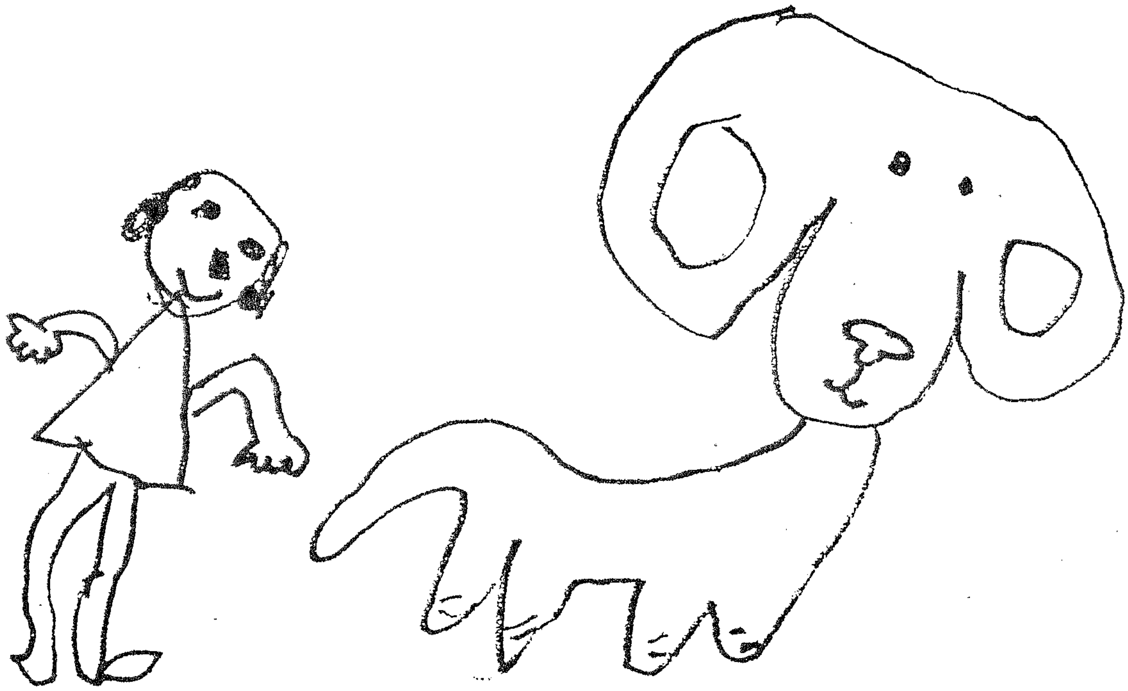
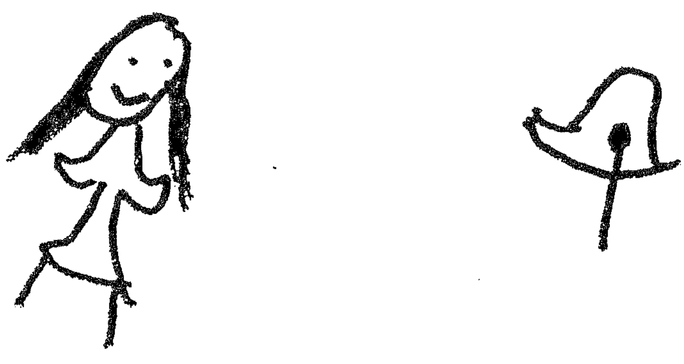


Student 4

Student 5



Student 6



Appendix 14 Transcripts of interviews with year 3 students on sound and hearing

Student 1

Interviewer: *What I want to ask you about is how you think you hear something. If I say to you how do you hear the sound of my voice, what is your response?*

Student: Well, sort of in the middle, not really low, not really high.

Interviewer: *That's the actual tone of my voice. What about how do you actually hear. How does the sound of my voice get to you?*

Student: Mmm.

Interviewer: *To start off, what do you actually hear me with?*

Student: Ears.

Interviewer: *Do you know how the sound of my voice gets to your ears?*

Student: Mmm.

Interviewer: *OK. Let's try something a little different. What if we were underwater. We were both swimming underwater and I made a noise like banging two pieces of wood together. Do you think you would hear me under the water?*

Student: Not very well.

Interviewer: *Would you hear me at all?*

Student: Yes.

Interviewer: *OK. What about if we were up in space and we were both space men out on Mars and I was talking to you. Do you think you would hear me then?*

Student: Not really.

Interviewer: *Why don't you think you might hear me in space?*

Student: I'm not sure.

Interviewer: *OK. Let's go back a bit then. If we were swimming under the sea and I make a noise that you can hear. What is between you and me?*

Student: Lots of water.

Interviewer: *If I am sitting here talking to you, what's between us?*

Student: Air.

Interviewer: *What about when we are out in space, is there anything between us up t here?*

Student: No.

Interviewer: *Why not?*

Student: Because there's no air and you can't breathe unless you have a back thing and there's no water.

Interviewer: *So do you think it is necessary to have the air for you to hear me?*

Student: Yes.

Interviewer: *Do you have any idea why it might be necessary for there to be air between us in order for you to hear me?*

Student: Mmm.

Interviewer: *Do you think the air has any part in the sound coming from me to you?*

Student: Yes.

Interviewer: *Do you know what part it plays, what it does?*

Student: No.

Student 2

Interviewer: *I want to ask you about sound and how you hear. So if I am sitting here talking to you can you tell me how you hear the sound of my voice?*

Student: Umm. By listening to you.

Interviewer: *And what do you use to hear me?*

Student: My ears.

Interviewer: *Do you know how the sound of my voice gets to your ears?*

Student: By sound waves.

Interviewer: *And how do those sound waves get to the ears?*

Student: No response.

Interviewer: *Is there anything between you and me?*

Student: Air.

Interviewer: *Do you think that air is necessary for the sound waves to get to your ears? Would they still get there if there was no air?*

Student: No

Interviewer: *So do you think the air's important?*

Student: Yes.

Interviewer: *What about if we were swimming in the ocean and we were deep down in the water and I banged two blocks together and made a noise, do you think you'd hear that under the water?*

Student: No

Interviewer: *So what's between us there?*

Student: Water.

Interviewer: *What about if we went right out in space and we were astronauts far out in space. Do you think if I spoke to you out there you'd be able to hear me?*

Student: Yes.

Interviewer: *What's between us when we're way out in space?*

Student: Space.

Interviewer: *Is there air between us?*

Student: Yes umm No (more definitely).

Interviewer: *So there's no air out in space so do you think you'd hear my voice?*

Student: No [tentatively]

Interviewer: *Do you think space would allow you to hear my voice?*

Student: No.

Interviewer: *What would you have to have there?*

Student: Some air.

Student 3

Interviewer: *Now I want to talk to you about sound and how you hear. So if I am sitting here talking to you now, how do you hear the sound of my voice?*

Student: It's nice and clear.

Interviewer: *What do you use to hear me?*

Student: My ears.

Interviewer: *Do you know how the sound of my voice gets to your ears?*

Student: Vibration.

Interviewer: *Yes, vibration of what?*

Do you know what's vibrating?

Student: Air

Interviewer: *Because between me and you there is lots of air, so the air's vibrating.*

How do the vibrations go through the air, do you know that?

Student: Mmm

Interviewer: *Do you know what's vibrating?*

Student: Mmm

Interviewer: *Well you said air, so it's the air vibrating.*

Interviewer: *If we were swimming together under the water and I made a noise by banging two blocks of wood together, do you think you'd hear that sound under the water?*

Student: Not very well.

Interviewer: *Do you think you'd hear it a little bit?*

Student: Mmm

Interviewer: *What's between us when we're under the water?*

Student: Water.

Interviewer: *What about if we go out in space and we're astronauts way out on Mars and I spoke to you out there, do you think you'd hear me?*

Student: Not without a microphone.

Interviewer: *Why not?*

Student: Because there is no air to vibrate out in space.

Student 4

Interviewer: *I want to ask you about sound and how you hear something. So if I am sitting here talking to you, can you tell me how you hear the sound of my voice?*

Student: Umm. I don't really know.

Interviewer: *What do you hear with?*

Student: My ears.

Interviewer: *Do you know how the sound from my voice gets to your ears?*

Student: No.

Interviewer: *What about if we are underwater, swimming together and I bang two bits of wood together to make a noise, do you think you'd hear that sound?*

Student: Yes.

Interviewer: *Would you hear it very clearly?*

Student: Not really.

Interviewer: *So what's between us when we're under there swimming around, what's between you and me?*

Student: Water.

Interviewer: *When we're sitting here, what's between us?*

Student: Air.

Interviewer: *Do you think if there wasn't any air there, you'd still hear me?*

Student: A bit.

Interviewer: *What about if we're out in space and we're two astronauts floating around out there and I talked to you out in space, do you think you'd hear me there?*

Student: Umm. Maybe.

Interviewer: *Is there any air out there?*

Student: No.

Interviewer: *So there is no air out in space but there is air here in the room. Do you think the air is important for hearing?*

Student: Yes.

Interviewer: *Do you know why?*

Student: No.

Student 5

Interviewer: *What I want to talk about is sound and how you hear. So when I am sitting here talking to you how do you hear the sound of my voice?*

Student: Good

Interviewer: *No, not what's my voice like but what do you use to hear it?*

Student: My ears.

Interviewer: *Do you know how the sound of my voice gets to your ears?*

Student: Vibrates.

Interviewer: *What vibrates?*

Student: Umm. What was the question again?

Interviewer: *How does the sound of my voice get to your ears?*

Student: I don't know.

Interviewer: *Vibrates is fine, but I am just saying to you, can you tell me what vibrates?*

What starts the sound and what gets the sound to your ears? Do you know?

Student: Umm. No.

Interviewer: *If we're swimming together underwater and I bang two blocks together to make a noise, do you think you could hear that sound underwater?*

Student: Sort of.

Interviewer: *So you mean not very clearly?*

Student: Yes.

Interviewer: *What's between us when we're swimming around under there?*

Student: Water.

Interviewer: *So what's between us now sitting here?*

Student: Table.

Interviewer: *Yes. What else?*

Student: Air.

Interviewer: *What if we go right out in space and we're a couple of astronauts flying around out there and I spoke to you out in space, do you think you'd hear me out there?*

Student: Yes. Some have little things going across here to the other person.

Interviewer: *Yes, that's a sort of microphone isn't it or a walkie-talkie, some sort of radio system.*

Student: Yes

Interviewer: *What if we didn't have that. Do you think you'd hear me if we didn't have that?*

Student: No.

Interviewer: *Is there anything between us when we're floating around out there in space?*

Student: Air.

Interviewer: *Is there air out there in space?*

Student: Yes.

Student 6

Interviewer: *What I'd like to do is ask you about sound and how you hear. So if I'm sitting here talking to you can you tell me how you hear the sound of my voice?*

Student: Well.

Interviewer: *I mean what do you hear it with, not is it loud or soft.*

Student: What do you mean?

Interviewer: *How do you hear it. What do you use to hear me?*

Student: My ears.

Interviewer: *Do you know how the sound from my voice gets to your ears?*

Student: No.

Interviewer: *Is there anything between us, between you and me?*

Student: Air.

Interviewer: *Do you think the air is important for you to hear my voice?*

Student: Yes.

Interviewer: *Do you think if there wasn't any air between us that you'd still hear me?*

Student: Umm. I'm not sure.

Interviewer: *What about if we were under the water, we were swimming around together under the water and I banged two blocks together, do you think you'd hear that sound?*

Student: Not very clearly.

Interviewer: *What's between us there?*

Student: Water.

Interviewer: *What about if we were out in space and were a couple of astronauts floating around out there and I spoke to you out in space, do you think you'd hear me?*

Student: If you had one of those space suits things.

Interviewer: *What about if we didn't have that and I just spoke to you, do you think you'd hear me?*

Student: No.

Interviewer: *Can you tell me why you don't think you'd hear?*

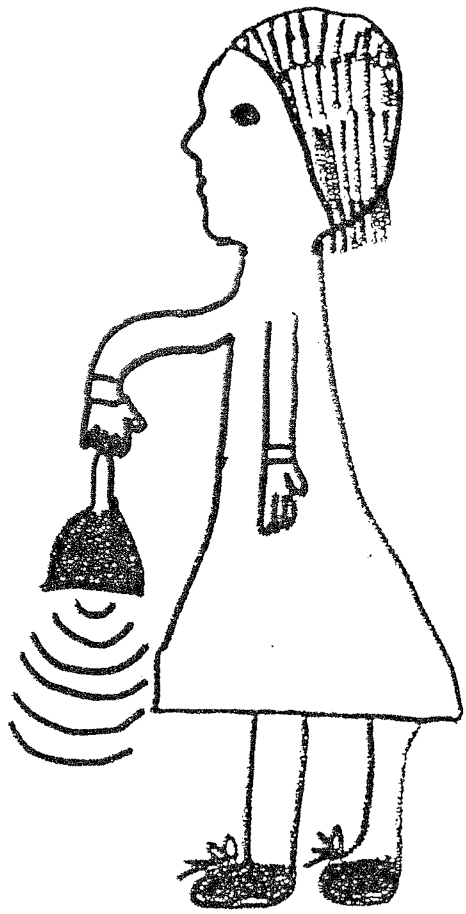
Student: Umm. No.

Interviewer: *Is there air out there, out in space?*

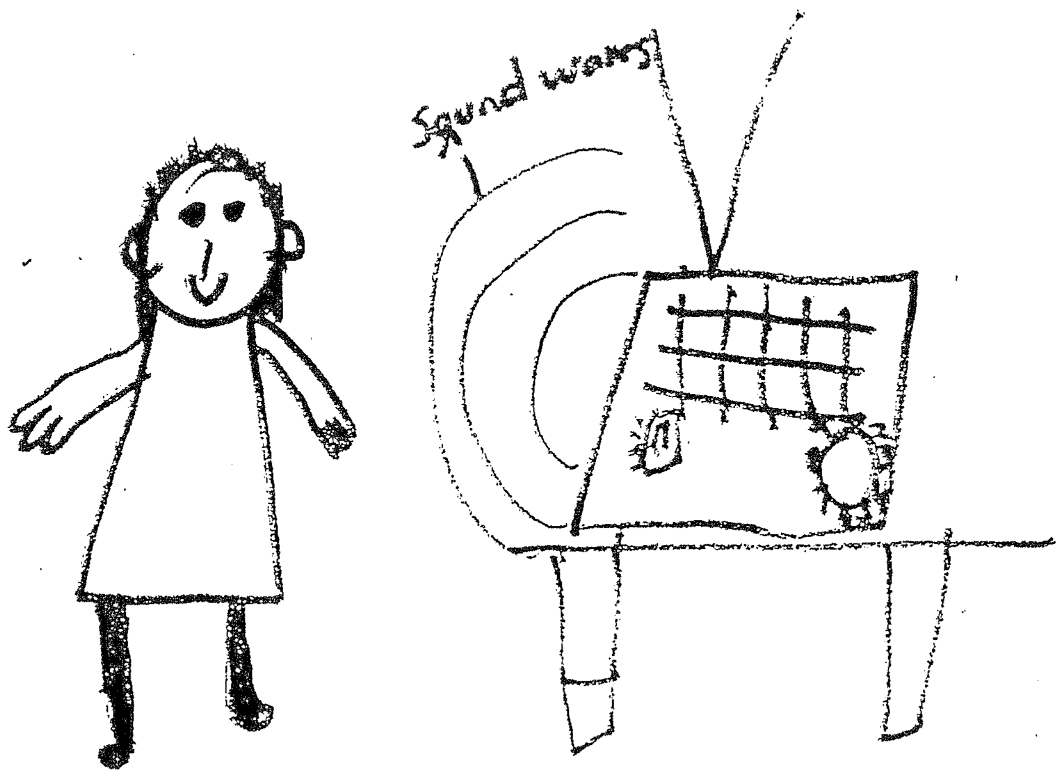
Student: I'm not sure.

Appendix 15 Drawings of year 3 students on sound and hearing

Student 1



Student 2



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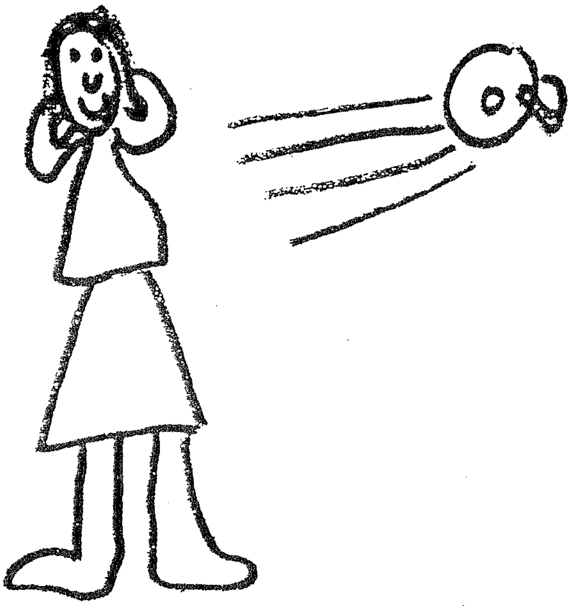
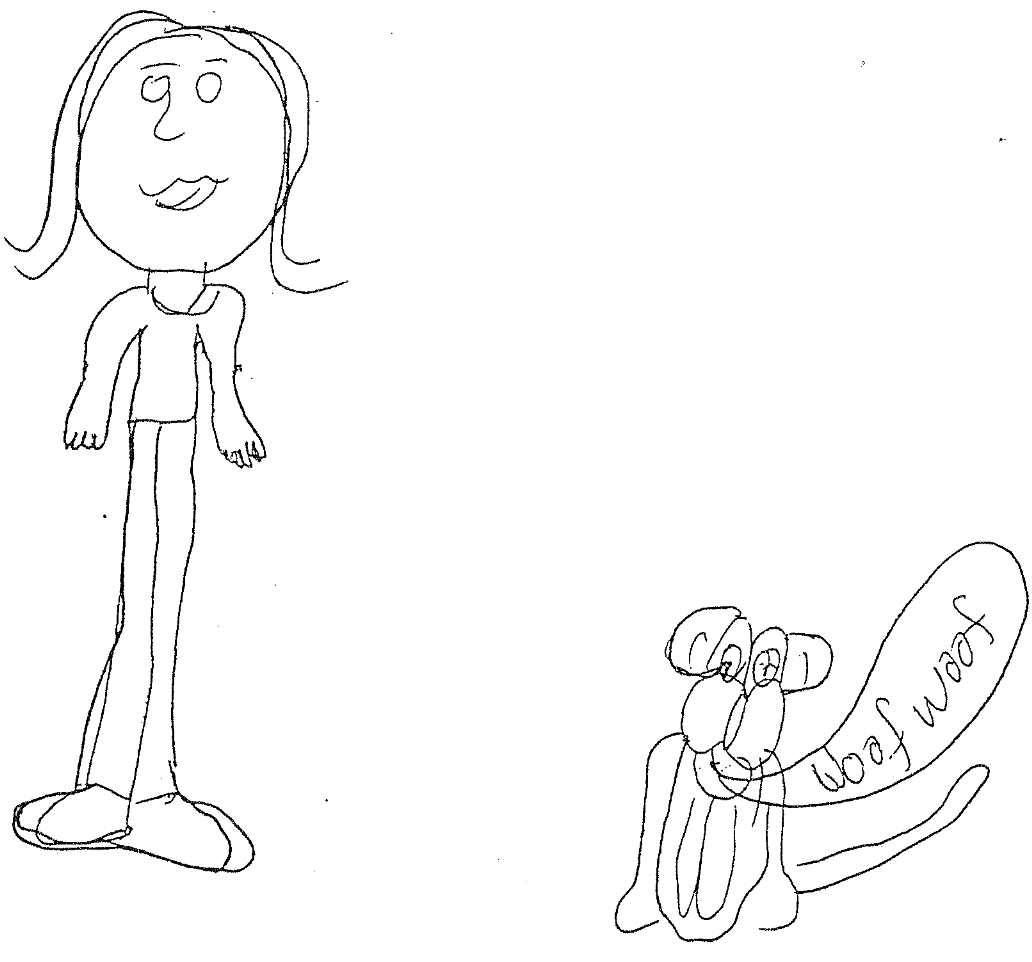
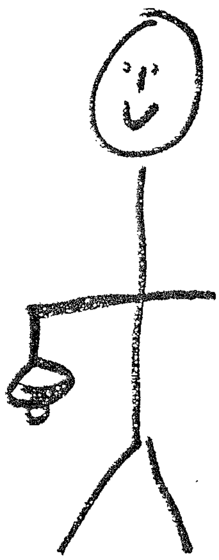


Student 4



Student 5



Student 6

Appendix 16 1998 teaching unit on sound and hearing

Sound and Hearing

Introduction

This Teaching Unit addresses the fundamental notion involved in a study of 'sound and hearing' which is how the sound gets from the source to the ear. The Teaching Unit is based on a constructivist teaching sequence and consists of two main stages, orientation, and elicitation and restructuring. It also incorporates Vygotsky's notion of constructivism which advocates guidance and assisted discovery by teachers and peers to 'lead' development.

A theoretical cognitive model has been postulated for the development of an understanding of 'sound and hearing' called the Development Map for the Standard Hearing Framework or, more simply, the Development Map for Hearing (see Figure 4.6 in thesis). This theoretical model is based upon the SOLO (Structure of Observed Learning Outcome) model of cognitive functioning. The sequence of discussions and activities in this unit is structured in such a way as to successively introduce and link together elements of the Development Map.

Learning is essentially a social process (Lemke,1990). It is important, therefore, to encourage students to express their ideas on 'sound' and, in discussions with their peers and the teacher, to make predictions as to what would happen under various circumstances.

The lessons are structured around a series of questions designed to start the students discussing the nature of sound and how it is transmitted. A possible response has been given for each question followed by an explanation of the level of cognitive functioning demonstrated by this response. As each question is posed allow the students time to respond freely with their ideas. Each question should lead into the next. Demonstrations and/or student activities have been included where it is considered these will aid understanding.

In the following unit, questions to be investigated by the students are written in italics, and instructions for the teacher in normal font. Additional information for the teacher is placed in brackets [ ].

The total time for this unit is approximately four 50-minute lessons.

1. Orientation Stage

At the commencement of the unit, give a brief introduction to inform the students that the course is about 'sound', and how they hear a sound. This is designed to encourage the students to think about the topic.

2. Elicitation and Restructuring Stage

Question: *'What do we need in order to hear?'*

Possible Responses: 'ears; a sound'

[The students' responses, 'ears' and 'a sound', introduce two elements of the intuitive or Ikonic notion '*we hear because we have ears*'. Responses which contain either of these elements are considered to be Unistructural in the Ikonic mode of the Development Map for Hearing. All children are aware from an early age that when something makes a sound they hear it with their ears, '*we listen, we hear*' (the notion of 'active listening'). This is intuitive and does not indicate a scientific understanding but, if the students link the two unistructural elements together, then they are considered to be Multistructural in the Ikonic mode.]

Question: 'How does the sound get from the source to the ear?'

Possible Responses: 'travels; sound waves; through the air'

[The question, *'How does the sound get from the source to the ear?,'* may produce the Ikonic response 'travels'. The linking together of the elements 'ear', 'sound', and 'travel' indicates a student operating at the Relational level in the Ikonic mode of the Development Map. Those students who respond 'travels through the air' are acknowledging the presence of the medium, even if they are not yet aware of its role. These students are considered to be operating in the Concrete Symbolic mode.]

[The remaining questions deal in turn with the nature of sound and sound waves, vibration of the source, vibration of the air, and, finally, vibration of the ear drum. These elements are not considered intuitive elements. They are all elements of the Concrete Symbolic mode of functioning and, as they make appropriate links between these elements, students demonstrate a developing scientific understanding of how a sound gets to their ears.]

Question: 'What is sound?'

Possible Responses: some students may say 'sound waves' or 'vibrations'; many will not know how to answer this

Give each student a tuning fork to allow them to investigate, for themselves, the notion of vibrations. Suggest that they strike the tuning fork on the rubber stopper provided and touch it to the wooden bench, and to their fingers, their cheek or their tongue. Students will be able to hear the sound, and to experience the 'vibrations'. If they touch the vibrating tuning fork to the wooden bench they will also feel the bench vibrating at the same time as they can hear the sound.

Allow the students to pluck the strings of a guitar, and to strike the skin of a drum. Ask the students what they had observed and why? Why did a tuning fork mounted on a wooden box sound so much louder. What was vibrating? What vibrated when the drum was struck or the guitar string was plucked? What else might be set vibrating when the guitar string or the drum skin vibrates. [The students should say the wood of the guitar or drum, and some may say the air inside as well].

[These activities are designed to make students aware of vibrations, and how the vibrations of one object are transferred to another.]

Question:	'How do the vibrations, e.g. from the tuning fork, get to the ear?'
Possible Responses:	'travel; through the air'
Question:	'What happens when the vibrations reach the ear?'
Possible Responses:	'we hear the sound; ear or eardrum vibrates'
Question:	'How do the vibrations get through the air?'
Possible Response:	most students unable to answer this.

Encourage the students to discuss these questions, particularly the two relating to how the vibrations get to the ear as this is regarded as the most difficult concept for students.

[The questions *'How do the vibrations of the source get to the ear?', 'What happens when the vibrations reach the ear?'* and, finally, *'How do the vibrations get through the air?',* are designed to 'lead' students along the pathway of developing understanding proposed in the Development Map for Hearing, and to elicit responses that link together the notions of 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear'. Such responses would indicate a transition from the Multistructural to the Relational level in the Concrete Symbolic mode of the theoretical Development Map for Hearing. If a response contains all of these four notions or Key Elements, then it is indicative of a student with a scientific understanding of 'sound and hearing' whose level of cognitive functioning is at the highest level of the hierarchical Development Map for Hearing. This student has thus acquired the Standard Hearing Framework. The aim of the Teaching Unit is to have all students functioning at this level at the completion of the Unit.]

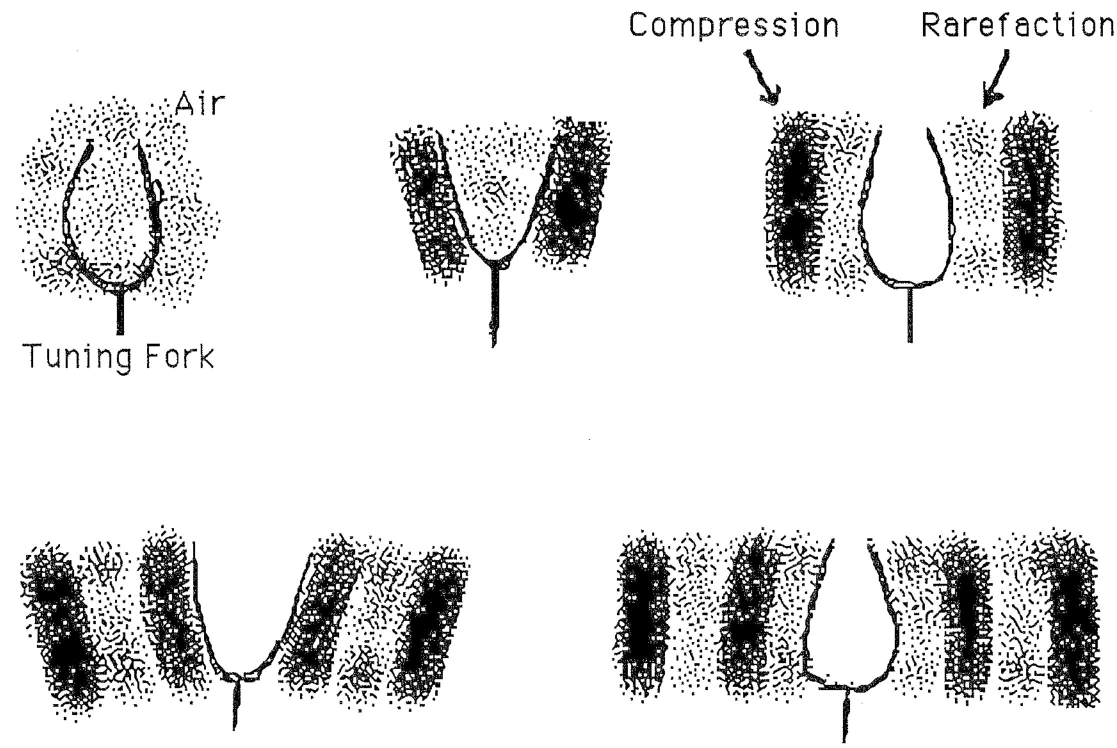
Discuss with the students that the air is made up of particles (molecules) and that the particles all around them are set vibrating by the vibrations of the source, e.g. the tuning fork, the guitar, or the drum. The students may not have encountered this concept previously although, if they have studied some chemistry, they may possess an understanding of the structure of matter and of molecules.

[The vibration of the air is the most difficult concept for the students to appreciate as they cannot see it. They can see and feel a tuning fork vibrating at the same time as they hear it making a sound. They can also feel the bench vibrating when the tuning fork touches it. This makes them aware that the vibrations of a sound source can be transmitted to other objects; that is, a vibrating object can set a second object vibrating. A discussion of the nature of 'air' will assist the students to understand how vibrations might be passed to the air and that when an object starts vibrating in the air, it sets the air particles vibrating as well.]

The following activity is designed to illustrate how vibrations are passed through the air. Line up approximately five students, shoulder to shoulder, but not quite touching. The remainder of the class can observe what happens. Stand next to the first student. Push the student nearest to you gently so he/she bumps into student number 2, who then bumps into number 3, and so on, down the line. The observers will note that each student bumped into the next one successively like a row of dominoes, but, unlike dominoes, each student quickly recovered his/her original position. What moved down the line was the disturbance, the individual students did not move very far. Explain to the students that this is how the vibrations from the source are transmitted through the air. The vibrating sound source pushes repeatedly against the molecules of air. The disturbed air molecules bump against their neighbours, then bounce back to their original positions. The neighbouring molecules do the same and, thus, the vibrations are transmitted through the air from the source to the ear. None of the individual molecules moves very far, what does move is the disturbance.

As the students push together and then pull apart again as they regain their original position, they are creating regions of high pressure (the squashes) and regions of low pressure (the stretches). This is how the vibrations are passed through the air, in alternating regions of high pressure (called compressions) formed when the molecules bump together, and regions of low pressure (called rarefactions) formed when the molecules bounce apart. These alternating areas of high and low pressure give rise to a pressure wave called a 'sound wave'.

Draw a series of diagrams on the board to show how these regions of high and low pressure are set up by the vibrating tuning fork.



Vibration of the Tuning Fork sets up regions of alternating high pressure (compression) and low pressure (rarefaction) in the surrounding air.

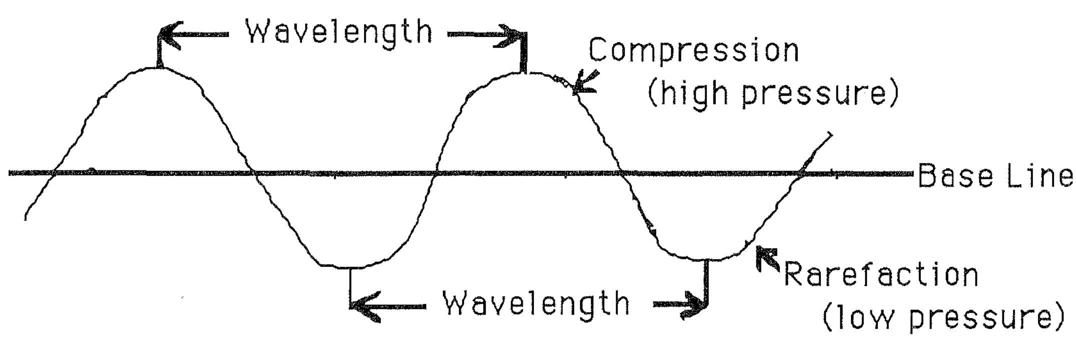
Another interesting analogy for the transfer of sound, given by Stevens and Warshofsky (1965, pages 10-11), is that of a waiter stepping onto the edge of a crowded dance floor, forcing the dancers nearby to give way. They in turn bump into other dancers creating a chain reaction. The bumping progresses across the room in a wave of jostling that flows outwards from the waiter through the dancers to the opposite edges of the floor. Sound moves through the air in the same way.

[The use of analogies is often recommended as a method of making difficult abstract concepts accessible to students (Duit, 1991; Thiele and Treagust, 1992). They have the power to evoke rich, almost instantaneous, mental pictures that enhance student learning. However care must be taken to ensure that an impression is not conveyed that the analogy is a true description of the target concept (Harrison and Treagust, 1993). The use of analogies encourages Ikonic functioning (Watson, Campbell and Collis, 1993) which was discussed in Section 2.5 of the thesis as being necessary support for development in the Concrete Symbolic mode.]

Give pairs of students a large spring called a 'slinky' to test for themselves how a sound wave travels. The students hold each end of the 'slinky' and extend it slightly. One student pushes to and fro, into the spring and out again. This pushing and pulling is just like a vibrating object. These pushes and pulls can be seen travelling along the spring just like the 'squashes' and 'stretches' of a sound wave. With the 'slinky' the students can demonstrate the wave travelling in a straight line parallel to the direction in which the 'slinky' is moving, where the 'slinky' is analogous to the particles of air vibrating. Explain to the students that a sound wave is a longitudinal wave in which the wave travels in a straight line parallel to the direction in which the particles are vibrating.

The regions of high and low pressure discussed previously can be drawn as a graph where the crests represent regions of high pressure and the troughs represent regions of low pressure. Before doing this, ask the students if they can draw an appropriate graph to illustrate a pressure wave.

If students are unable to do this, draw a typical graph on the board. Label a compression and a rarefaction as well as showing how the wavelength of that wave can be determined. [The distance between each compression (i.e. between 2 crests) or each rarefaction (i.e. between 2 troughs) or between any two corresponding points on neighbouring waves is the **wavelength**. The wavelength for the note Middle C is about 1.3 metres. The wavelength of sound made during normal speech varies between about 5cm and 2.5 metres.]



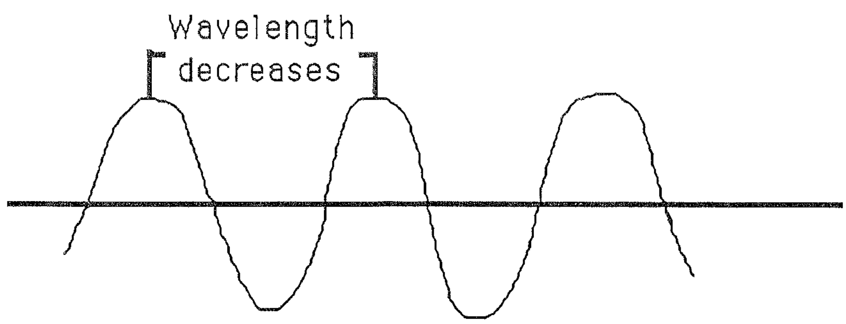
(To this point has taken approximately two 50-minute lessons)

Explain to the students that the height of the peaks shown in the figure, indicating the maximum pressure, gives a measure of the intensity of the sound and this is related to the loudness of the sound. The distance between the peaks, the wavelength, is a measure of the pitch or frequency of the sound, which is the number of vibrations made each second by the body disturbing the air molecules.

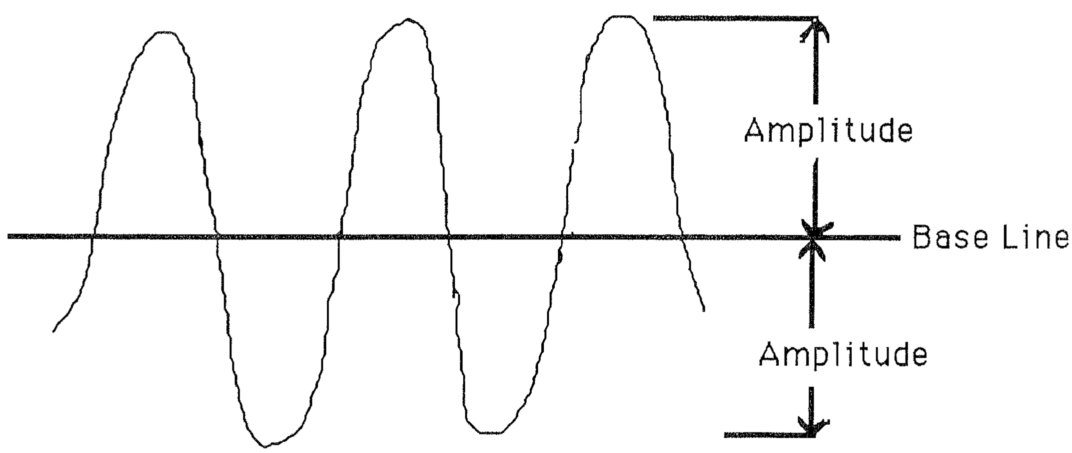
Ask the students then how they would represent a sound of higher frequency than the one shown in the diagram. Ask them to explain their drawing. What is the significance of its shape?

Ask the students how they would draw a graph of a louder sound than the one you have drawn, and, again, to explain their diagram.

[As the object producing the sound vibrates faster, the frequency increases and, therefore, the distance between the peaks in the pressure wave decreases. The figure below, in which the peaks are closer together, illustrates a wave at a higher frequency than the one above.



As the number of vibrations per second increases, i.e. **as the frequency increases**, the **wavelength decreases**, i.e. the distance between each wave decreases.



As the **loudness** of the sound **increases,** the **amplitude** or height of the wave **increases.**

The **amplitude** of a wave is the maximum distance that each particle moves away from its usual resting position which is marked by the base line.]

Set up a signal generator, an amplifier, a loudspeaker with the front panel removed, and a cathode ray oscilloscope (CRO). This can then be used to show the students how the membrane of the speaker vibrates when a sound or signal is generated and, at the same time, they can see the pattern of the sound wave on the screen of the CRO as the frequency of the sound changes.

Use the same equipment to measure the range of frequencies that the students can hear. The signal generator will allow you to select frequencies in the range 20 to 20,000 vibrations per second or hertz.

[Humans can hear sounds in the range 20 - 20,000 vibrations per second; dogs 5 - 50,000; porpoises 50 - 150,000. As humans get older the range of frequencies they can hear decreases. An interesting exercise for the students is to compare the highest frequency they can hear with the highest that the teacher can hear. Students could also research these figures themselves. This too is an ideal opportunity to discuss the harmful effects of prolonged exposure to loud music or noise.]

Set up an alarm clock or a timer sitting on a piece of foam in a bell jar connected to a vacuum pump. Set the alarm ringing. Ask the students to predict what they think will happen to the sound of the alarm if the air is pumped out of the bell jar. Can they explain why? Then seal the bell jar and gradually pump all the air out. The students should observe that the sound diminishes as the air is removed until the point at which all the air has been removed and they can no longer hear the sound. Then ask them to suggest what will happen if the air is let back into the bell jar. If you allow the air back into the bell jar, students will be able to hear the sound once again.

[This activity is designed to illustrate the necessity of a medium for the transmission of sound. This addresses the Key Elements given in the Development Map for Hearing of 'vibration of the medium', and 'travel through the medium', and should assist students to understand that, unless a medium is present, the transmission of sound will not occur.]

(One 50-minute lesson)

[If sound is due to the vibration of a source and these vibrations can be transferred to other objects, then students should draw the conclusion that any object capable of vibrating should be able to conduct sound]

The final activity looks at the transmission of sound in different media, namely air, wood, steel, and string.

[This activity is designed to assist students to understand that other media besides air can transmit sound.]

Students, working in pairs, should determine through which of the following media they can hear the sound of a ticking clock more clearly, one metre of air space, or one metre of wood, or one metre of steel rod of similar diameter to the wood. Ask the students through which medium they can hear best, and can they explain why.

Students can also make a 'string telephone' by joining two aluminium cans by a length of string passed through the base of each can. Students can test for themselves whether the string is better slack or taut.

[It is anticipated that students will reach the conclusion that sound can travel through all materials which are capable of vibrating, such as air, water, steel, wood, or stretched string and that sound travels more easily and more quickly through materials with particles that are close together, i.e. **denser** materials. Therefore, solids will conduct sound more quickly than liquids which, in turn, will conduct sound more quickly than gases.]

[From the discussion of the movement of the particles of the air and of other media, students may also conclude that the speed of sound will be affected by the temperature of the medium that transmits it. In a cold medium, particles move slowly and reduce the speed at which sound is transmitted. When the same medium is heated, its particles jostle one another more rapidly and speed up the transmission of sound.]

(One 50-minute lesson)

Conclusion

It is anticipated that all students should now have a clear understanding of the nature of sound, and of the vital role played by the medium in the transmission of that sound. The Key Elements of the Development Map for Hearing, 'vibration of the source', 'vibration of the medium', 'travel through the medium', and 'vibration of the ear', were addressed in turn during the course of the Teaching Unit, and finally linked together.

A number of the practical activities included in this Teaching Unit are found in conventional teaching units. The main difference between this Unit and conventional teaching is that students are encouraged to express their own ideas and to make predictions as to what would happen under certain circumstances. The role of the teacher is to assist students' discovery, not simply to 'tell' them the facts, and thus to 'lead' their development of an understanding of 'sound and hearing'. A questionnaire is available that could be used to determine how effective the Teaching Unit has been. Administering the questionnaire prior to, and at the conclusion of the Teaching Unit, would enable comparisons to be made of the changes in levels of cognitive functioning of students, and thus give a measure of the effectiveness of the Teaching Unit, as well as providing profiles of achievement of individual students.

Appendix 17 Responses of year 9/97 students to questionnaire on sound and hearing at each phase of the investigation

Students in the Instruction Group are designated by a number plus the letter (I); students in the Non-Instruction Group are designated by a number only. Researcher's notations are written in [ ].

Appendix 17.1 Pre-instruction responses

Student Number	Question Number	Response
1	1	The child can hear the bird in the tree because sound travels. The sound is coming out of the bird's mouth, it travels through by sound waves and then into the boys ears. No. of key elements present: 1.5 [no mention of medium or vibrations although does mention sound waves]
	2	Option selected: (ii) (i) This could be true but there are no sound waves. (iii) Sound waves travel from the gong to the ear not the other way round. (iv) The air doesn't vibrate. (v) This is true but you would also need noise waves. (vi) This one could be true.
	3 (i)	Yes, it would be fuzzy because sound doesn't travel through water well.
	(ii)	Yes, because it is in the open.
	(iii)	No. How far away are you?
	(iv)	It depends on what the wall is made out of.
	(v)	Yes, because you can still hear, the glass isn't that thick.
	(vi)	Yes, because the sound waves will still generate.
2(I)	1	Sound waves travel from the bird who is singing in the tree and go out in all directions. Some of these sound waves hit the childs ear and because of this he hears the sound of the bird singing. His ear drum is the part of the ear that picks up the sound. No. of key elements present: 1.5 [no mention of medium or vibrations though the student mentions sound waves]

	2	Option selected: (iv) (i) Because that would mean you could only hear the sound if you were in the room. But probably you could hear it outside the room as well. Also it doesn't say how the sound gets to your ears. (ii) I don't think its possible just to concentrate and listen to the sound. There must be sound waves travelling from the gong to your ear. (iii) Because there are no sound waves coming from your ears.The sound waves are coming from the gong. (v) It doesn't say how you hear the noise. It doesn't even say how the gong makes a noise. (vi) This is OK but it doesn't say how the vibrations get to your ear, or how you hear the noise.
	3 (i)	Yes, the vibrations can travel through the water, though probably not as easily as air.
	(ii)	Yes, the vibration can travel along the steel.
	(iii)	Yes, it is easy for the sound to travel along the tight string.
	(iv)	No, the sound waves cannot reach the person's ear because there is a wall in the way.
	(v)	No, there is no way the sound waves can get out.
	(vi)	Yes, the sound waves can travel easily to you. But they take a while to travel so when you hear them the car is gone.
3(I)	1	When the bird sings, it sends out "sound waves" into the air. They travel through the air and reach your ear. They enter the ear and vibrations are caused which allows you to hear. No. of key elements present: 3 [student has mentioned the ear vibrating but has not understood that sound waves are vibrations]
	2	Option selected: (iv) (i) no comment. (ii) You don't have to concentrate to hear some sounds like the gong. (iii) The sound waves start at the gong not the ear. (v) no comment. (vi) no comment.
	3 (i)	Yes, faintly. The sound waves cause vibrations in the water but isn't as loud.
	(ii)	Yes, sound waves can travel around corners.
	(iii)	Yes, the vibrations are sent down the string to the other person.

	(iv)	Yes, if it was very quiet you might not but louder you could.
	(v)	No, there is no air in the vacuum, therefore the sound waves can't travel.
	(vi)	Yes. (no explanation)
4(I)	1	The sound that the bird is making is made up of lots of vibrations. The vibrations all have different wavelengths. The wavelengths travel through the air towards the boy's ears which pick up the vibrations as a sound. The shorter the wavelengths the higher the sound. No. of key elements present: 3.5
	2	Option selected: (v) (i) This is not precise enough. (ii) You would not have to concentrate to hear the sound. (iii) There are no sound waves travelling from your ear. (iv) There are lots of vibrations travelling around the room and your ears only pick up some of them. (vi) You hear the gong as it is struck not vibrating afterwards.
	3 (i)	Yes, because sounds travel through water.
	(ii)	Yes, because the sound of something striking steel is very loud.
	(iii)	Yes, because the vibrations would travel through the string into the tins.
	(iv)	No, because it would take longer for the vibrations to travel to the person as they travel in straight lines.
	(v)	No, because there is no air for the vibrations to travel through.
	(vi)	Yes, because the noise a siren makes is very loud.
5(I)	1	Vibrations are made when the bird sings. The vibrations travel into the childs ear and [are] heard. The less distance the sounds have to vibrate the louder the sounds. No.of key elements present: 3 (no mention of medium)
	2	Option selected: (iii) (i) no comment. (ii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	No. (no explanation)
	(ii)	Yes. (no explanation)

	(iii)	No. (no explanation)
	(iv)	Yes. (no explanation)
	(v)	No, because the sound can't travel out to your ears.
	(v)	Yes. (no explanation)
6	1	The sound waves are vibrated through the ear [sic] [does student mean 'air'] through to the ear drum. No. of key elements present: 2.5 [no mention of medium or travel through medium]
	2	Option selected: (iv) (i) Just because it echoes around the room doesn't mean you can hear it. (ii) Often you don't have to be concentrating just to hear. That isn't how we hear anyway. (iii) No sound waves come from your ear. (v) You do hear through your ears but it takes more than that to hear. (vi) This does not explain how you hear.
	3 (i)	Yes, sound waves can travel under water.
	(ii)	Yes, the sound vibrates through the glass [sic] [assume the student means 'girder'].
	(iii)	Yes, the sound vibrates along the string.
	(iv)	No, if the other person was talking quietly, you couldn't hear them, no matter how high, so long as it was over your head.
	(v)	No, the sound could not travel through the vacuum.
	(vi)	Yes, because the sound waves can still reach you.
7	1	Because sound travels. No. of key elements present: 1 [no mention of vibrations, medium, the ear]
	2	Option selected: (iv) (i) Echo is a vibration. (ii) no comment. (iii) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, vibrations.
	(ii)	No, noise doesn't travel through brick walls.
	(iii)	Yes, vibrations.

	(iv)	No. (no explanation)
	(v)	No. (no explanation)
	(vi)	Yes, vibration.
8	1	Because sound waves travel through the air into his ears which collect and sort the data so the brain can recognise the sounds the bird makes. No. of key elements present: 2.5 [mentions sound waves but not vibrations, hence 0.5]
	2	Option selected: (i) (ii) You don't have to concentrate to hear the sound. (iii) The sound waves travel from the gong to your ear, not vice versa. (iv) Doesn't explain why air vibrating makes sound. (v) How do you hear it with your ears? (vi) Why do you hear sounds from vibrations.
	3 (i)	Yes, because air also carries sound under water.
	(ii)	Yes, sound waves can travel through walls, etc.
	(iii)	Yes, sound travels along string.
	(iv)	Yes, but only if you were listening.
	(v)	No, vibrations don't reach out because of the foam.
	(vi)	Yes, because sound waves still travel certain distances in air.
9(I)	1	The sound of the bird travels by invisible sound waves through the air. The sound waves are picked up by the child's ear and amplified in the ear drum. No. of key elements present: 2.5 [mentions sound waves but not vibrations]
	2	Option selected: (iv) (i) The sound does not echo, it travels in sound waves. Something also needs to strike the gong to produce a sound and make the air vibrate. (ii) You do not have to concentrate to listen to the sound but your ears receive the sound wave. (iii) The sound waves need to travel through the air from the gong to your ear in order for you to hear the sound. (v) In order for the sound to get to your ears it must travel. (vi) If the gong vibrates the air must vibrate as well and the sound must travel to your ears.

	3 (i)	Yes, because sound can travel through water and boat engines are very naughty [sic].
	(ii)	Yes (no explanation)
	(iii)	No, because sound travels through the air not string.
	(iv)	No, as the brick wall would stop a lot of the sound waves.
	(v)	No, as there is no air for the sound waves to travel through.
	(vi)	Yes, as the police car could be travelling faster than the speed of sound.
10(I)	1	The child can hear the bird singing in the tree because sound waves from the birds voice travelling through the air and the child has ears which are able to pick up the sound. No. of key elements present: 2.5 [mentions sound waves but not vibrations]
	2	Option selected: (vi) (i) It is wrong because the gong vibrates. (ii) The person should not have to concentrate to hear the sound. (iii) Sound waves do not travel from your ear but the other way around. (iv) The vibrations travel all around the room not just to your ears. (v) No sound has been made in this sentence so how do we [know] if it is true.
	3 (i)	No, because the water would muffle the sound.
	(ii)	Yes, because vibrations are sent through the steel and around the wall.
	(iii)	Yes, because vibrations are sent through the tight string.
	(iv)	Yes, because the sound would travel over the top of the wall.
	(v)	No, because vacuums allow no sound through them.
	(vi)	Yes, because the sound waves are only just reaching your ear.
11(I)	1	The child can hear the singing of the bird because he has ears. These are two organs that belong to many animals. The ear is made up of lots of other small nerves that connect to the brain which enables the child to hear the singing of the bird in the tree. No. of key elements present: 1 [no mention of vibrations, medium, travel through medium, or vibration of ear]

	2	Option selected: (iv) (i) This is incorrect because things do [sic] [student appears to have left out 'not'] have to echo to enable our ears to pick up the sound. (ii) This one is also incorrect because you don't have to concentrate to hear only to listen. (iii) This one is incorrect because sound waves don't travel from your ears but to your ears. (v) This is incorrect because it doesn't tell you how the sound gets to your ears. (vi) What has the gong vibrating got to do with you hearing the sound? Vibration alone doesn't make a noise.
	3 (i)	Yes, because the sound vibrations can travel through the water.
	(ii)	Yes, because the vibrations can travel through the wall [sic] [student appears to mean travel through the wall as along the girder because in (iv) she says it can't travel through a wall]
	(iii)	Yes, because it can travel along the string like talking on a phone.
	(iv)	No, because it can't travel through a wall.[see (ii)]
	(v)	No, because the sound can't get out.
	(vi)	Yes, because how could it suddenly stop.
12(I)	1	Well your ear can pick up sound waves that travel through the air so when a bird chirps the noise gets picked up by these sound waves and our ears pick up these sounds. No. of key elements present: 2.5 [student does not understand that the noise is the sound wave]
	2	Option selected: (iii) (i) Well this is sort of right, but how can the sound echo and be heard, it doesn't explain how we hear it. (ii) The sound is produce [sic] we don't produce the sound, we don't need to concentrate to hear things. (iv) This could be right. I'm not sure. (v) This is right but how does the sound get to your ears. (vi) no comment.
	3 (i)	Yes, because sound increased under water.
	(ii)	Yes, because the sound would vibrate through.
	(iii)	No, sound waves cannot be picked up through this method.
	(iv)	No, because quiet sound cannot be picked up that easily.

	(v)	Yes, because bell jars pick up sound waves well.
	(vi)	Yes. (no explanation)
13(I)	1	Sound waves are sent out from the birds voice box and these waves travel to the childs ears. The waves are then interpreted by the brain, which recognises the sound. No. of key elements present: 1.5 [no mention of vibration or medium though has notion of sound waves travelling to ear]
	2	Option selected: (iv) (i) When a sound echoes it is the waves or vibrating particles re-bounding off a surface. [student did not mention vibrations in Q.1] (ii) Even if you don't concentrate you will hear the sound. (iii) The waves are sent out from the gong not your ears. (v) You don't hear the strike without the waves travelling to your ears. (vi) Again you can't just hear the sound.
	3 (i)	Yes, the sound waves travel through water too.
	(ii)	No, the sound waves won't be able to travel through solid surfaces.
	(iii)	No, they are too far apart.
	(iv)	No, the waves travel in reasonably straight lines.
	(v)	No, there are no particles for the vibrations to travel through.
	(vi)	Yes, sound waves are sent out in all directions.
14	1	A child can hear a bird singing in a tree because the bird is making a sound that travels through the air into the ear to the ear drum where you can hear the sound. No. of key elements present: 2.5 [no mention of vibration or vibration of ear]
	2	Option selected: (iv) (i) Because you can hear sounds if it doesn't echo around the room. (ii) I think that this isn't right because you don't concentrate to hear a sound. (iii) No, because it would travel from the object that was making the sound to the ear not the other way around. (v) Because you can't just hear the sound. The air has to vibrate. (vi) This is OK but it's half right, half wrong.
	3 (i)	Yes, because the engine vibrates in the water.
	(ii)	Yes, because the steel vibrates and makes a loud sound.

	(iii)	Yes, because the tins vibrate.
	(iv)	No, because the walls too high sound is not travelling to her.
	(v)	No, because it can't vibrate.
	(vi)	Yes, because the noise is still vibrating through the air.
16(I)	1	The child can hear the bird in the tree through his ears. The sound from the bird travels through the air and into his/her ears.The ears are always listening to all of the sounds that are happening and the sound of the bird goes into the child's head and the child registers it as a bird. No. of key elements present: 2.5
	2	Option selected: (iii) (i) The sound of the gong wouldn't echo around the room necessarily unless the room was large and did echo with every sound that was made. (ii) You don't actually concentrate for the sound, because you still hear things when you don't concentrate don't you? Your ears hear everything. (iv) You cannot make the air vibrate - otherwise it would always be vibrating and you couldn't hear anything at all. (v) It is not necessarily the clapper that makes the sound, it's the gong of the drum that hits against the clapper. (vi) This isn't a bad statement, and it could be true, but I thought the other one would have been more likely.
	3 (i)	I think you could because the vibrations would probably travel through the water and get to your ears
	(ii)	Yes, I think that you could hear a faint bang through the wall if you were that close to it.
	(iii)	No, I don't know, but I think if you were talking quietly it wouldn't work, but if you were rather loud you might be able to.
	(iv)	Yes, you could hear over the top of the wall, depending on how loudly they spoke.
	(v)	No, the sound would have to travel through too many things.
	(vi)	Yes, because the sound would still be close to you, but slowly it would fade away as the car got further away.
21	1	The bird makes the noise, the sound waves travel through the air into the boys ears and he hears it. No. of key elements present: 2.5 [mentions sound waves but not vibrations]

	2	Option selected: (vi) (i) No comment. (ii) The sound needs to travel for you to be able to listen to it. (iii) The sound waves would need to travel from the gong to your ear, not from your ear to the gong. (iv) Not sure. (v) This might be true, but it does not say how the sound gets from the gong to your ears.
	3 (i)	Not sure, the water might muffle the sound.
	(ii)	No response.
	(iii)	Yes, the sound could travel along the string.
	(iv)	Yes, the sound could travel through or over the wall.
	(v)	Not sure. The foam and the bell jar might muffle the sound.
	(vi)	Yes, even though the siren has passed you can still hear it.
22(I)	1	The bird sings which makes sound waves which travel through the air and enter our ear drums. Then something happens and a message is sent to our brain which says that a bird is singing in a tree. No. of key elements present: 2.5 [no mention of vibrations]
	2	Option selected: (iv) (i) When it says that the sound echoes around the room, it doesn't necessarily say the sound waves will enter your ears, and therefore you would not hear it. (ii) We don't need to concentrate to hear. It comes naturally to us, just like breathing. (iii) The sound waves can't travel from your ear because that isn't where the sound is coming from? The clapper striking the gong or the actual gong. (v) I don't understand. What do you hear (vi) I think this is unclear. I don't understand it.
	3 (i)	No. I don't know. I just think you wouldn't be able to.
	(ii)	Yes, because the vibrations would travel through the wall.
	(iii)	Yes, because the sound waves travel down the rope and therefore you hear it at the other. Also, I have done this and know it works.
	(iv)	No. I don't know why.
	(v)	No, because the sound waves couldn't travel through the vacuum.

	(vi)	Yes, because the sound waves would still reach your ears.
23	1	This all depends on how far away the child is to the tree and the bird. Since he can hear the bird then this person must be reasonably close to the tree. When the bird sings, the sound waves of the birds voice travel through the air and straight to the boy. He can then hear the sound. No. of key elements present: 2.5 [no mention of vibrations or how boy hears sound, ie no mention of ears - mentions vibrations in Q. 2 & 3]
	2	Option selected: (iv) (i) The sound has vibrations and these sound waves travel around the room. If the room is large and hollow then you will get an echo. (ii) Unless you cover you ears then of course you hear the sound. You don't need to concentrate to hear the sound. (iii) No, the sound waves travel from the gong to your ears not the other way round. (v) The sound waves travel to your ears, you don't hear the clapper strike the gong with your ears. The sound waves are what you hear. (vi) You hear the sound waves vibrating, not the gong vibrating.
	3 (i)	No, because sound travels through air, not water.
	(ii)	Yes, the vibrations would travel along the steel pole to your ear.
	(iii)	Yes, if the string is tight then the sound vibrations travel along the string.
	(iv)	No, the sound is cut off by the wall.
	(v)	No, foam absorbs the sound and the sound can't travel out of a vacuum.
	(vi)	Yes, the sounds of the siren travel through the air to your ears.
24	1	The child hears the sound through their ears which then travels through the ear canal to the ear drum and the sound is interpreted by the brain. When reached at the ear drum vibrates very fast enabling the sound to be heard. No.of key elements present: 1.5 [no mention of vibration, medium, travel through medium]

	2	Option selected: (iv) (i) The gong may not echo around all of the room. (ii) You may not be concentrating but you may still hear the sound. (iii) Sound waves don't travel from your ear. They travel to your ear. (v) The clapper may not hit the gong very hard and you would still hear it. (vi) Even if the gong didn't vibrate you may still hear the sound.
	3 (i)	Yes, because the water vibrates around you.
	(ii)	No, because it is in something closed.
	(iii)	Yes, because the sound travels along the string.
	(iv)	No, because your sound is blocked by the brick wall.
	(v)	No, because all air trapped and sound can't travel.
	(vi)	Yes, because the sound vibrates through the air to your ears.
25	1	The child can hear the bird in the tree with his/her ears. The sound travels through vibrations (sound waves) and into their ear drums - the brain processes those readings and tells the child what he just heard. No. of key elements present: 3 [no mention of medium]
	2	Option selected: (iii) (i) It doesn't say anything about vibrations - it can't echo without them. (ii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, the sound can travel through the water.
	(ii)	Yes, the vibrations [doesn't say of what]
	(iii)	No, sound can't travel through a thin piece of string.
	(iv)	No, not if they are talking to the wall not over it.
	(v)	No, because all the sound waves have been cut off.
	(vi)	No, because it might stop their hearing for a while.
26	1	The sound travels from the tree with bird in it and the ear receives the sound or message. No. of key elements present: 1.5 [no mention of vibration, medium or how ear receives sound]

	2	Option selected: (iii) (i) If it echoed you would hear it repeat itself. (ii) You don't necessarily have to concentrate. I listen all the time without concentrating. (iii) Sound waves don't travel from your ear to the gong, only from the gong to the ear when the gong makes the sound. (iv) You can't feel it vibrating. (v) It doesn't explain how you hear it. (vi) It doesn't say how you hear it.
	3 (i)	No, because you are underwater and the engine is above.
	(ii)	No, you could hear it vibrate but not actually hear the hammer because the bricks are solid.
	(iii)	Yes, well you would be able to hear them anyway. That is if they are close together.
	(iv)	No, because the high wall blocks the sound waves.
	(v)	No, you can hear the vibration but not the alarm.
	(vi)	Yes, because it is loud and still close by.
27	1	The bird produces sound waves which travel through the air. When it reaches the child, the sound goes in his ear and is picked up by the brain. Sound travels in wave lengths. Some sounds travel further and can be louder. No. of key elements present: 2.5 [no mention of vibration or how ear receives sound]
	2	Option selected: (iv) and (vi) (i) This isn't quite accurate because when the gong is struck, the sound doesn't echo, but the air waves vibrate. (ii) This isn't correct because you only have to concentrate to hear a sound if it is far away. (iii) The sound waves actually travel from the gong to your ears. (v) This is basically true, but you hear the sound produced by the clapper striking the gong. (vi) [Student added the word 'produced' to the end of the statement]
	3 (i)	Yes, if you weren't too far away, noises travel quickly through water.
	(ii)	Yes, if you have your ear on the girder only.
	(iii)	No, sound wouldn't travel through the string, though it could reach you through air.

	(iv)	No, sound wouldn't travel through the brick.
	(v)	No, sound waves need something to travel through.
	(vi)	Yes, you can hear sirens a distance away.
28	1	The bird singing sets off vibrations through the air, when these vibrations met [sic] with the childs ear they send messages to the brain and then the child can determine that it is in fact a bird singing, pitch, tone, etc. No. of key elements present: 3.5 [no mention of vibration of ear]
	2	Option selected: (iv) (i) This doesn't explain how the noise gets into your ear, and it isn't really echoes. (ii) That doesn't work because even when you do [sic] [student appears to mean don't] concentrate you hear things. (iii) The sound waves couldn't really start from your ear, they start from the noise. (v) This doesn't describe it at all. Hear it? (vi) Again, you hear the sound, how do you hear the sound ?
	3 (i)	Yes, things are louder when you are under the water (I'm not sure of this answer)
	(ii)	Yes. I don't really understand this question. But maybe because when steel hits steel the sound waves travelling through the air are a lot sharper.
	(iii)	Yes, because they did it on Sesame Street and it worked.
	(iv)	No, I doubt it considering it's talking quietly. Because the wall would be too tall for the sound waves to travel over.
	(v)	No, because there is no way the sound waves can reach anywhere when the alarm clock is in a vacuum. There is no air for the waves to travel in.
	(vi)	Yes, the sound waves are still passing through the air even after the car has passed so you can still pick them up.
30(I)	1	The sound the bird makes travels through the air in waves of varying lengths to the childs ear which transmits the information to the brain which recognises the sound as a bird singing. No. of key elements present: 2.5 [no mention of vibration or how ear receives sound]

	2	Option selected: (iv) (i) Sound doesn't echo it bounces off the walls. (ii) Concentration has nothing to do with hearing the sound. (iii) The waves don't travel from your ears to the gong. (v) No sound waves included in the statement. (vi) The vibrations form sound waves from which we hear the sound.
	3 (i)	No, water absorbs most of the sound as the particles are packed together.
	(ii)	No, the solidness of the brick wall blocks the vibrations, therefore sound is unable to travel through the girder.
	(iii)	Yes, sound travels as vibrations along the tight string.
	(iv)	No, the sound waves/vibrations are unable to pass through, under or over the wall.
	(v)	No, foam absorbs the sound as the particles are very tightly packed.
	(vi)	Yes, as sound travels more slowly than light.
31	1	No response
	2	Option selected: (iii) (i) no comment. (ii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes (no explanation)
	(ii)	no response
	(iii)	Yes (no explanation)
	(iv)	no response
	(v)	Yes (no explanation)
	(vi)	Yes (no explanation)
32(I)	1	The bird singing causes the air to vibrate and move, which in turn hit other particles of air like dominoes until it reaches the childs ears where the vibrations are received and turned into sound by the brain depending on the intensity and frequency of the vibrations. No. of key elements present: 4

	2	Option selected: (iv) (i) Sound isn't a physical thing that you can see and feel and so therefore the gong can't exactly "make" sound. (ii) Wrong because sound just doesn't appear if nothing causes it. Something needs to happen for you to be able to receive it. (iii) Wrong because nothing is being done to your ears to make sound waves. People do not send out little invisible nets for example to gather up all the sound. (v) You do hear it with your ears however there needs to be something else happening for you to be able to hear it. (vi) The gong may vibrate but that is not what makes you hear the sound.
	3 (i)	No, because sound waves cannot travel very well through water.
	(ii)	Yes, because vibration would travel through the steel to your ear if your ear was right up against the steel.
	(iii)	Yes, the vibrations can travel up the string.
	(iv)	No, because the sound waves cannot travel through the brick wall - from one substance to another very well.
	(v)	No, because there is nothing for the vibrations to travel through - no particles to be hit.
	(vi)	Yes, because the sound can travel through the air quite far.
33(I)	1	The sound produced by the bird travels through the air in waves. These sound waves travel slower than the light waves do so therefore the child sees the bird before he hears it. His ears pick up the sound waves and the nerves send it to the brain. No. of key elements present: 2.5 [no mention of vibration or how ear receives sound]

	2	Option selected: (iv) (i) How then does the sound get to your ears and be read by your brain, if it just echoes around the room you will not hear the sound. (ii) You do not have to concentrate to hear the sound. Your ears pick it up without you consciously meaning to hear it. (iii) This could be almost right but the sound waves would travel from the gong to your ears not from your ears to the gong. (v) This is true but the sound has somehow got to get to your ears, it has to travel and so the sentence needs to say how you hear it. (vi) This is also true but like (v) how does the sound get to you so that you can hear it. The sentence does not answer that.
	3 (i)	Yes, the boat engine sends vibrations through the water that your ears pick up and hear although you wouldn't hear it as well as if you were next to it.
	(ii)	No, the solid brick wall would prevent the vibrations from carrying to you.
	(iii)	Yes, because the vibrations from the speaking in the tin would travel through the string and to your ear.
	(iv)	No, because the wall would block the vibrations unless she spoke loud enough that the vibrations went over or through the wall to your ear.
	(v)	No, the force of the vacuum would prevent the vibrations from passing through the vacuum.
	(vi)	Yes, because the sound travels slower than the car and so stays behind for a split second after the car has passed.

Appendix 17.2 Immediate post-instruction responses

The immediate post-instruction questionnaire was given to the Instruction Group only.

Student Number	Question Number	Response
2(I)	1	The birds vocal chords make a noise and set the air vibrating. This vibration of the air reaches the child's ear. The vibrating goes into the ear and the ear drums turn it into noise. No. of key elements present: 4
	2	Option selected: (iv) (i) This sentence doesn't explain how you hear the sound, it just says it echoes around the room. (ii) You can't just concentrate and hear the sound, the sound must travel to you somehow. (iii) The sound waves don't go from your ear to the gong they go the other way around. (v) Doesn't describe it very well it doesn't say how you hear it with your ears and how the sound gets to your ears. (vi) It doesn't say how the sound gets to your ears.
	3 (i)	Yes, the boat engine sets the water vibrating and this travels to your ears
	(ii)	Yes, the vibrations travel along the steel and reach your ears.
	(iii)	Yes, the vibrations travel along the string to your ears.
	(iv)	Maybe, it depends on how loud the person is talking.
	(v)	No, because the vibrations can't travel through a vacuum [student doesn't say why not]
	(vi)	Yes, because the vibrations take a while to reach you.
3(I)	1	The bird is the source of sound. It tweets and it creates vibrations that form sound waves. Because the sound waves go off in all directions, the boy can hear it. The sound waves reach the boy's ear, and it vibrates the ear drum and the boy is able to hear. No. of key elements present: 2.5 [no mention of medium]

	2	Option selected: (iv) The gong sets the air vibrating, but sound waves travel to your ear, not vibrations [student appears not to have understood the nature of sound waves] (i) no comment. (ii) When you hit a gong, it sends off sound waves. (iii) The sound waves don't start from your ear, they start at the gong. (v) It has sound waves, vibrations as well. (vi) It sends sound waves as well.
	3 (i)	Yes, because sound waves travel through water as well (eg. dolphin sonar). Because the closer the particles are together, the closer the vibrations are, therefore not losing much energy.
	(ii)	Yes, because sound waves travel through steel well. Because the closer the particles are together, the closer the vibrations are, therefore not losing much energy.
	(iii)	Yes, because the sound waves travel down the string caused by vibrations.
	(iv)	Maybe, depending on how quietly they were talking, how high the wall is, how thick it is or what the wall is made of.
	(v)	No, because there is no air in a vacuum to set vibrations.
	(vi)	Yes, it fades away but you can still hear it because the sound waves travel all around.
4(I)	1	The bird makes vibrations deep down in its voice box. These vibrations then travel to the boy's ears in wavelengths. The smaller and closer together the wavelengths are the higher the sound would be. Sound cannot travel through a vacuum only through air. No. of key elements present: 3.5 [no mention of vibration of ear]
	2	Option selected: (iv) (i) The sound would echo, but it does not specify how the sound is heard. (ii) You do not have to concentrate really to hear a sound. You hear lots of sounds around you but you don't necessarily listen to them. (iii) The sound waves come from the gong not your ear. (iv) This does not specify how the sound gets to your ears. (vi) You do not actually hear the gong vibrating, you hear the air that vibrates around the gong.

	3 (i)	Yes, because sounds travel better through water than in air.
	(ii)	Yes, because sound can travel through solids.
	(iii)	Yes, because the vibrations travel down the string to the tin and you hear it.
	(iv)	No, because the air that is set vibrating is stopped by the wall.
	(v)	No, because sound does not travel through a vacuum.
	(vi)	Yes, because sound can travel for quite a while before not being able to hear it.
5(I)	1	The bird singing sends vibrations into the air. The vibrations travel through the air to the child's ear. In the ear tiny hairs pick up the vibrations and the brain recognises these vibrations as different sounds. No.of key elements present: 4
	2	Option selected: (iv) This one is right! (i) Nothing is said about vibrations. (ii) Nothing is said about vibrations. (iii) Sound waves are set off from the gong and travel to your ear. (v) Nothing is said about vibrations. (vi) The vibrations travel to your ear.
	3 (i)	Yes, because the vibrations travel through the water.
	(ii)	Yes, because the vibrations would travel [student has not said through what]
	(iii)	No, because the vibrations wouldn't travel that far (definitely not along the string)
	(iv)	No, the vibrations wouldn't be able to travel through or over.
	(v)	No, because there is nothing for the vibrations to travel through.
	(vi)	Yes, because the vibrations would still be in the air.
9(I)	1	The bird makes a sound which sets the air particles vibrating. The particles transfer energy through the air in sound waves.The boy's ear picks up the sound waves which set a membrane vibrating. Delicate hairs inside the ear pick up the sound. No. of key elements present: 4

	2	Option selected: (iv) (i) The sound does not echo, it travels in sound waves. (ii) You do not have to concentrate to listen to a sound as your [ear] picks the sound waves up. (iii) Sound waves travel from where the sound is made to your ear. (v) The sound needs to travel to your ears somehow. (vi) The vibrations need to travel through the air.
	3 (i)	Yes, the motor would set the water particles vibrating and sound waves travel to your ear.
	(ii)	No, the particles are too tightly packed together and much of the energy would be lost on the way.
	(iii)	Yes, the sound waves would pass through the string and straight into your ear.
	(iv)	No, as the energy (most) would be lost as it transfers from air to wall to air again.
	(v)	No, there are no particles for the sound waves to pass through.
	(vi)	Yes, as sound is slower than light and sound waves can travel a long way and police sirens are loud.
10(I)	1	Sound waves from the birds mouth vibrate the air and these vibrations travel to the ear and vibrate hairs in the air [sic] [ear?]. No. of key elements present: 4
	2	Option selected: (iv) (i) The air has not vibrated and no sound waves have been made. (ii) Vibrations are caused and your ear picks them up. (iii) No vibrations have been made [sic] (v) Sound waves are made and vibrations are sent through the air. (vi) The vibrations come to your ear.
	3 (i)	Yes, vibrations caused in the water and go to your ear.
	(ii)	Yes/No [no response circled] The hammer causes vibrations through the wood [sic] and to your ear. [student has not read statement - there is no wood present]
	(iii)	Yes, vibrations are sent through the string.
	(iv)	Yes, vibrations travel through the air and through the wall.
	(v)	Yes, the vibrations are sent through the bell jar.

	(vi)	Yes, the air will still be vibrating so you will hear it.
11(I)	1	He can hear the bird singing because he has ears. He can hear the singing through his ears because when the bird starts singing its glands [sic] in its neck start to vibrate which starts air particles vibrating right to the boys ears. This then sets the ear drum vibrating and causes the boy to hear the singing of the bird. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound does not necessarily echo around the whole room. (ii) You do not need to be concentrating to hear something. (iii) Soundwaves don't just come out of your ears and travel to the sound, the sound goes to your ears. (v) You don't just hear something it has to have a way of getting there. (vi) You can't hear something just if it is vibrating.
	3 (i)	Yes, because it would send the water vibrating.
	(ii)	Yes, because the sound would vibrate through the wall.
	(iii)	Yes, it would send waves down the string.
	(iv)	Maybe, it depends on how quietly they were talking.
	(v)	Yes, it would send the glass vibrating.
	(vi)	Yes, because it would send the air around vibrating.
12(I)	1	Well the bird makes his noise and the sound waves or vibrations in the air carry it all around and once they reach the person their ear drums start to vibrate as well and that is how you hear a bird sing. No. of key elements present: 4
	2	Option selected: (iv) (i)This is sort of right, but how does it echo around the room and how do we hear it. (ii) This is completely wrong, how do you hear it and how does it get to you. (iii) This is almost right except the sound waves travel from the gong to the ear. (v) How do you hear it, there needs to be an explanation. (vi) This is alright but how does the sound get to your ear.
	3 (i)	Yes, sound waves still go under water.
	(ii)	Yes, because steel and metal vibrates and carries sound.
	(iii)	No, because sound can't travel through things like this.

	(iv)	No, light sound can't travel through brick walls.
	(v)	No, because the bell jar is air tight and sound waves travel in air.
	(vi)	Yes, because the loud noise would still be vibrating through the air.
13(I)	1	The birds voice box begins vibrating and then sets the air particles vibrating. The vibrations travel through the air in waves. The waves then reach the childs ear and the vibrations are sent through the nerves and other things in the ear. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound can still be heard if the gong is outside. It doesn't need to echo to be heard. (ii) You can hear the sound even if you don't concentrate. (iii) The sound waves don't travel from the ear they travel from the sound source. (v) You can't just hear the sound it has to travel to your ear. (vi) The gong then sets the air vibrating and that is how you hear the sound.
	3 (i)	Yes, water particles carry the vibrations better than air.
	(ii)	Yes, metal is a good substance for particles to vibrate through.
	(iii)	Yes, the vibrations are carried along the string.
	(iv)	No, brick doesn't have particles that carry vibrations well.
	(v)	No, there are no particles in the vacuum.
	(vi)	Yes, sound waves are sent out in all directions.
16(I)	1	The child can hear the sound of the bird through his/her ear. The sound of the bird travels in sound waves to the childs ear the sound waves fluctuate as to how loud and the pitch of the sound is. The air vibrates inside the child's ear and this is how the child can hear the sounds of the bird in the tree. No. of key elements present: 2.5 [no mention of medium or vibration of source or of medium, though says air in ear vibrates]

	2	Option selected: (iv) (i) This is a wrong statement because the sound waves from the gong go out in all directions and aren't as loud as they are closer to the gong - the gong doesn't necessarily echo around the room. (ii) Do you hear things when you aren't concentrating? Yes, you do - so you still hear things without listening out for them. The sound waves travel to your ear without you noticing. (iii) The sound isn't coming from your ear it is coming from the gong, so the sound waves travel from the gong to you - not from you to the gong. (v) You can only hear the sound when the air is vibrating and not when your ears just hear it. The clapper may strike the gong a long way away from you and you may not hear the sound. (vi) Not all objects, voices, things vibrate when they make noises but you still hear them don't you? So you can hear things when they aren't vibrating as such.
	3 (i)	Yes, you can hear better underwater than in air - you would hear a faint nutter [sic] of the boat engine.
	(ii)	Yes, the steel girder would vibrate and you would hear the noises of the bang of the hammer.
	(iii)	Yes, the sound waves would travel along the string and you would hear the sounds (voices).
	(iv)	No, depending on how loud you were talking you probably couldn't hear the voices.
	(v)	No, the vacuum jar would keep in all of the vibrations and sound waves.
	(vi)	Yes, the siren doesn't just stop immediately as it goes past, it fades away into the distance.
22(I)	1	The bird's voice box vibrates and the vibrations (sound) travel through the air to the child's ears. The vibrations enter the child's ear drum and nerves react to send a message to the brain saying that a bird is singing in a tree. No. of key elements present: 3.5 [student did not say how vibrations travel through the air]

	2	Option selected: (iv) (i) Yes, the sound echoes but it doesn't say that the vibrations enter your ear so that you can hear it. (ii) We don't need to concentrate to listen. The vibrations are still going to enter our ears whether we concentrate or not. (iii) The sound waves would have to travel from the gong to our ears for us to hear, not the other way round. (v) This is sort of right. But it doesn't say that the vibrations enter our ears to hear it. (vi) Yes the gong vibrates but again it doesn't say that the vibrations enter our ears.
	3 (i)	Yes, because vibrations can travel through water.
	(ii)	I don't know.
	(iii)	Yes, because the vibrations travel down the string.
	(iv)	I don't know.
	(v)	No, because vibrations cannot travel through a vacuum
	(vi)	Yes, because the vibrations will still enter our ears, only after the car has passed.
30(I)	1	The bird singing sets the air surrounding bird vibrating and the vibrations travel through the air to your ears and set child's ear drum vibrating which sends a message to the brain. No. of key elements present: 4
	2	Option selected: (vi) (i) Sound doesn't echo. And the sound is made by vibrations not just by being struck. (ii) Concentration - you can hear anyway. (iii) Sound waves travel from the gong to your ear. (iv) The gong needs to be struck to vibrate and for the vibrations to travel to your ears. (v) You hear what? The clapper? The gong?
	3 (i)	Yes, sound travels better through water than through air.
	(ii)	Yes, the vibrations travel along the girder.
	(iii)	Yes, the vibrations of you talking travel along the string.
	(iv)	No, the air vibrations would rebound from the wall.
	(v)	No, the foam absorbs the sound of the alarm clock [no mention of effect of vacuum]
	(vi)	Yes, sound travels slower than light.

32(I)	1	When the bird sings it makes the air vibrate. The vibrations travel through the air - as the particles hit eachother and transfer the energy. The vibrations travel through the air and to the ear where the vibrations are picked up by the ear drum. No. of key elements present: 4
	2	Option selected: (iv) (i) Your ears have to pick something up, you don't just hear things. (ii) Sound isn't just heard, there has to be something that happens to make something physical that you can pick up. (iii) Your ear isn't making the sound. Your ears don't just send out "nets" and gather up the sound. (v) You do hear it with your ears but the sound needs to travel somewhere. (vi) The gong vibrates <u>but</u> it also makes the air vibrate which makes the sound.
	3 (i)	Yes, because the sound can travel through the water like it travels through the air - bumping the particles.
	(ii)	Yes, because the particles are very close together so they will travel well through the steel
	(iii)	Yes, because it can vibrate through the string.
	(iv)	No, because they are not talking very loud and the sound has to travel through a few mediums (and it doesn't travel <u>over</u> the wall).
	(v)	No, because there is no air particles or any other type of particle to make vibrate.
	(vi)	Yes, because the sound can travel quite a long way through the air.
33(I)	1	The birds vocal chords produce vibrations that travel through the air in sound waves. These vibrations reach the childs ear and set the air inside the ear vibrating until the vibrations reach the ear drum. No. of key elements present: 3.5 [student does not say how vibrations travel through the air]

	2	Option selected: (iv) (i) With this - how does the sound reach your ear - what makes the sound and how is it echoing - it doesn't explain properly. (ii) You don't need to listen or concentrate you just hear it through the vibrations. (iii) How are the sound waves produced and how do they travel through the air. This doesn't answer these. (v) How do you hear it, how do the sounds get to your ears. (vi) Yes, but how does the sound get from the gong to your ears.
	3 (i)	Yes, because the vibrations travel from the engine through the water - the water vibrates - and to your ear.
	(ii)	Yes, because the vibrations travel through the steel and the brick to your ear, although only softly.
	(iii)	Yes, because the voice sets the tins and string vibrating and the vibrations travel to your ear but not if she whispers too softly.
	(iv)	Maybe, because it would depend how quietly whether the vibrations would be enough to set the wall vibrating - probably not, or whether the vibrations could go over the wall.
	(v)	No, because there is nothing to pass the vibrations through the vacuum.
	(vi)	Yes, because the vibrations are probably still travelling through the air after the car's gone past.

Appendix 17.3 Delayed post-instruction responses

Student Number	Question Number	Response
1	1	Because sound travels through the air in waves (sound waves) into the child's ear. No. of key elements present: 2.5 [no mention of vibrations although does mention sound waves]

	2	Option selected: (iii) (i) It does travel through the room but in sound waves not echoes. (ii) Although the clapper strikes the gong you don't concentrate to hear, it travels through the air. (iv) no comment (v) Although this is true you don't just hear it you also need sound waves. (vi) This is true but again you need sound waves.
	3 (i)	Yes, because sound also travels underwater.
	(ii)	Yes (no explanation)
	(iii)	Yes, because the tins vibrate and you hear the noise.
	(iv)	No, because sound doesn't go through solid things.
	(v)	Yes, sound would travel through glass. A bit muffled though.
	(vi)	Yes, because the sound is still floating in the air.
2(I)	1	The child can hear the sound of the bird singing because when the bird makes a noise, this sends vibrations through the air, which travel and hit the child's ear, and in the ear the vibrations are picked up and converted to sound. No. of key elements present: 3.5 [does not say that air is vibrating]
	2	Option selected: (iv) (i) This does not describe how <u>you</u> hear the sound and how it gets to you. (ii) This is wrong because you don't concentrate and so can hear sound but sound travels <u>to</u> you. (iii) This is wrong because the sound waves do <u>not</u> travel from your ear to the gong but the other way round. (v) This does not describe <u>how</u> you hear the sound. (vi) This again does not describe <u>how</u> you hear the sound.
	3 (i)	Yes, because the boat engine can set vibrations in the water going.
	(ii)	Yes, because the steel can vibrate with the sound of the hammer.
	(iii)	Yes, because the sound you make can travel along the tight string.
	(iv)	Yes, because the sound waves can travel through the wall as the wall can be set vibrating.
	(v)	No, because there is no way the vacuum can be set vibrating.

	(vi)	Yes, because the sound waves take quite a time travelling to you.
3(I)	1	The bird is the sound source. It makes the air particles move. It creates sound waves that travel through the air and to the child. The sound waves vibrate in the ear and the child can hear the sound. No. of key elements present: 3.5
	2	Option selected: (iv) (i) no comment. (ii) It needs to make sound waves. (iii) The sound comes from the gong, not the ear. Sound waves don't come from the ear. (v) It needs to make sound waves. (vi) no comment.
	3 (i)	Yes, sound travels very well under water because the particles are very close together.
	(ii)	Yes, sound travels very well through the metal. The particles are very close together.
	(iii)	Yes, the sound goes along the string and vibrates the cans.
	(iv)	Maybe, depending on how quiet the person is talking.
	(v)	No, there are no particles in the vacuum so the sound waves can't travel.
	(vi)	Yes, it gets quieter as it goes but you can still hear it.
4(I)	1	When the bird sings it sends out sound waves that travel through the air and the boy's ears pick up these vibrations. No. of key elements present: 3 [no mention of source producing vibrations nor of air vibrating but does say ear vibrates]
	2	Option selected: (iv) (i) This doesn't explain how the sound from the gong is made. (ii) You don't have to listen to a sound to hear it. (iii) The waves carry from the gong to your ear not the other way round. (v) This is a too simple explanation. (vi) It does not say how you pick up the vibrations.
	3 (i)	Yes, because sounds travels well through water.
	(ii)	Yes, because the steel would set the wall vibrating and so on.
	(iii)	Yes, because the sound would travel well through the string.
	(iv)	No, because there is no sound vibrations heard through a wall.

	(v)	No, because there is no sound in a vacuum.
	(vi)	Yes, because there are still the vibrations of the siren around.
5(I)	1	The bird makes a sound which makes the air vibrate and the vibrations travel to the childs ears. No.of key elements present: 3.5 [doesn't say ear vibrates]
	2	Option selected: (iv) (i) no comment .] (ii) no comment.] (iii) no comment.] [student says none of these makes (v) no comment.] sense] (vi) no comment.]
	3 (i)	no response.
	(ii)	no response.
	(iii)	no response.
	(iv)	No, the vibrations can't travel over.
	(v)	No, because there is nothing to vibrate.
	(v)	Yes, the vibrations are still in the air.
6	1	Sound waves come from the bird's voice box in to the boy's ear to his ear drum from where signals are sent to the brain. No. of key elements present: 1.5 [no mention of medium or vibrations; travel is implied as 'come from ----to']
	2	Option selected: (iv) (i) Whether it echoes or not, you still hear it. (ii) Listening is not about concentration, it is to do with sound waves. (iii) You cannot receive the sound waves if they are going away from your ears. (v) This is not HOW you HEAR it. (vi) The vibrations (sound waves) must travel to your ear drum.
	3 (i)	Yes, vibrations travel under water.
	(ii)	no response.
	(iii)	no response.
	(iv)	no response.
	(v)	no response.
	(vi)	Yes, the thing doesn't have to be right in front of you to hear it.

7	1	Sound is transformed into sound waves and carried in the wind until you can't hear the noise any more. No. of key elements present: 1 [no mention of vibrations, medium, the ear]
	2	Option selected: (iii) (i) You need sound waves to pick up a sound. (ii) You don't have to concentrate to hear a noise. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, water is moving and sound travels slowly.
	(ii)	No, it can't vibrate.
	(iii)	Yes, string vibration.
	(iv)	No, wall blocks out the sound.
	(v)	No. (no explanation)
	(vi)	Yes, the sound waves don't just stay with the car it goes to a distance way from the noise making object.
8	1	The sound waves travel through the air, picking up the sound of the bird and carrying it to the person and beyond. The person hears this noise. No. of key elements present: 1.5 [mentions sound waves but not vibrations; no mention of ears]
	2	Option selected: (iv) (i) Doesn't explain how you hear. (ii) You don't have to concentrate to hear the sound. (iii) Sound waves travel from the gong to your ear. (v) Doesn't explain how you hear it. (vi) no comment.
	3 (i)	Yes, sound waves travel through water.
	(ii)	Yes, some sound waves travel through wall.
	(iii)	Yes, vibration travels along string.
	(iv)	No, sound not loud enough to travel distance.
	(v)	No, nowhere for vibrations to travel if sitting on foam.
	(vi)	Yes, sound travels in all directions.

9(I)	1	The bird emits sound waves which set the surrounding air vibrating. The tiny hairs in the child's ears pick up the vibrations and send messages to the brain which is translated into sound. No. of key elements present: 4
	2	Option selected: (iv) (i) Sound does not echo, it passes in sound waves which set the air vibrating. (ii) You do not have to concentrate to hear. (iii) Sound waves travel to your ear, not from it. (v) This does not explain how sound travels to your ears and how you pick it up. (vi) This does not explain how the sound gets to your ears from the gong.
	3 (i)	Yes, because the sound would set the water particles vibrating.
	(ii)	Yes, because the steel would vibrate.
	(iii)	Yes, because the vibrations would pass into the can and along the string.
	(iv)	No, because the vibrations would have to pass from the air, through the wall, and through the air again and the vibrations would not be strong enough.
	(v)	No, there are no particles for the vibrations to travel through.
	(vi)	Yes, the vibrations reach you after the car.
10(I)	1	Sound vibrations from the bird travel through the air and the child picks up the vibrations through his ear. No. of key elements present: 3.5 [does not say that air vibrates]
	2	Option selected: (iv) (i) no comment. (ii) No, because there are no mention of sound waves or vibrations. (iii) ditto. (v) Same as before. (vi) Same as before.
	3 (i)	Yes, because vibrations are sent easily through water.
	(ii)	Yes, the sound vibrations travel through the wood [sic] and the air to your ears.
	(iii)	Yes, the vibrations travel through the string.
	(iv)	Maybe, it depends how quietly she is talking.

	(v)	No, because it is a vacuum.
	(vi)	Yes, because vibrations are still moving through the air.
11(I)	1	The child may hear the bird through his ears, the sound from the bird sends the air particles vibrating. The vibration of the air sends the tiny hairs in our ears vibrating which enables the child to hear the singing of the bird. No. of key elements present: 3.5 [travel through the air is implied]
	2	Option selected: (iv) (i) No all sounds echo around the room, eg you hear sounds outside and they are vibrating around the room. (ii) You don't have to concentrate to hear something. (iii) The sound travels from the gong to your ear not vice versa. (v) This is correct although it doesn't explain <u>how</u> you hear the sound. (vi) Some things vibrate but you don't always hear a sound.
	3 (i)	Yes, it sends the water particles vibrating although it depends on how close you are.
	(ii)	Yes, it sends the wall vibrating.
	(iii)	Yes, the sound moves down the cord.
	(iv)	No, talking quietly wouldn't be enough to send the bricks vibrating.
	(v)	Yes, the glass would vibrate.
	(vi)	No, because the air particles are vibrating in the opposite direction.
12(I)	1	Sound from the bird is picked up by the vibrations in the air, depending on how loud the bird sings as to how far the noise is carried. We hear the noise because the vibrations in the air go into the ear and make the ear drum vibrate as well. No. of key elements present: 4
	2	Option selected: (iv) (i) How do you hear the sound? (ii) How can you hear it? What can you hear it with? (iii) no comment. (v) Does not explain how your ears hear it. (vi) Does not explain how you hear the gongs vibration.
	3 (i)	Yes (no explanation)
	(ii)	Yes (no explanation)

	(iii)	No (no explanation)
	(iv)	Yes (no explanation)
	(v)	No (no explanation)
	(vi)	Yes (no explanation)
13(I)	1	Particles in the air near the bird are set vibrating when the bird makes a noise. These particles then set other particles vibrating - these are called sound waves. The waves travel to the childs ear and eventually a message is sent to the brain which enables the child to identify the sound. No. of key elements present: 4
	2	Option selected: (iv) (i) You can hear the sound even if there is nothing for it to echo off. (ii) You can hear the sound if you're concentrating or not. (iii) The sound waves don't travel from the ear, they travel from the sound source - the gong. (v) This is true but there is much more to it than just hearing the sound. (vi) Because the gong vibrates, it doesn't mean that it is how you hear the sound.
	3 (i)	Yes, sound travels better through water than air.
	(ii)	Yes, sound travels very well through steel.
	(iii)	Yes, the sound vibrates along the string.
	(iv)	No, if they were talking loudly you could probably hear them.
	(v)	No, there are no particles in a vacuum - so no sound can be heard.
	(vi)	Yes, sound waves travel out in all directions.
14	1	The sound of the bird singing travels through the air and into the ear. Once it reaches the ear drum the ear drum vibrates and ----- [sic]. No. of key elements present: 3 [no mention of vibration of air]

	2	Option selected: (iv) (i) I think that this is incorrect because it echoes around the room but it doesn't mean that you hear it. (ii) Yes, if you concentrate you can hear the sound but it doesn't mention anything about the vibrations, etc. (iii) Sound waves can't travel from your ear because there is no sound coming from your ear. (v) Yes, you hear it but it doesn't say anything about the gong making the air vibrate, etc. (vi) You just can't hear the sound it has to travel through your ear, etc.
	3 (i)	Yes, because the noise would vibrate through the water to the swimmer under the water.
	(ii)	Yes, because it vibrates.
	(iii)	Yes, the string vibrates when the talker is talking.
	(iv)	No, because the noise has to rise and talking quietly doesn't vibrate the sound.
	(v)	Yes, because it vibrates the glass.
	(vi)	Yes, because the air is still vibrating.
16(I)	1	When the bird sings the vibrations of the sound waves travel through the air to the child's ears. The child can hear the sound through his/her ear lobe. No. of key elements present: 3
	2	Option selected: (iv) (i) Your ear can hear all sorts of sounds and not all of them echo - this means that you don't hear it just because of the echo. (ii) You don't have to concentrate to hear a sound. Your ear hears it automatically. (iii) This is around the wrong way. Sound waves travel from the gong to your ear. (v) You don't just hear it - sound waves have to travel through the air for you to hear it. (vi) This is wrong.
	3 (i)	Yes, the vibrations and loud noise under the water would be possible to hear.
	(ii)	Yes, you would hear the vibration through the steel.
	(iii)	Yes, the sound travels along the string to your ears.
	(iv)	No, the vibrations wouldn't go over the top of the wall.

	(v)	No, the sound couldn't get out for you to hear the alarm clock.
	(vi)	Yes, the siren doesn't disappear straight after it has passed you.
21	1	The bird makes the sound. The vibrations travel through the air in sound waves. The child hears the noise with his ears. No. of key elements present: 3 [no mention of vibration of air nor how the ear receives the sound]
	2	Option selected: (iv) (i) I don't think the sound echoes. (ii) Doesn't mention sound waves or vibrations. (iii) The sound waves would travel through the air <u>from</u> the gong to your ear. (v) This is true but not detailed enough. (vi) Also true but not detailed enough.
	3 (i)	Yes, the sound can go through the water.
	(ii)	no response.
	(iii)	Yes, the sound travels along the string.
	(iv)	Yes, the sound can go through the wall.
	(v)	no response.
	(vi)	Yes, if the car is close by, you should still be able to hear it.
22(I)	1	The bird sings and makes vibrations which travel through the air and into the child's ear. The vibrations hit the cochlea in the ear and a message is sent to the brain telling the child that there is a bird singing in the tree. No. of key elements present: 3.5 [does not say that air vibrates - although in Q 2 (vi) does say air vibrates]
	2	Option selected: (iv) (i) I don't know. (ii) You don't need to concentrate to hear. It just happens. (iii) The sound waves would travel from the gong to your ear, not the other way around. (v) Yes, but the sentence says nothing about the vibrations. (vi) The gong vibrates which would set the air vibrating so I think that it is almost the same as no. 4 and the sound would be heard anyway.
	3 (i)	Yes, because the water can carry vibrations.
	(ii)	Yes, perhaps not very well. Same as the last, ie the vibrations can travel through the wall.

	(iii)	Yes, because the vibrations can travel down the string.
	(iv)	No, probably not, as the vibrations might not make it through the wall.
	(v)	No, because there is nothing that can vibrate in the vacuum.
	(vi)	Yes, the noise would be heard later, but could still be heard.
23	1	As the bird sings or makes any kind of sound, invisible sound waves travel through the air particles and the boy picks up these waves. Tiny hairs in the boy's ear pick up the vibrations and change them into a specific sound, eg words. No. of key elements present: 3 [only mentions vibrations in the ear - does say 'vibrations travel through the air' in Q2 (ii)]
	2	Option selected: (iv) (i) You don't actually hear the echo, what you hear is the vibrations. (ii) You don't have to concentrate to hear a sound. Vibrations travel through the air to your ears whether you are concentrating or not. (iii) Sound waves travel from the gong to your ear not the other way round. (v) To be able to hear it with your ears, vibrations have to travel through the air, so to be able to hear it the vibrations have to be able to reach your ears. (vi) You don't hear the vibrations. The vibrations are what travel through the air to your ears. The vibrations make the sound.
	3 (i)	Yes, the water contains air and sound vibrations can travel through the air, so you can hear under water.
	(ii)	Yes, as you hit the piece of steel, vibrations travel along the girder right to your ear.
	(iii)	Yes, sound vibrations travel along the string if it is pulled tight.
	(iv)	No (no explanation)
	(v)	No (no explanation)
	(vi)	Yes, sound waves still travel through the air whether the sound is on one side or the other.
24	1	The child hears the sound because the bird's sound travels on sound waves. No.of key elements present: 1 [no mention of vibration, medium or ear]

	2	Option selected: (iv) (i) The sound doesn't echo it travels on sound waves. (ii) You don't have to concentrate you just hear it. (iii) Sound doesn't travel from your ear it travels to your ear. (v) You don't hear it as soon as it is hit. (vi)The sound waves vibrate and carry the sound to your ears.
	3 (i)	Yes, there are also sound waves in the water.
	(ii)	Yes, the sound would travel and be carried in sound waves.
	(iii)	Yes, the sound would carry on the string and then vibrate in the tin and your ears.
	(iv)	No, the wall would stop the sound waves travelling to her.
	(v)	No, because the sound is trapped and there are no sound waves able to get out.
	(vi)	Yes, the sound would still travel on the sound wave as it passes.
25	1	Sound waves travel through the air and the child can pick up the bird chirping through his/her ears. No. of key elements present: 2.5 [no mention of vibrations]
	2	Option selected: (i) & (iv) (ii) It may only be a soft strike so they don't take much notice. (iii) The sound waves would travel from the gong to your ear not from ear to gong. (v) This doesn't describe the sound waves. (vi) How do you hear the sound ?
	3 (i)	Yes (no explanation)
	(ii)	Yes (no explanation)
	(iii)	No (no explanation)
	(iv)	No (no explanation)
	(v)	Yes (no explanation)
	(vi)	Yes (no explanation)
26	1	Sound waves travel through the air.When the bird tweets the sound waves travel to the ear. No. of key elements present: 2.5 [no mention of vibration]

	2	Option selected: (iv) (i) This means you could be only able to hear the echo and by the time it reaches your ear it could be very faint. However, we can hear the actual gong. (ii) We automatically hear things, there is no need to really concentrate. (iii) If any thing the sound waves from the gong would travel to the ear, not from the ear to the gong. (v) It doesn't explain how you hear it. (vi) You would be able to feel the vibration and hear them after the gong's been struck, not when the gong is struck.
	3 (i)	Yes (no explanation)
	(ii)	No (no explanation)
	(iii)	Yes (no explanation)
	(iv)	No (no explanation)
	(v)	Yes (no explanation)
	(vi)	Yes (no explanation)
27	1	The bird's voice box vibrates sending vibrations or sound waves through the air. These are received by the boy. The vibrations are picked up by the ear drum which sends messages to the brain enabling the boy to hear. No. of key elements present: 3.5 [does not say that the air vibrates - in Q. 2 (iv) actually says 'air doesn't vibrate']
	2	Option selected: (vi) (i) Sound doesn't echo. (ii) You don't have to be concentrating to hear a certain sound to be able to pick it up. (iii) Sound waves travel from the gong to the ear not vice versa. (iv) Air doesn't vibrate, sound waves are sent. (v) You hear the noise produced after the gong is hit, not when.
	3 (i)	Yes, sound waves travel through water molecules.
	(ii)	No, the sound waves/vibrations would be stopped by the brick wall.
	(iii)	No, sound doesn't travel through string.
	(iv)	No, sound won't travel through brick.
	(v)	No, sound waves don't travel through vacuum.

	(vi)	Yes, sirens are loud and the sound waves travel freely through air.
28	1	When the bird sings vibrations are sent through the air. A child's ear will catch the vibrations. Those vibrations will then send signals to the brain and thus it will turn the vibrations into a sound which will be heard. No. of key elements present: 3.5 [does not say that air vibrates]
	2	Option selected: (iv) (i) This is wrong because when the gong is struck it sends off vibrations not just a sound. And this sentence doesn't describe how you hear it, it only describes what happens without anyone hearing it. (ii) You can't just concentrate on a sound or even just listen for it. Your ear picks up the vibrations. (iii) Your ear doesn't make sound waves the gong does. Your ear picks up sound waves from the gong not vice versa. (v) 'Hear it', this doesn't describe how you hear it. (vi) This again doesn't describe how you 'hear' it.
	3 (i)	Yes, this could be heard because the boat's engine would send vibrations through the water which your ear would pick up.
	(ii)	No, because the vibrations wouldn't travel far at the end of a steel girder, once the vibration was let off it. Besides the solid brick wall would cushion the vibrations.
	(iii)	Yes, this could be heard because the vibrations would travel along the string and then enter the tins.
	(iv)	No, this would not be heard because the brick wall would block the vibrations. By the time the voice hit the wall and travelled up the wall the vibrations would be lost.
	(v)	No (no explanation)
	(vi)	No (no explanation)
30(I)	1	The child can hear the sound of the bird singing because 1) The bird singing makes vibrations, 2) The vibrations travel through the air, 3) The child's ear receives the vibrations, 4) The vibrations are sent as messages to the brain, 5) The brain recognises the sound, 6) From there the child is able to recognise the sound of a bird and locate it. No. of key elements present: 3.5 [does not say that the air vibrates]

	2	Option selected: (vi) (i) Sound doesn't echo. (ii) You don't need to concentrate to hear the sound. (iii) The sound waves don't go from ear - gong (if the gong is struck). (iv) The gong needs to be struck [sic] [student has made an error because it says in the question that the gong is struck] (v) Your ears receive the vibrations but don't hear it the brain hears it similarly to the way our eyes receive the picture but don't see it.
	3 (i)	Yes, sound travels through dense materials very well.
	(ii)	No, the bricks would absorb the sound waves (vibrations)
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, the sound waves would be reflected.
	(v)	No, sound waves can't travel through a vacuum.
	(vi)	Yes, the speed of sound is slower than the speed of light.
31	1	Because the sound waves of the bird echos and the child can hear because his ears respond. No. of key elements present: 1 [no mention of vibration, medium, or how the ear hears the sound]
	2	Option selected: (i) and (iii) (ii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, because of sound vibration.
	(ii)	No (no explanation)
	(iii)	Yes, because of the vibration.
	(iv)	Yes, because it would echo.
	(v)	No (no explanation)
	(vi)	Yes, because of the sound vibration.
32(I)	1	The bird sings and makes the air vibrate. The air particles vibrate and hit each other sending the vibrations continuing on. The vibrations reach the ear of the child and are picked up by the ear. No. of key elements present: 4

	2	Option selected: (iv) (i) This is kind of what happens however what is sound and how does it echo around the room. (ii) You don't have to concentrate to hear sounds as the vibrations just travel everywhere. (iii) Why are the sound waves travelling FROM the ear? It's not like they are nets which collect sound. (v) Well yes, you do hear it, but sound isn't just nothing, something needs to be heard. (vi) The gong does vibrate but how does that make you hear the sound if it only vibrates?
	3 (i)	Yes, because sound can travel better through denser mediums like liquids.
	(ii)	Yes, because sound can travel through any medium except a vacuum.
	(iii)	Yes, because the air in the tin vibrates, makes the string vibrate, makes the other tin vibrate, which makes the air inside it vibrate and so you can hear it.
	(iv)	No, because sound travels better through denser mediums than air.
	(v)	No, because sound cannot travel through a vacuum because there are no particles to vibrate
	(vi)	Yes, because the sound travels through the air.
33(I)	1	The noise of the bird's voice makes vibrations which travel through the air in sound waves of different frequencies. The air vibrates along these waves and eventually the vibrations reach the boy's ear and set the ear vibrating and then the ear drum. The boys brain picks up these vibrations and tells the boy what it is he is hearing. No. of key elements present: 4

	2	Option selected: (iv) (i) The echoes are created by vibrations. This does not explain this or how it reaches you ear. (ii) This does not explain how the sound gets to your ear nor does it mention vibrations. (iii) This is the wrong way round, the sound waves travel from the gong to your ear not the other way around. (iv) Correct. (v) Yes, but this doesn't explain how the sound gets to your ears. (vi) Yes, but this also doesn't explain how you hear it or how the sound travels from one point to another.
	3 (i)	Yes, because the vibrations of the engine set the water vibrating and these vibrations reach your ear.
	(ii)	Yes, because the steel girder would vibrate intensely and these vibrations would reach your ear especially if you were touching it.
	(iii)	Yes, because the voice would set the string vibrating and it would reach your ear.
	(iv)	Yes, but faintly because the vibrating air would have difficulty making the wall vibrate although sound could go over.
	(v)	No, because there is nothing in the vacuum to vibrate so sound would not get through it.
	(vi)	Yes, because the sound is still vibrating through the air.

Appendix 17.4 12-month delayed post-instruction responses

Student Number	Question Number	Response
1	1	The child can hear by the sound waves of the birds cherp [sic]. It travels through the air at the speed of light. You can not see sound travel through the air. No. of key elements present: 2 [no mention of vibrations although does mention sound waves; no mention of ears]

	2	Option selected: (iii) (i) It has to travel through the air at the speed of light. (ii) It doesn't just concentrate to hear sound. (iv) Could be true. (v) Again, it travels through the air. (vi) no comment.
	3 (i)	Yes, because sound doesn't spot [sic] [stop?] underwater.
	(ii)	No, birck [sic] doesn't let sound through.
	(iii)	Yes, it is still travelling through the air.
	(iv)	Yes/No, depends on what the wall is made of.
	(v)	Yes, it all vibrates so you can hear it.
	(vi)	Yes, the sound is still travelling in the air.
2(I)	1	The bird sings and its voice box makes the air in its mouth vibrate and this pushes particles of air outside and the air vibrates, the vibrating air (sound waves) reaches the child's ear and goes into its ear drum where it gets turned into an electrical sound which the child hears. Thus the child hears the bird singing. No. of key elements present: 3.5 [does not say ear drum vibrates]
	2	Option selected: (iv) (i) This doesn't say how you hear the sound, ie how it reaches your ears. (ii) This is wrong as you don't concentrate and hear a sound, the vibrating air reaches your ears and then you hear a sound. (iii) This is the wrong way around. The sound waves travel through the air to your ear, not from your ear. (v) This doesn't say how you hear it with your ears, eg doesn't mention vibrations travelling through air. (vi) This again doesn't say that the vibrations travel through the air to your ears.
	3 (i)	Yes, because sound waves travel well through water (it is denser).
	(ii)	Yes, because sound waves travel well through steel and more quickly as the particles are closer together.
	(iii)	Yes, because sound waves can travel along a string as long as it is tight.
	(iv)	No, because the sound waves bump onto the wall and reflect off it.

	(v)	No, because sound waves can't travel through a vacuum as there is not particles to vibrate
	(vi)	Yes, as the sound waves take a while to reach you and so the car might be gone.
3(I)	1	• The bird makes a sound • The sound waves travel through the air • The sound waves reach the boy and they enter the ear • The vibrations in the ear travel through past the 3 smallest bones and in through the liquid and into the cochlea. The vibrations are sent off as electrical pulses to the brain and the sound is heard. No. of key elements present: 3 [does not say that air vibrates]
	2	Option selected: (iv) (i) You need to have sound waves that you can hear. (ii) Need sound waves. (iii) The sound waves begin at the gong. (v) There needs to be sound waves. (vi) no comment.
	3 (i)	Yes, sound travels very well in water because it is denser than air.
	(ii)	Yes, because sound can travel through steel well.
	(iii)	Yes, because the vibrations travel through the string.
	(iv)	Yes, depending on the height sound waves can go over objects.
	(v)	No, because the vacuum has no air, therefore the sound waves cannot travel
	(vi)	Yes, because sound waves travel in all directions. It will also have a dopler [sic] effect.
4(I)	1	With its ears. The sound travels out of the birds mouth or whatever and then gets picked up in the boy's ears. The sound travels through the air in vibrations called sound waves and at different pitches. The sound waves are different lengths. No. of key elements present: 3 [no mention of air particles vibrating nor of ear vibrating]

	2	Option selected: (iv) (i) The sound won't necessarily echo around the room. (ii) Don't have to concentrate to hear a sound. (iii) Sound waves don't come out of your ear. (v) This explanation is too simple. (vi) This is what more or less happens as well.
	3 (i)	Yes, because sounds travels through water.
	(ii)	Yes, because the sound could travel through the steel/wall/steel.
	(iii)	Yes, because the sound is just moving particles which would move across the string.
	(iv)	No, because the sound bounces off the wall.
	(v)	No, because sound can't travel through a vacuum [doesn't say why not]
	(vi)	Yes, because of the doppler effect.
5(I)	1	Bird sends vibrations into the air when it sings. The vibrations travel through the particles in the air to the childs ear, and set the ear vibrating and the child hears the sound. No.of key elements present: 4 [doesn't say specifically here that air particles actually vibrate but does say so in Q.3 (v)]
	2	Option selected: (iv) (i) It doesn't say how the sound actually travels. (ii) Doesn't explain properly. (iii) The sound waves travel to your ear not from your ear. (v) Doesn't explain fully. (vi) Doesn't explain fully.
	3 (i)	Yes, because the sound travels through the water particles.
	(ii)	Yes (no explanation)
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, because the sound wouldn't be loud enough.
	(v)	No, because there are no particles to be set vibrating.
	(v)	Yes (no explanation)
6	1	The sound waves from the birds music travel to the childs ears. No. of key elements present: 1.5 [no mention of air or vibrations]

	2	Option selected: (iv) (i) no comment (ii) You don't have to concentrate to hear it (iii) Sound waves don't travel FROM your ear. (v) This does not describe HOW you hear it with your ears. (vi) See Q 5.
	3 (i)	no response.
	(ii)	no response.
	(iii)	no response.
	(iv)	No, the sound waves can't travel through.
	(v)	no response.
	(vi)	Yes, but only quietly.
7	1	Sound waves travel through the air from the bird to the childs ear. No. of key elements present: 2.5 [no mention of vibrations]
	2	Option selected: (iv) (i) Echo is a sound wave. (ii) You don't have to concentrate to hear a noise usually. (iii) Sound has to travel to your ear. (v) How do you hear it. (vi) You can't hear a vibration
	3 (i)	Yes, the movement of the water.
	(ii)	No, the wall is touching the steel girder.
	(iii)	Yes, the string is held straight and not sagging.
	(iv)	No, there is an obstical [sic] in the way.
	(v)	No. (no explanation)
	(vi)	Yes, sound waves travel in all directions.
8	1	You can hear the bird because it makes vibrations that travel along the sound waves from the bird to the childs ears. No. of key elements present: 1.5 [no mention of air but does mention vibrations]
	2	Option selected: (iv) (i) This doesn't explain how you hear it! (ii) You don't have to concentrate to hear the sound. (iii) Sound waves travel from the gong then to your ear. (v) Doesn't explain how you hear it. (vi) Doesn't explain how you hear vibrations!
	3 (i)	Yes, vibrations travel through water - but sound may be faint.

	(ii)	No, wall may absorb sound vibrations.
	(iii)	Yes, vibrations travel along string.
	(iv)	No, wall may absorb the sound.
	(v)	No, because the alarm clock is sitting on foam, so no vibrations can get out of the bell jar.
	(vi)	Yes, sound wave vibrations travel in all directions!
9(I)	1	When the bird sings the sound travels through the air in vibrations. The vibrations reach the ear of the boy where they go through air, liquid, air and are picked up by minute hairs which transfers them to messages to the brain of the sound, its pitch, and loudness. No. of key elements present: 3 [does not say that air particles vibrate nor that the ear drum vibrates]
	2	Option selected: (iv) (i) The sound does not echo, the vibrations get off [sic] by the gong do as they travel through the air. (ii) You do not have to concentrate to hear and your ears pick up vibrations in the air anyway. (iii) The sound waves travel from the gong to your ear. (v) The gong vibrates which sets the air vibrating and sound waves are received by your ears. (vi) The vibrations of the gong set the surrounding air vibrating and your ears pick up the sound waves.
	3 (i)	Yes, sound travels through water.
	(ii)	No, you would get the vibrations but not the noise as it would be too quiet.
	(iii)	Yes, the vibrations travel through the tin, along the string, through the other tin into the other's ear.
	(iv)	No, as when the vibrations hit the wall they would mostly bounce back, not being strong enough to go through.
	(v)	No, there are no particles for the vibrations to travel through.
	(vi)	Yes, as the police car would send off sound waves as it is going just which would reach your ears after the car has passed.
10(I)	1	The vibrations from the birds mouth vibrate and travel through the air and are picked up by the boys ear. No. of key elements present: 3.5 [does not specifically say ear or ear drum vibrates]

	2	Option selected: (iv) (i) The ear isn't mentioned. (ii) There are no vibrations. (iii) Vibrations are set [sic] by the gong. (v) No vibrations mentioned. (vi) They haven't travelled through the air.
	3 (i)	Yes, sound can also travel under water.
	(ii)	Yes, vibrations are sent through the steel.
	(iii)	Yes, the sound vibrates through the string to the receiver.
	(iv)	Yes, the vibrations travel through the air.
	(v)	No, because it is a vacuum so nothing will send the vibrations.
	(vi)	Yes, the vibrations are still travelling in the air.
11(I)	1	The boy can hear the bird because the sound of the bird's singing viabrates [sic] the air particles which viabrate [sic] the boy's eardrum therefore he can hear the bird's singing. No. of key elements present: 4 [travel through the air is implied]
	2	Option selected: (iv) (i) It may echo, but that doesn't necessary [sic] mean you hear the sound. (ii) You don't need to concentrate to hear something. (iii) Air waves don't travel from your ear but to your ear. (iv) This is true. (v) This is also true but no. 4 gives more detail to how you hear the sound. (vi) Yes this does happen but again no. 4 gives more detail.
	3 (i)	Yes, the water would vibrate the sound through.
	(ii)	Yes, the particles in the brick would viabrate [sic].
	(iii)	Yes, the string would carry the sound.
	(iv)	No, the soft talking doesn't viabrate [sic] the particles.
	(v)	No, there are no air particles in the vacuum.
	(vi)	Yes, the doppler effect.
14	1	Because bird sings and the sound vibrates through the air to the boy's ear. No. of key elements present: 3 [does not say specifically that air particles and ear vibrate]

	2	Option selected: (iv) (i) This could be true although number four is the correct one. (ii) Because your [sic] going to hear the sound if you listen for the sound or not because it is loud. (iii) Your ears do not send out sound waves through the air from your ears to the gong. It's common sense. (iv) This is the best discription [sic]. (v) Well, of course you would hear it in your ears but it's not describing how you hear noises. (vi) Yes, again. This is true but once more it's not a good description of what it sounds like.
	3 (i)	Yes, because the sound viabrates [sic] through the water.
	(ii)	Yes, because it would vibrate the girder to the other side.
	(iii)	Yes, because it vibrates.
	(iv)	No, because the sound can not travel directly to you it would have to travel over the wall.
	(v)	Yes, because it would vibrate and send out heaps of noise.
	(vi)	Yes, because the sound stays and vibrates in the air.
16(I)	1	The child can hear this because he/she has ears that pick up sound waves that run through the air. If the sound waves are very soft there is a chance that they can't hear it, and if they are loud it is most likely they would hear it. No. of key elements present: 2.5 [no mention of vibrations]
	2	Option selected: (iii) (i)The sound does not echo the room, that isn't how you hear things. (ii) You don't have to concentrate to hear the sound, your eardrum picks it up through the sound waves. (iii) This is right because that is how you hear things. (iv) It is not vibrations that travel to your ears, it is sound waves. (v) This could be said to be right, because that's what happens but no.3 best describes it. (vi) You don't hear the gong vibrating so much, it is the sound waves that make you hear it.
	3 (i)	Yes, because the engine would vibrate the particles in the water and you would hear it.
	(ii)	Yes, again it's the vibrations creating sound waves.
	(iii)	Maybe, depends how loud they are speaking!

	(iv)	No, the sound waves would bounce off the wall.
	(v)	Yes, because it would create vibrations which make sound waves to be heard.
	(vi)	Yes, the siren doesn't just stop after its gone past, you still hear it in the distance.
21	1	The bird makes the sound. The sound waves travel through the air and they vibrate inside the child's ear and he hears it. No. of key elements present: 3 [no mention of vibration of air]
	2	Option selected: (iv) (i) I don't think the sound echoes. (ii) Doesn't mention sound waves, air vibrating or ears. (iii) Sound waves travel from the gong to ear not other way around. (v) I think this one is right but it doesn't mention air vibrating. (vi) no comment.
	3 (i)	Yes, the sound waves can travel through the water.
	(ii)	Yes, sound waves can travel along steel girder.
	(iii)	Yes, sound waves can travel along string.
	(iv)	Yes, sound waves can travel through wall.
	(v)	Not sure.
	(vi)	Yes, sound waves are still able to travel to you.
22(I)	1	The bird sings and the sound travels through the air in sound waves. The sound waves travel through the air and to the boys ears. Once in the boys ears they travel through to the cochlea and move tiny little hairs inside it. The little hairs then create a message that travels through to the brain. The boy then knows that there is a bird singing in the tree. No. of key elements present: 2.5 [no mention of vibrations]

	2	Option selected: (iv) (i) No, the sound does not necessarily echo. The sound travels in waves not echo. (ii) We don't have to concentrate to hear a noise. We hear everything automatically. (iii) The sound waves travel the other way round. They travel from the sound source to the ear. (v) This is right but it doesn't really give the correct, full details like no. 4. (vi) Yes the gong vibrates but it has to travel through the air as well.
	3 (i)	Yes, because the sound would travel through the water and into the ear like normal.
	(ii)	Yes, the sound waves can still travel through the steel, etc.
	(iii)	Yes, but only if the string was tight because the sound waves travel down the string and into the ear, etc.
	(iv)	Possibly, if the area around you was quiet, you should be able to hear her, but other sounds may be louder and then it would not be possible to hear her.
	(v)	No, the sound waves that are given off by the clock would not be able to travel through the vacuum because there are no air particles for the sound waves to pass through.
	(vi)	Yes, there is no reason why you shouldn't hear it, it would just be later than after hearing the other car.
23	1	The air is full of sound waves that are tiny vibrations in the air. When the bird makes even the slightest sound, the sounds are converted into sound waves that travel through the air to the boys ears. The boy can only hear the sound if the vibrations reach him - if they don't then the boy is too far away to hear thus the sound waves can't travel that far. No. of key elements present: 3.5 [doesn't say precisely that the air itself vibrates nor that ear vibrates]

	2	Option selected: (iv) (i) The sound does echo around the room but it is not the echo you hear, it is the vibrations. (ii) If the sound waves can reach your ear then you should not need to concentrate to hear them. (iii) The sound waves travel the other way round: from the gong to your ear, not from your ear to the gong. Then it would be the gong doing the listening. (v) It is true that you hear it with your ears, but this statement does not tell you how, exactly, you hear it. (vi) The gong does vibrate but the sound you hear is vibrations or sound waves too not just 'a sound' that happens to occur.
	3 (i)	Yes, the water contains air so sound waves travel through the air - the sound would be muffled but still hearable.
	(ii)	Yes, the sound waves would vibrate along the steel to your ear. The vibrations would travel along it giving a ringing sound.
	(iii)	Yes, if the string is taut, then the vibrations could easily travel along the string.
	(iv)	No, as the wall would obstruct the sound waves discontinuing their flow. If the person was talking loudly then the sound waves could continue over the wall.
	(v)	No (no explanation)
	(vi)	Yes, there are still sound waves in the air and sound waves don't only travel forwards but backwards.
24	1	The child can hear because of sound vibrations in the air which travel through the ear [sic] [air?] on sound waves which make something trigger in the brain. No.of key elements present: 3 [doesn't actually say that air particles vibrate; no mention of ear]

	2	Option selected: (iv) (i) Sound has to travel on sound waves not just echo around the room. (ii) Even if you had your eyes closed you would still hear the sound. You don't use your eyes to listen. (iii) Sound waves don't travel from your ear. It's not making a noise. (v) It does strike the gong but you need vibrations. (vi) It does vibrate but it needs sound waves to help the sound to be heard.
	3 (i)	Yes, sound travels the same under water.
	(ii)	Yes, it would vibrate causing you to hear the sound.
	(iii)	Yes, the sound travels along the string because it is tight.
	(iv)	No, sound would not travel through a brick wall.
	(v)	No, the sound waves could not travel to your ears.
	(vi)	Yes, the sound is still travelling on the sound waves.
25	1	The sound waves carry through the air into the childs ear. The ear picks up the sound and registers it at the brain. The brain says its a bird singing. No. of key elements present: 2.5 [no mention of vibrations]
	2	Option selected: (iii) (i) This is also true. (ii) This is also true. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes (no explanation)
	(ii)	No (no explanation)
	(iii)	No (no explanation)
	(iv)	Yes (no explanation)
	(v)	No (no explanation)
	(vi)	Yes (no explanation)
26	1	The sound waves travel through the air and enter the childs ears. No. of key elements present: 2.5 [no mention of vibration]

	2	Option selected: (iv) (i) You hear the beater actually hit the gong not just the echo. (ii) No one has to concentrate to hear. (iii) They wouldn't go from the ear, the sound waves would travel to the air [sic] [ear?]. (v) Of course you hear it with your ears but there is more to it. (vi) This is the same as no. 1.
	3 (i)	Yes, it would be faint amongst the gurgling of the water.
	(ii)	Yes (no explanation)
	(iii)	Yes, because of vibration and echo.
	(iv)	No, because the wall is a sound barrier.
	(v)	No, you would hear vibration but not the ringing.
	(vi)	Yes (no explanation)
27	1	Bird produces vibrations, picked up by molecules in air, travel in sound waves, reach child, interpreted by brain, turned into sound. No. of key elements present: 3.5 [does not say how child receives signal]
	2	Option selected: (iv) (i) The sound doesn't echo around the room, it travels in sound waves. (ii) It is not necessary to concentrate to hear the sound. Sound waves travel to the ear. (iii) Sound waves travel from the gong to the ear, when struck. (iv) You hear the sound produced with ears. (v) Gong vibrates when struck sending sound waves to the ear - you hear the sound.
	3 (i)	Yes, sound travels easily through water molecules.
	(ii)	Yes, sound travels through the steel to ear.
	(iii)	Yes, sound vibrations travel.
	(iv)	No, sound waves interfered with, don't reach you.
	(v)	No, vacuum stops sound waves travelling to the ear.
	(vi)	Yes, sirens produce a loud noise which can be heard from large distances.

30(I)	1	The bird makes a sound which sets the air vibrating. The vibrations travel through the air in the form of sound waves to the child's ear. The brain then recognises the sound and direction from which the waves have come as a bird singing in the tree. No. of key elements present: 3.5 [does not say that ear vibrates]
	2	Option selected: (vi) (i) Sound doesn't echo. (ii) You don't need to concentrate and listen to hear. (iii) Sound waves travel from the object making the sound not the other way round. (iv) The gong needs to be vibrating first. (v) With your ears you hear a sound.
	3 (i)	Yes, sound travels better through dense substances.
	(ii)	Yes, sound travels through dense substances.
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, the vibrations can't get through the wall.
	(v)	No, sound doesn't travel through a vacuum.
	(vi)	Yes, Doppler effect.
31	1	Because of the sound waves, and he has ears so he can hear. No. of key elements present: 1 [no mention of vibration, medium or how the ear hears the sound]
	2	Option selected: (i) (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, because of vibrations.
	(ii)	Yes, because of the vibrations
	(iii)	Yes, because of vibrations.
	(iv)	Yes, sound travels through the air.
	(v)	Yes, because of vibrations.
	(vi)	Yes, because of the vibrations.

32(I)	1	When the bird sings it makes particles in the air vibrate. These vibrations travel through the air as one particle hits the one next to it and transfers the energy. This continues on and when the vibrations pass the child they are picked up in the ear and transferred in to sound by the brain. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound does echo around the room however, <u>what</u> is it that is echoing around the room? And how do we hear it? (ii) You don't have to concentrate to hear sounds, they just travel past you. (iii) The sound is coming from the gong <u>not</u> the ear. You don't send out 'nets' of sound waves from your ear to 'catch' sound. (v) This is in a way true but <u>what</u> is the sound so that you can hear it? (vi) The gong does vibrate but that is not the sound. Something has to go from the gong to your ears.
	3 (i)	Yes, because sound travels better in denser mediums than air so it still gets to you.
	(ii)	Yes, because the sound vibrations can travel through the steel just as they do in air.
	(iii)	Yes, because the vibrations can travel along the string and echo in the tins at the end.
	(iv)	No, because the amplitude is not great enough for the vibrations to travel through the air-wall-air and to the ear. The height of the wall makes no difference.
	(v)	No, because sound cannot travel in a vacuum because sound is vibrations of particles and there are no particles in a vacuum.
	(vi)	Yes, because the sound still travels on even after the object causing it has gone. It does not terminate the sound (waves) as they have already been produced.

Appendix 18 Responses of year 9/98 students to questionnaire on sound and hearing at each phase of the investigation

Students in the Instruction Group are designated by a number plus the letter (I); students in the Non-Instruction Group are designated by a number only. Researcher's notations are written in [ ].

Appendix 18.1 Pre-instruction responses

Student Number	Question Number	Response
1(I)	1	The birds chirping is carried by sound waves, like tiny vibrations, through the air to the ear and picked up by the ear drum. The ear drum vibrates and sound is heard. No. of key elements present: 3.5 [student does not actually say medium vibrates]
	2	Option selected: (iv) (i) If the sound echoed around the room it wouldn't reach your ears. (ii) Just because you're concentrating (using your brain) it doesn't make your ears work harder. (iii) The sound comes from the gong not your ear. (v) This doesn't explain why you hear it with your ears. You could just as well hear it with your nose. (vi) Again it doesn't explain how you hear the sound.
	3 (i)	No, because the engine part runs above the water. You might be able to hear it very muffled.
	(ii)	Yes, you could hear it over the top of the wall.
	(iii)	Yes, because the string vibrates and causes sound to be heard.
	(iv)	No, sound doesn't carry well through solid things.
	(v)	No, because there is no air to carry vibrations.
	(vi)	Yes, because sound carries.

2(I)	1	When the bird sings it sets off vibrations in the air. The vibrations travel along through the air reaching your ear. The things in your ear decode the vibrations into sound and you can hear the bird singing. No. of key elements present: 4
	2	Option selected: (iv) (i) It doesn't mention your ear. (ii) You don't have to concentrate to listen. (iii) The sound waves would travel <u>from</u> the gong <u>to</u> your ear not the other way round. (v) The gong vibrates when hit by the clapper and makes a sound which sets the air vibrating which goes to your ears. You don't just <u>hear</u> it. (vi) How do you hear the sound?
	3 (i)	Yes, because sound travels better under water.
	(ii)	Yes, because the steel would vibrate and you could hear it from the end you are nearest to.
	(iii)	Yes, the vibrations your friend's voice makes travel along the string to your ear which decodes the vibrations into what your friend said.
	(iv)	Yes, the sound waves produced by your friend's voice could go over the wall to your ear.
	(v)	No, because sound travels through air to your ear so if there is no air there is no sound.
	(vi)	Yes, because you could hear it as the car goes further up the street.
3(I)	1	When the bird sings it sends sound waves or vibrations across. It then hits our ear drum, enabling us to hear the bird singing. No. of key elements present: 2 [no mention of the medium, although in Q.2 does mention 'vibrations through the air' and 'air vibrations']

	2	Option selected: (iii) and (iv) (i) The gong cannot just be struck and you automatically hear it, it sends vibrations through the air. (ii) You don't really have to concentrate. Hearing comes naturally to everyone unless they have a hearing problem (iii) To enable to hear the noise, the gong vibrates in your ear - vibrations through the air (v) This is part right, there has to be a process - air vibrations in which you hear it. (vi) This, too, is part right, the gong does vibrate but it doesn't say how it gets to your ears - ie air vibrates.
	3 (i)	No, water stops the vibrations because of no air beneath the water surface.
	(ii)	No, you could hear the hammer on the steel if there wasn't a brick wall, it stops all of the vibrations.
	(iii)	Yes, the vibrations travel through the string and is made louder by the echo of the tin.
	(iv)	No, the wall stops most of the vibrations.
	(v)	The vacuum in the jar has no air in it and the foam traps the existing noise.
	(vi)	Yes, a police siren sends out louder vibrations than the passing car [student has misread the statement]
4	1	The child can hear the sound of the bird singing in the tree because the bird's singing noise in its throat starts the air vibrating and the vibrations pass through the air until they reach the child's ears. No. of key elements present: 3.5 [student has not said how ear receives the signal, although she appears to understand the transmission process very well]

	2	Option selected: (iv) (i) The sound that the gong makes doesn't just echo around the room it has to travel on sound waves (ii) Concentrating on the sound doesn't help you to hear the vibrations because the vibrations reach you anyway. (iii) For the sound waves to travel from your ear to the gong, it would mean that the ear was making vibrations creating a noise. (v) You don't immediately hear it because you have to wait for the vibrations from the gong to hit your inner ears. (vi) The sound that you hear is the sound of the vibrations vibrating the air not the gong actually vibrating.
	3 (i)	No, there is only a little bit of air to vibrate so it would be a very small noise, if any.
	(ii)	No, the vibrations don't go through a solid wall.
	(iii)	Yes, the vibrations in the air would touch the string and be passed along.
	(iv)	No, if they are talking quietly the vibrations would not be strong enough to go over the high wall
	(v)	No, because there is no air in the jar, there are no vibrations.
	(vi)	Yes, you would only hear it slightly because it is aimed in front of the car to warn people.
5(I)	1	When the bird sings, the noise travels through the air and if there is a child nearby, the bird can be heard by the child. The child can determine where the noise of the singing bird is coming from because one ear will be closer to the direction of the bird and will pick up the noise more. Then the brain uses the sense of direction to indicate that the singing bird is in the particular tree. No.of key elements present: 2.5 [no mention of vibration]
	2	Option selected: (iv) (i) The room might not let the noise echo. It might absorb the noise. (ii) Usually when a gong is struck, there is no need to concentrate in order to listen to the sound. (iii) The sound waves need to travel towards the ear in order for the gong to be heard. (v) There has to be vibrating air otherwise the gong cannot be heard. (vi) It is no use if only the gong vibrates the air needs to as well.

	3 (i)	Yes, the boat engine would send vibrations through the water.
	(ii)	No, the solid brick wall wouldn't let the vibrations through.
	(iii)	Yes, because the vibrations would travel through the tight string to the other person.
	(iv)	No, the sound waves can't travel through the bricks
	(v)	No, the vibration can't get through the bell jar.
	(v)	Yes, because the car is out in the open and so it can be heard for quite a distance.
6(I)	1	A child can hear a bird singing in a tree because the bird makes a sound and it travels in sound waves into the child's ear to its brain where it registers. No. of key elements present: 1.5 [no mention of medium or vibrations]
	2	Option selected: (v) (i) Because you hear the sound of the gong before it echoes around the room, although you do hear it after. (ii) Because you automatically hear the sound because it is loud so you don't need to concentrate to hear it. (iii) Because the sound waves travel from the gong where they have been set off from. (iv) Because it doesn't only go to my ears but to my brain, so I have to acnowledge [sic] that the sound is there, there for [sic] I have to be hearing it. (vi) Because I don't hear the actual gong vibrating, I hear the waves of sound it produces.
	3 (i)	Yes, because you would hear the vibrations being sent through the water to my ears.
	(ii)	Yes, because it would vibrate through the girder to my end.
	(iii)	Yes, because the string would carry the sound vibrations of your friend's voice and be amplified by the tin cans.
	(iv)	No, because there is no way of the sound being able to be heard through a wall made out of materials that don't vibrate sound.
	(v)	Yes, because the glass would echo the sound.
	(vi)	Yes, because it is still close so you can hear it leaving, but fading.

7(I)	1	The bird's voice is actually waves travelling through the air to the kid's ears. Ears are like radars and they pick up the frequencies in the air (sound waves). No. of key elements present: 2.5 [no mention of vibrations nor how the ear receives the signal]
	2	Option selected: (v) (i) no comment. (ii) You don't really need to concentrate to hear the sound of a gong. (iii) The sound doesn't travel from your ear to the gong. It is the opposite. (iv) no comment. (v) I think this is right because the clapper does strike the gong and you do hear it with your ears. (vi) This is also right: the gong does vibrate when it is struck and you do hear the sound.
	3 (i)	Yes, the waves of sound can still travel underwater.
	(ii)	Yes, the waves travel the [sic] [through?] the girder.
	(iii)	Yes, the sound carries along the string.
	(iv)	No, it would be too quiet to hear through the wall because the sound waves would be too weak.
	(v)	Yes, the waves of sound would travel through the foam, the desk, to our ears and we would hear it.
	(vi)	Yes, because the waves would still reach our ears.
8	1	The sound waves break it up and carry it through the air and enters the ears of the child where the waves vibrate in the ear drum piecing it all together. No. of key elements present: 3 [mentions sound waves and vibration of ear drum but not vibration of medium]
	2	Option selected: (vi) (i) no comment. (ii) You don't have to concentrate to hear the sound, it gets there by itself. (iii) Your ear doesn't help make the sound but the ear hears it. (iv) no comment. (v) The clapper strikes the gong but then the sound isn't magiclly [sic] in your ears straightaway.

	3 (i)	No, unless your really close the sound waves are blocked by the water?
	(ii)	Yes, the wall vibrates as the sound echos and hits the wall.
	(iii)	Yes, the sound vibrates down the string and then vibrates in to the tin.
	(iv)	No, the sound bounces right off it back to you.
	(v)	Yes, 'cause it is so small and there is such a big noise the bell jar vibrates a lot.
	(vi)	No, 'cause it breaks the sound wave and the noise stops.
9	1	The sound of the birds singing in the tree can be heard by the child because the sound of the bird travels along in sound waves to the child's ear where it is the carryed [sic] to the ear drum this all happens in about 0.1 of a second. No. of key elements present: 1.5 [mentions sound waves but not vibrations, no mention of medium]
	2	Option selected: (vi) (i) no comment. (ii) This is wrong because you don't have to concentrate to listen to things. (iii) The sound waves come from the gong not your ear. (iv) The air does not vibrate. (v) I can't think of a reason why this is wrong.
	3 (i)	No, because the sound comes from the engine on the top of the water.
	(ii)	No, because brick is very solid.
	(iii)	Yes, because the sound waves travel along the string.
	(iv)	Yes, because the sound waves go above the wall and over.
	(v)	Yes, because the sound waves can get through the glass.
	(vi)	Yes, because sound waves travel a long distance.
10	1	The sound waves from the noise the bird makes travels through the air and enters his ear. It vibrates the ear canal and onto the ear drum. No. of key elements present: 3 [mentions sound waves and vibration of ear drum but not vibration of medium]

	2	Option selected:(iv) (i) You are not nescecerily [sic] going to be in a room. (ii) You don't have to concentrate to hear the sound. (iii) no comment. (v) no comment. (vi) no comment.
	3 (i)	no response.
	(ii)	no response.
	(iii)	Yes, the sound would echo through the tins and vibrate down the string.
	(iv)	no response.
	(v)	No, the jar is airtight and the sound can't escape.
	(vi)	No, (no explanation)
11	1	As the bird sings it makes sound waves that the child can hear. No. of key elements present: 1 [no mention of vibrations, medium, travel through medium or vibration of ear]
	2	Option selected: [no selection made] (i) no comment. (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, if you were very close to it, No, if you were far away.
	(ii)	no response.
	(iii)	no response.
	(iv)	no response.
	(v)	no response.
	(vi)	no response.
12	1	The bird makes a sound which is really a vibrasion [sic] or sound wave at a level that a child can hear it hits the childs ear drum and rings and that sends a message to the brain. No. of key elements present: 2 [no mention of medium nor how the sound reaches the ear]

	2	Option selected: (iv) (i) It does but when it is striked [sic] you need sound waves to hear them with. (ii) You don't need to concentrate because you do it automatically without thinking about it. (iii) No, because the sound is made from the gong and then into your ears. (v) Yes you do but you need sound vibrasions [sic] to hear it with. (vi) Yes but also your ear sends out vibrasions [sic] as well
	3 (i)	Yes, because the engine is under the water as well as you.
	(ii)	Yes, because the sound would echo.
	(iii)	Yes, because the sound goes along the string.
	(iv)	No, because theres [sic] something big so you carn't [sic] hear them.
	(v)	Yes, because the glass would'nt [sic] stop the sound coming out.
	(vi)	Yes, because sound can carry.
13(I)	1	The birds voice carries in sound waves (vibration) (moving air) these reach the child's ears entre [sic] them and the ear drums pick up the different frequencies of sound. The faster the vibration the higher the sound. No. of key elements present: 2.5 [student did not mention the medium at first although wrote 'moving air' later under the word 'vibration']
	2	Option selected: (iv) (i) Sound is vibrations not echoes. (ii) no comment. (iii) The sound waves travel from the gong to your ear. (v) no comment. (vi)The gong vibrates the air and the vibrations travel to your ears.
	3 (i)	Yes, the engine vibrates the water.
	(ii)	no response.
	(iii)	Yes, the sound vibrates the string sending it to the other end.
	(iv)	No, the vibrating air is not strong enough to pass through the wall.
	(v)	No, there is no air so nothing can vibrate.
	(vi)	Yes, the air is still vibrating.

14	1	The child is close enough to hear the bird singing in the tree. But also because when the bird sings sound waves travel through the air until they reach the child and the child can pick up the sound waves. Like a radio frequency - the radio picks up the sound waves in the air. No. of key elements present: 2.5 [no mention of vibration or vibration of ear]
	2	Option selected: (iv) (i) no comment. (ii) Even if you didn't concentrate you would hear the sound subconsiously [sic]. (iii) The sound waves would travel from the gong to my ear not the other way round. (v) no comment. (vi) no comment.
	3 (i)	Yes, because you would hear the rumble even under water.
	(ii)	Yes, because the solid brick wall would vibrate with the sound.
	(iii)	Yes, because the sound waves/vibration would run directly down the string.
	(iv)	No, because the sound waves/vibrations would bounce straight off the wall.
	(v)	Yes, but the sound would only carry very muffled vibrations.
	(vi)	Yes, because the siren is very loud and can still be heard.
15(I)	1	Vibrations from the birds' singing travel through the air on sound waves. These sound waves travel to the child's ear and with the help of his brain, it is worked out what he can hear and where it is coming from. No.of key elements present: 3 [does not say that medium vibrates nor how ear receives the sound wave]

	2	Option selected: (iv) (i) The gong does make a sound but the sound doesn't just echoe [sic] round the room. (ii) This is wrong because you don't have [to] concentrate to listen to sounds, they are all around us. (iii) This sentence is saying that you are anticipating the sound and you send out sound waves to collect it and bring it back to your ear (v) You don't just hear it with your ears, it is more complicated than that. (vi) You can't hear vibrations, they aren't a sound.
	3 (i)	Yes, because the sound would travel on vibrations through the water.
	(ii)	No, the thick bricks stop the sounds travelling on the vibrations.
	(iii)	Yes, the vibrations/sounds travel along the string to your ears.
	(iv)	No, the vibrations and sound can't go through the wall.
	(v)	No, because it's a vacuum, there is no air for the vibrations to travel along.
	(vi)	Yes, because the vibrations and sound are still carried in the air.
16	1	He can hear through his ear. The ear has bird sounds that travel into his ear and through his ear drum. The sounds are vibrations through the air which are actually called sound waves. No. of key elements present: 3
	2	Option selected: (iii) (i) This isn't correct. Your ear hears it first and then it echos [sic] around the room. (ii) This isn't write [sic] [right] because your ear has to listen and you dont concerntate [sic] on sound. (iii) I think this is the best sentence because your ear is hearing it not the room (iv) This isn't it because it's sound that we hear and the air vibrating isn't sound. (v) This isn't it because there are sound waves that go into your ears. (vi) The gong does vibrate but sound waves come off the gong after it is hit. [Student understands that sounds are vibrations but not that the air itself vibrates to transmit the sound]

	3 (i)	Yes, because the sound waves still come to your ears.
	(ii)	Yes, because two things are being hit together.
	(iii)	Yes, the sound waves vibrate through the string to your ear.
	(iv)	Yes, you can hear that person because it's a brick wall.
	(v)	No, the sound waves can't get through.
	(vi)	No, because there would be no siren if it has passed.
17	1	The sound waves carry the birds voice like small vibrations through the air until the boy's ears pick the sound up. No. of key elements present: 3
	2	Option selected: (i) (ii) The concentration level is non-existent. The sound comes naturally. (iii) The sound waves travel from the gong to your ear. The gong is making the noise not your ear! (iv) Even though this is what happens it is not what I hear. (v) This happens but is not heard. (vi) This happens but is not heard.
	3 (i)	Yes, the sound can travel through water.
	(ii)	Yes, even though the wall's in the way the piercing sound will make it to your ear drum.
	(iii)	Yes, the sound waves vibrate along the string to your ear.
	(iv)	No, there is a wall in the way to block out the quiet voice.
	(v)	No, there is no air for the sound to travel.
	(vi)	Yes, even though it is faint it still travels through the air.
18	1	When the bird sings the sound travels in waves through the air to the persons ear. Because the waves are different sizes and lengths the birds song comes through in different pitchers [sic] No. of key elements present: 2.5 [no mention of vibration]
	2	Option selected: (vi) (i) The sound would bounce off the wall and you get different pitchs [sic] of the gong. (ii) The sound has to travel first. (iii) The sound waves travel from the gong to your ear. (iv) The air wool [sic] vibrate but it would be silent. (v) It has to travel first.
	3 (i)	No, because you get water in your ear.
	(ii)	Yes, the noise is so loud and sharp.

	(iii)	Yes, but only faintly.
	(iv)	Yes, but it would be very muffled. It also depends how high the wall is.
	(v)	No, there is no air for the sound to travel through.
	(vi)	Yes, but it would be faided [sic].
19	1	The bird is singing in the tree and the child can hear it because of the sound waves that travel through the air from the childs ear to where the bird is singing. No. of key elements present: 2.5 [student has sound waves travelling in reverse direction]
	2	Option selected: (iii) (i) You need sound waves for sound to carry. (ii) Same as the above. (iv) Same as the above. (v) Same as the above. (vi) Same as the above (you need sound waves for sound to carry)
	3 (i)	Yes, sound travels in water because when it hits things it bounces back.
	(ii)	No, because the sound waves can't travel through a solid brick wall.
	(iii)	Yes, the sound waves travel along the string and travels into the other childs ear.
	(iv)	No, the sound waves bounce back off the wall so the other person can't hear, because the sound waves don't reach their ear.
	(v)	No, the sound waves aren't released into the air.
	(vi)	Yes, the sound waves are still left behind.
20	1	When a sound is produced the vibration makes the ear drum vibrate which lets us hear the sound. No. of key elements present: 2 [no mention of the medium nor how the sound reaches the ear].

	2	Option selected: (iv) (i) The sentence doesn't say anything about the sound travelling to your ears. (ii) You don't need to concentrate to listen to the sound. (iii) The sound waves should travel from the gong to the ear. (v) It doesn't say what happens to the sound waves. (vi) It doesn't say anything about your ears.
	3 (i)	Yes, because of the vibrations in the water.
	(ii)	Yes, because of the vibrations.
	(iii)	Yes, because the tight string. The sound wave travel along it.
	(iv)	No, because the sound waves won't travel through brick if you spoke quietly.
	(v)	No, because the vacuum will stop the sound waves reaching us.
	(vi)	Yes, because the sound wave [sic] travel to your ears.
21	1	The child can hear the bird singing in the tree by the sound from the birds mouth travelling extra fast through the air as vibrations and going into the boys ear and vibrating then it hits the ear drum and the boys mind processes and knows the object singing sounds like a bird. No. of key elements present: 3.5 [student has not said that the air particles vibrate - although does say this in Q3(vi)]
	2	Option selected: (iv) (i) The sound does not echo it vibrates. (ii) Concentrating is not an issue when listening to a gong as it is so loud. Even an infant who can't concentrate can hear it. (iii) This is almost right except sound waves travel from the gong to your ear not the ear to the gong. (v) You hear the vibrations not the sound. (vi) The air vibrates and you hear the vibrations.
	3 (i)	Yes, although not clearly you would hear a muffled sound as you can when someone talks under water.
	(ii)	Yes, brick walls are not as high as 10m so the vibrations would travel over.
	(iii)	Yes, sound vibrations travel over the top.
	(iv)	Yes, sound vibrations travel depending on how quietly she is talking you could still hear.
	(v)	No, a vacuum is sound proof as is a bell jar.

	(vi)	Yes, police sirens are loud so vibrations travel to your ears.

Appendix 18.2 Immediate post-instruction responses

The immediate post-instruction questionnaire was given to the Instruction Group only.

Student Number	Question Number	Response
1(I)	1	The air molecules vibrate from the sound of the birds singing, the air molecules bunch up and relax alternately so that the sound is passed through the air by sound waves. They reach the ear and enter. No. of key elements present: 3.5 [student has now said medium vibrates but has omitted to say ear vibrates]
	2	Option selected: (iv) (i) The sound will echo around the room but you mightn't hear it because the air mightn't vibrate enough. (ii) You use your brain to concentrate and you use your ears to hear. (iii) The sound waves travel through the air from the gong to your ear. (v) You hear the sound waves. (vi) The gong vibrates the air around it.
	3 (i)	Yes, because you can hear sound under water.
	(ii)	Yes, you can hear through solids.
	(iii)	Yes, because the air vibrates the string which carries the sound waves.
	(iv)	Yes, because the sound waves carry upwards.
	(v)	No, because there is no air to vibrate around the alarm.
	(vi)	Yes, because sound waves carry in all directions.
2(I)	1	When the bird sings it makes the air particles vibrate. That vibration gets passed along the air particles until it reaches the childs ears. No. of key elements present: 3.5 [has not said how ear receives signal] [pre-instr. 4]

	2	Option selected: (iv) [pre-instr. (iv)] (i) It doesn't tell you how you hear it. The sound would echo around the room but it still doesn't tell you how you hear it. (ii) You don't have to concentrate to listen to sound. (iii) The sound waves travel from the gong to your ear and not the other way round (v) It doesn't tell you how you hear it. It doesn't mention sound waves or anything vibrating. (vi) It doesn't tell you how you hear it or mention the air particles vibrating.
	3 (i)	Yes, because sound travels better through water (particles are closer)
	(ii)	Yes, the steel particles vibrate through the wall and to the other end where your ear is.
	(iii)	Yes, the vibrations of 1's voice travel along the string to 2's ear expand in the can and reach your ear.
	(iv)	Yes, the vibrations would go up and over the wall to your ear.
	(v)	No, because there is no air in the jar so the sound can't travel to your ear.
	(vi)	Yes, you could hear it as it goes further up the street still.
3(I)	1	When the bird sends a noise the noise travels through the air - or sound waves- it then hits the ear drum and that vibrates letting us hear. No. of key elements present: 3 [no mention of vibration of medium]
	2	Option selected: (iv) (i) This sentence is partly correct, but it doesn't say the process in which you can hear with. (ii) This sentence is incorrect because you don't have to concentrate to hear - it happens naturally. (iii) This sentence would be correct if it didn't say: from your ear - they don't travel from your ear - they travel from the gong. (v) Again this doesn't tell us the process. (vi) The [sentence] is partly correct - but it again doesn't tell us the process.
	3 (i)	Yes, water is exactly the same process and [sic] with air.
	(ii)	No, the sound waves can't travel through dense products such as bricks.

	(iii)	Yes, the sound [sic] through the string and echoes in the tin.
	(iv)	No, the sound waves bounce back and you are unable to hear.
	(v)	No, there is no air to let the sound travel through - and the foam absorbs it.
	(vi)	Yes, you could probably hear it because the siren would leave your ear ringing.
5(I)	1	When the bird sings, the noise travels through the air (vibration method) and reaches the child's ear. The child knows what direction the bird is because of where the sound and vibrations are coming from. The vibration hits the childs ear drum so that he senses the noise and hears it. No.of key elements present: 2.5
	2	Option selected: (iv) (i) If the sound echoed around the room, the brain and ears would be able to tell where the noise is coming from (ii) You don't need to concentrate to hear the sound of a gong! There is almost no way you could block it out of your hearing it is so loud. (iii) Why would the air from your ear vibrate and go to the gong. Your ear can't predict a sound that is going to happen. It **receives** the sound. (v) This is correct but it is not detailed enough. Needs more information. (vi) Needs more information and is not detailed enough.
	3 (i)	Yes, the sound would vibrate through the water easily.
	(ii)	Yes, this action is quite loud and so could be heard.
	(iii)	Yes, the vibrations travel easily through the straight, tight piece of string.
	(iv)	No, the quiet talking wouldn't make it through the high brick wall.
	(v)	No, if there is no air in the jar because it is vacuumed [sic] the noise can't vibrate and travel at all.
	(vi)	Yes, because light (seeing the car) travels faster than sound so the noise gets sort of left behind.

6(I)	1	Because the bird makes a sound from its voice box and the vibrations, that are high, hit other air particles that hit more and so move in a wavelike movement outward (like this - [student has drawn concentric circles around a centre point] till it reaches your ear which receives the sound and then it travels through the ear, the little hairs in your ear register, it hits your ear drum and the vibrations are sent to your brain where it tells the child that what it is hearing is a bird singing in the tree. No. of key elements present: 4
	2	Option selected: (v) (i) Because you aren't hearing the sound of the echo (the air particles bouncing back for the second time) but the initial sound of the gong being struck. (ii) Because you don't need to concentrate and listen for the sound, you will automatically hear it, as it is loud. (iii) Because the sound waves travel to your ear from the gong when it is struck. (iv) Because the air vibrations don't just reach your ears, but they have to go through your ears and register in your brain. (vi) Because you don't hear just the vibrations of the gong, but the sound of it being struck.
	3 (i)	Yes, because the vibrations made by the motor travel through the water particles to your ears and brain.
	(ii)	Yes, because the particles are close together in a steel girder and so if you hit it the vibrations travel through it to the other side.
	(iii)	Yes, because the vibrations from your voice travel along the string and are echoed by the can.
	(iv)	No, because bricks don't carry sound.
	(v)	No, because if there are no air particles to be hit and vibrated and the clock can't rattle about on the desk then it can't be heard by us.
	(vi)	Yes, because the sound waves are just reaching you as it goes by and you can hear it fading in the distance.
7(I)	1	The bird makes a sound and makes the air particles push each other and it makes different patterns depending on the frequency of the sound. The waves travel to the kid's ears and make the ear drum vibrate - so he can hear the sound. No. of key elements present: 3

	2	Option selected: (iv) (i) no comment. (ii) no comment. (iii) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, there is still air underwater so the sound can still travel in the water.
	(ii)	Yes, the sound would travel through the steel easily.
	(iii)	Yes, the sound travels along the string.
	(iv)	Yes, the sound would go through the brick or over the wall
	(v)	No, because the sound can't travel in nothing - it needs air particles to push other air particles to move the sound along.
	(vi)	Yes, you can still hear it because it would only be a few metres away from you.
13(I)	1	The birds voice box vibrates sending waves of vibrating air out of its mouth. These waves travel through the air and reach the childs ears the vibrating goes in the childs ear vibrating the ear drum the brain changes those vibrations into electronic waves and registers as a bird singing. No. of key elements present: 4
	2	Option selected: (iv) (i) The sound doesn't just echo, it vibrates air that travels to your ear. (ii) The gong makes a loud sound so you don't have to concentrate to hear it. (iii) The sound waves travel from the gong to your ear, not your ear to the gong. (v) You don't just hear it the air vibrates and travels to your ears. (vi) Yes the gong vibrates but the air around it does too.
	3 (i)	Yes, the motor vibrates the water, sound waves travel to your ears, the water vibrates your ear drums.
	(ii)	No, the wall would absorb all the vibrations before they reached the other person.
	(iii)	Yes, the vibrations travel along the string until they reach the other end.
	(iv)	No, the sound waves are not strong enough to go over or through the wall.

	(v)	No, there is no air inside the jar to vibrate, so therefore the sound cannot reach your ears.
	(vi)	Yes, the sound waves travel through the air to your ears whether the car is in front or behind or opposite doesn't matter.
15(I)	1	The warbling of the bird's song vibrates the air and creates sound waves. The vibrating air travels to the childs ear and his/her ear drum accepts the sound and the brain registers and tells him what he can hear. No. of key elements present: 3.5
	2	Option selected: (iv) (i)The sound doesn't echo exactly, the air around it vibrates and the vibrations spread on to other air particles. (ii) You don't have to concentrate to hear the sound, sound is all around and this one is the loudest. (iii) The air doesn't travel from your ear to the gong then bring the sound back again. (v) You do hear it with your ears but it's not that simple. You hear the sound with your ear drum and cochlea hairs. (vi) You don't hear the gong vibrate, you hear the sound on air vibrations. Also you don't hear the air vibrate either.
	3 (i)	Yes, the water particles would vibrate and carry the noise.
	(ii)	No, the particles of the brick would be too dense for the vibrations to travel through.
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, the sound wouldn't travel over the wall.
	(v)	No, there is no air for the vibrations to travel on.
	(vi)	Yes, the air would still be vibrating.

Appendix 18.3 Delayed post-instruction responses

Student Number	Question Number	Response
1(I)	1	When the bird sings its voice hits the air and travels towards the boys ear in waves, the tiny air particles vibrate and when they reach the boys ear they enter it. The waves get weaker the further away they are from the thing making the sound waves. No. of key elements present: 3.5 [student does not actually say ear vibrates]
	2	Option selected: (iv) (i) The sound may still echo around the room but it is not how you hear the sound in the first place. (ii) When you concentrate you use your brain, to hear something the sound waves only have to enter your ear, you don't have to concentrate. (iii) The gong is making the sound not your ear so the sound waves should travel from the gong to your ear. (v) The sound waves must travel to your ears, then you can hear it. (vi) The gong has to vibrate the air around the gong for you to hear it.
	3 (i)	Yes, sound waves can travel through water.
	(ii)	Yes, sound waves could be carried over the top of the wall otherwise you couldn't hear it.
	(iii)	Yes, the string will vibrate with your voice, so you can hear it.
	(iv)	No, it wouldn't travel through solid things such as brick.
	(v)	No, there is a vacuum so there is no air to vibrate and carry the sound.
	(vi)	Yes, because the sound waves go in all directions.
2(I)	1	When the bird sings the air around it vibrates. It passes these vibrations on like a set of dominoes but the air never actually changes place.The air keeps on vibrating towards the childs ear and the bits in the ear vibrate and send messages to the brain and the child can understand what the noise was. No. of key elements present: 4

	2	Option selected: (iv) (i) It doesn't explain how you hear the sound or mention sound waves, vibrations or your ears at all. (ii) You don't have to concentrate to hear things, it doesn't mention vibrations or sound waves at all. (iii) The sound waves travel from the gong to your ear not the other way round. (v) It doesn't explain how you hear. (vi) It doesn't explain how the sound gets to your ears.
	3 (i)	Yes, sound travels better under water than in air as the particles are closer together.
	(ii)	Yes, sound travels through steel as steel is dense so the sound waves travel faster than in air.
	(iii)	Yes, the sound waves can travel along the string to your ear.
	(iv)	Yes, the sound waves don't go straight ahead they can go over things as well.
	(v)	No, if there is no air the sound waves can't travel so you couldn't hear the ringing.
	(vi)	Yes, the sound waves can travel backwards to your ear.
3(I)	1	The bird sends vibrations through the air - these vibrations travel at a great speed and then it hits your ear drum and you can hear. No. of key elements present: 3 [does not say that air particles vibrate, nor ear]
	2	Option selected: (iv) (i) This doesn't tell us how we can hear it. (ii) You don't have to concentrate - there's a process. (iii) That's partly right - but it doesn't say anything about air vibrations. (v) You do hear it through your ears - but again it doesn't tell us about the process. (vi) The gong does vibrate - but there is nothing about the process.
	3 (i)	Yes, the air vibrations travel through the water.
	(ii)	No, the air vibrations can't go through the brick wall.
	(iii)	Yes, the vibrations travel through the string and the can echos it.
	(iv)	No, the brick wall stops the vibrations.
	(v)	No, there is no air for the vibrations to travel through.

	2	Option selected: (iv) (i) This sentence doesn't say anything about hearing the noise. (ii) To hear a sound (especially a gong) there is no need to concentrate. (iii) The sound waves don't travel to your ears only. They travel in all directions. (v) This doesn't describe how it is heard or how it gets through the air to the ears. (vi) This doesn't mention how the noise makes the air vibrate and how it gets to the ears.
	3 (i)	Yes, the propeller would send the waves with the sound away in all directions and the swimmer would hear it.
	(ii)	Yes, the such loud noise would penetrate through the wall to the listener.
	(iii)	Yes, the sound travels in a straight line through the tight and straight piece of string.
	(iv)	No, the sound wouldn't make it through the brick wall because the sound is not loud enough and the sound doesn't go up and over the wall.
	(v)	No, because the bell has had all the air sucked out of it (vacuum) there is no air for the ringing bell's sound to travel through and so can not be heard.
	(v)	Yes, because light is faster than sound the car would have passed and because the sound is not as fast the sound can still be heard.
6(I)	1	The birds voice box lets off vibrations of sound. These vibrations hit the air particles and continually set off the surrounding air in a domino effect. When the vibrations reach the childs ear they resonate in the ear drum and registering in the brain as a birds song. No. of key elements present: 4

	2	Option selected: (iv) (i) Because you aren't just hearing the echo, but the vibrations have travelled to your ear then brain. (ii) Because you don't have to concentrate to listen to the sound, you just hear it. (iii) Because the sound waves travel from the gong to your ear not from the ear to the gong. (v) Because you don't just hear it with your ears but with your brain. (vi) Because you don't hear the vibrating sound but the vibrations.
	3 (i)	Yes, because the boat engine would set the water particles vibrating and so on and the vibrations would travel to your ears in your brain and you could say, that's a boat engine.
	(ii)	Yes, because when the hammer strikes the steel girder it sets off tiny vibrations through it that will travel through to the other side that you are listening at.
	(iii)	Yes, because the vibrations you are making when you talk will resonate in the tin, as if an ear canal, and then send the vibrations along the string to the other person to receive it and the words will become clear by the tin.
	(iv)	No, because the vibrations of sound you make when you talk just bounce right back off the wall.
	(v)	No, because if there is no air then there is no way for the sound to travel by hitting other air particles and if the foam is there the alarm clocks movements cannot be heard.
	(vi)	Yes, because the vibrations coming from the siren are only just reaching you (in the domino effect) and so you can still hear it.
7(I)	1	The child can hear the bird because sound waves are travelling through the air to the child's ears. The wave length of the sound determine the frequency of the sound. The waves of sound travel by pushing air molecules to form a domino effect. No. of key elements present: 3 [no mention of vibrations nor how the ear receives the signal but has said that air molecules are moved by the sound wave]

	2	Option selected: (iv) (i) This doesn't explain how you hear it. (ii) Concentrating isn't how you hear the sound. (iii) The sound waves don't travel <u>from</u> your ear to the gong. (iv) Yes, because the air does vibrate. (v) You don't hear the clapper. (vi) This is correct but it doesn't explain how you hear the sound.
	3 (i)	Yes, the sound waves would travel through the water.
	(ii)	Yes, you would hear it through the steel girder.
	(iii)	Yes, the sound would travel through the string.
	(iv)	Yes, if you had good hearing (sound waves travel in every direction from the source)
	(v)	No, there is no air for the sound to travel through.
	(vi)	Yes, the sound waves would still reach you.
8	1	The bird sings and the sound is captured and carried in sound waves along where it enters the childs ears and vibrates down to his ear drum. Here the sound is captured and can be heard. All this happens in a matter of seconds. No. of key elements present: 2 [mentions sound waves and vibration of ear drum but does not mention the medium]
	2	Option selected: (iii) (i) When the sound echoes around the room, it doesn't mean that it suddenly finds itself in your ears. (ii) We don't have to concentrate to listen to a sound, once the sound waves have entered your ear, then you hear the sound. (iv) The vibration of the air doesn't carry the sound to your ears, sound waves do. (v) This is wrong because when the clapper strikes the gong you can't just expect the sound to be in your ears just like that! (vi) Not everything that vibrates makes a sound so it isn't the object vibrating itself getting the sound to your ears.
	3 (i)	No, because water muffles sound waves stopping them getting to you.
	(ii)	Yes, because it would be a very strong sound and some of the sound waves will be able to pass through the wall!
	(iii)	Yes, because the sound waves will vibrate down the string.
	(iv)	No, because the sound waves aren't strong enough to get over or through the wall.

	(v)	No, because the bell jar would stop the sound waves getting out.
	(vi)	Yes, because the sound waves aren't instantaneous in getting the sound to you so you would still hear it directly after it has passed you.
9	1	The birds voice sends sound waves to the childs ears so he can hear the bird. No. of key elements present: 1.5 [mentions sound waves but not vibrations, no mention of medium - mentions vibrations in Q3(iii)]
	2	Option selected: (vi) (i) The sound does not necessarily echo around the room. (ii) You do not have to concentrate to hear the sound. (iii) They don't travel from your ear. (iv) The air does not vibrate. (v) no comment.
	3 (i)	No, because the engine is on the top of the water, only the propeller is in the water.
	(ii)	No, because the bricks are very solid and you can't hear through them.
	(iii)	Yes, because the vibrations travel along the string.
	(iv)	Yes, because the sound waves go over the wall.
	(v)	Yes, but only faintly because the jar blocks some of the sound.
	(vi)	Yes, because sound waves travel a long distance.
10	1	The bird singing in the tree is heard by sound waves that are sent through the air and are picked up by vibrations in the boys ear drums. No. of key elements present: 3 [mentions sound waves and vibration of ear drum but not vibration of medium]
	2	Option selected: (iv) (i) What happens if you are outside. This theory could only work in a confined space. (ii) You shouldn't have to concentrate to hear it. (iii) The sound waves come from the gong not your ear. (v) The sound needs to travel on sound waves/vibrations before it reaches your ears and you hear it. (vi) no comment.
	3 (i)	no response.
	(ii)	No, the vibrations would be stopped by the brick wall.

	(iii)	Yes, the sound vibrations/waves would travel down the string and bounce off the side of the tin into your ear.
	(iv)	No, the sound waves would bounce straight back off the wall.
	(v)	No, there is no way for the sound vibrations or waves to escape.
	(vi)	No, (no explanation)
11	1	When the bird sings it sends out sound waves/vibration which the child can pick up and hear. No. of key elements present: 1.5 [no mention of medium, travel through medium or how ear receives signal]
	2	Option selected: [no selection made] (i) no comment. (ii) no comment. (iii) no comment. (iv) no comment. (v) no comment. (vi) no comment.
	3 (i)	Yes, if close. No, if far away. Depends on how close to the boat you were.
	(ii)	no response.
	(iii)	Yes, don't know I just heard that you could.
	(iv)	No, again it depends on how loud or quietly, quietly is. If it is quite quiet then you usually can't hear someone anyway.
	(v)	No, no air, no sound (nowhere for the sound to travel)
	(vi)	no response.
12	1	Well the bird makes a noise and that gives off sound vibrassions [sic] and it travels through the air and to the child. It hits the childs ear drum and starts to move which sends a mesige [sic] to the boys brain and he hears the bird singing. No. of key elements present: 3
	2	Option selected: (iii) (i) It does but it doesn't mean you can hear it. (ii) You don't have to concentrate to hear a noise. (iv) It isn't air vibrating it's sound waves vibrating. (v) You don't hear it with your ears you hear it when it hits your ear drum. (vi) It does but your ear drum hears it.
	3 (i)	Yes, because the engine is in the water too with your ears.

	(ii)	Yes, because it would vibrate the sound into your ears.
	(iii)	Yes, because the sound travels on the string into your ears.
	(iv)	No, because the sound bounces off the wall back to you.
	(v)	Yes, because it doesn't need air to be heard.
	(vi)	Yes, because sound travels.
13(I)	1	The birds voice box makes vibrations and sends them out into the air, sound waves. These travel until they reach the child, the childs ears collect these sound waves, they go into the childs ear and vibrate his ear drum which sends messages to the brain where they are translated into sound. No. of key elements present: 3.5 [student did not say that the air itself vibrated]
	2	Option selected: (iv) (i) The gong vibrates when it is struck sending sound waves around the room. (ii) You don't have to concentrate to hear a loud sound like a gong that's been struck. (iii) The sound waves travel from the gong to your ear. (v) This doesn't explain how the sound got to your ears. (vi)The gong vibrates, but the air vibrations is what you hear.
	3 (i)	Yes, the vibrations from the motor travel through the water.
	(ii)	No, the brick wall would absorb the vibrations making it difficult to hear.
	(iii)	Yes, the vibrations are sent along the string to the other person.
	(iv)	No, the brick wall would absorb the weak sound waves.
	(v)	No, there is no air for the bell to vibrate.
	(vi)	Yes, the sound waves still travel through the air even though they have passed you they will just be softer.
14	1	Because the sound waves/currents in the air pick up the noise which then carries the sound to the boys ear which in turn pick up the right sound waves. No. of key elements present: 2.5 [no mention of vibration or vibration of ear]

	2	Option selected: (iv) (i) The gong doesn't make a 'sound' it just sets the air vibrating which you then pick up with your ears. (ii) Because the gong would make a very loud noise you would not have to concentrate on it. (iii) This is wrong because the sound doesn't travel from my ear to the gong. (v) You do hear it with your ears but the gong and the air must vibrate for you to hear it. (vi) The gong is not the only thing that vibrates.
	3 (i)	Yes, because the water would be vibrating with the sound.
	(ii)	Yes, because the wall would vibrate with the sound.
	(iii)	Yes, because the string would vibrate and carry the sound to you.
	(iv)	No, because the wall wouldn't vibrate and the air would not vibrate enough for you to hear the sound.
	(v)	No, because the foam and vacuum and bell jar would absorb all the sound before it gets to you.
	(vi)	Yes, because the air would still be vibrating with the sound even when the car has passed.
15(I)	1	As the bird sings, it vibrates the air around it and the sound travels on wavelengths through the vibrating air to the childs ear. No.of key elements present: 3.5 [does not say how ear receives the sound]
	2	Option selected: (iv) (i) no comment. (ii) You don't need to concentrate to hear the sound of the gong. (iii) The air doesn't leave your ear to pick up the sound then come back again. (v) You don't just hear it with your ear, you hear it with other smaller inside parts of your ear. (vi)You do not hear the sound of the vibration as this one suggests, the wavelength carries the sound <u>on</u> the vibrations.
	3 (i)	Yes, because the vibrations can travel through the water to your ears still.
	(ii)	No, the solid brick is too dense for the sound to travel through.
	(iii)	Yes, because the string is taut, you can hear the sound travelling along on the vibrations.
	(iv)	No, your voice cannot carry that high or through solid brick.

	(v)	No, there is no air inside for the vibrations and wavelengths to travel on.
	(vi)	Yes, the air will vibrate for some time with the wavelengths carrying the sound so you shall be able to hear it.
16	1	The child can hear the sound of the bird with his ears. Sound waves travel into his ears which produces sound. No. of key elements present: 1.5
	2	Option selected: (iv) (i) The sound waves come to your ears the [sic] echo around the room. (ii) You don't concentrate on listening to the sound. The sound waves travel into your ears without you having to do anything. (iii)The sound waves don't travel from your ears they travel to your ears. (v) The clapper strikes the gong and produces sound waves which vibrates into your ears so you can hear it. (vi) The gong vibrates and sends sound waves into your ears.
	3 (i)	Yes, the water vibrates and sends sound waves into your ears.
	(ii)	Yes, the sound still would send sound waves through the wall.
	(iii)	Yes, the sound vibrates through the string producing sound waves.
	(iv)	Yes, the sound waves go over the wall.
	(v)	No, the sound can't vibrate out and send sound waves.
	(vi)	Yes, the sound still produces sound waves which you then can hear the siren.
17	1	The sound of the bird make vibrations through the air - sound waves. These sound waves travel to your ears and vibrate in your ear drum, making you hear the sound. No. of key elements present: 3.5

	2	Option selected: (i) (ii) When hearing a sound, you rarely concentrate to hear it. If this was the case, it is not what I hear. (iii) This is not what I hear and it isn't the process in how I or anyone hears it. (iv) This is the process in how I hear the gong, not what I hear. (v) This is not what I hear, it is what a person would say to me if I heard it. (vi) This is saying what happens to the gong and, again, someone is telling me I hear it. [Student's responses make little sense]
	3 (i)	Yes, if you were listening hard, the vibrations will be travelling along.
	(ii)	Yes, it is a piercing sound, there will be strong vibrations.
	(iii)	Yes, the vibrations from her voice travel along the string making me hear what she is saying.
	(iv)	No, if she/he was talking very softly, the vibrations will not be strong enough.
	(v)	no response.
	(vi)	no response.
18	1	The vibration from the birds throat travels through the air. These vibrations are called sound waves. Different pitches have different sorts of vibrations (sound waves). All this makes up what the child can hear. No. of key elements present: 2.5
	2	Option selected: (iv) (i) The gong does echo but it's the air and sound vibrating making the noise. (ii) How can you concentrate and try and listen for a sound if you don't know if you will hear it and what it sounds like. (iii) The sound waves travel from the gong not your ear. (v) The gong has to vibrate for you to be able to hear it. (vi) The gong has to vibrate the air so a sound wave can travel to your ear.
	3 (i)	No, because there would be water in your ear and there is no air for the sound to vibrate.
	(ii)	Yes, because metal on metal is quite loud.
	(iii)	Yes, but it would be soft because the string tight.

	(iv)	Maybe, very softly/not much sound because the sound can go over the wall.
	(v)	No, because there is no air for the sound to vibrate.
	(vi)	No (no explanation)
19	1	The child can hear the bird singing in the tree because of the sound waves that reach the childs ear. Depending on how close or how far away the child is standing from the tree with the bird singing in it, the volume will vary. The sound waves from the birds singing travel through the air to the childs ear. No. of key elements present: 2.5
	2	Option selected: (iv) (i) Wrong, because although it echoes around the room the sound waves are needed to carry the sound to ears. (ii) Wrong, every time you listen to something you don't have to concentrate. (iii) Sound waves don't come from your ears, they are produced from the gong when struck. (v) You can't just 'hear' something, you need sound waves to travel the sound to your ears. (vi) You can't just 'hear' the sound you need sound waves to travel the sound to your ears.
	3 (i)	Yes, vibrates the water sending vibrations to the ear.
	(ii)	Yes, sound waves are sent through the steel pipe which vibrates.
	(iii)	Yes, voice, sound waves carry along the string.
	(iv)	Yes, sound waves bounce off the wall, and vibrate into the air.
	(v)	No, vibrations are kept bottled up.
	(vi)	Yes, sound waves are vibrating into the air even when car has passed.
20	1	When the bird sings it sends out sound waves which are picked up by the childs ears so that the child can hear the bird singing. No. of key elements present: 1.5 [no mention of the medium nor how the sound reaches the ear - does mention medium in Q3]

	2	Option selected: (i) (ii) You don't need to concentrate to listen to the sound. (iii) Sound waves generally travel from the gong through the air to your ear. (iv) The gong sends sound waves. (v) The gong sends sound waves through the air to your ear. (vi) The gong sends sound waves.
	3 (i)	Yes, because the motor is making the water vibrate so you will hear the vibration.
	(ii)	Yes, because the steel makes a big sound when it is hit with a hammer.
	(iii)	Yes, because the sound waves travel along the tight string so you can hear the sound.
	(iv)	no response.
	(v)	No, because the sound waves the alarm gives off cannot reach your ear.
	(vi)	Yes, because the sound waves carry to your ear.
21	1	The sound travels through the air on what are known as sound waves. The sound of the bird is carried very very quickly to the ear drum of the child. It then registers in the childs brain. No. of key elements present: 2.5
	2	Option selected: (iv) (i) This is nearly right but there is nothing about the vibrations to make the sound echo. (ii) Concentration is not needed to hear a gong. A tiny baby could hear it. (iii) This is the wrong way around. Gong to ear. (v) You don't hear things with your ears, you hear things with what's inside your ears. (vi) The gong also makes a sound. Sounds don't come through vibrations.
	3 (i)	Yes, you would hear a muffled sound. Vibrations travel through water.
	(ii)	Yes, as the hammer is making a loud noise it vibrates the wall.
	(iii)	Yes, vibrations travel along the string.
	(iv)	No, the waves can't travel through the wall, they are blocked.
	(v)	No, vacuum jars are sound proof, and the foam muffles sound.

	(vi)	No, it is a very loud sound and takes a while to register.

Appendix 18.4 12-month delayed post-instruction responses

The 12-month delayed post-instruction questionnaire was given to the Instruction Group only. One student was no longer attending the school.

Student Number	Question Number	Response
1(I)	1	The air in the birds throat moves the cords [sic] in its voice box, then the bird opens its mouth and the air vibrations are carried through the air to the child on sound waves. The sound waves then reach the childs ear and enter. No. of key elements present: 3.5
	2	Option selected: (iv) (i) The sound has to be somehow be carried around the room for it to echoe [sic]. (ii) You use your brain to concentrate but you can't use your brain to make sound waves. (iii) The sound waves travel from the gong to your ear not your ear to the gong. (v) You hear the gong with your ears but the sound needs to be carried from the gong to your ear. (vi) The gong has to set the air vibrating for you to hear the sound.
	3 (i)	Yes, sound waves can travel through the water.
	(ii)	Yes, over the top of the wall.
	(iii)	Yes, the air vibrates the string and carries the sound waves.
	(iv)	No, the sound waves would hit the wall and stop.
	(v)	No, there is no air to create sound waves.
	(vi)	Yes, the sound waves move in all directions.

2(I)	1	The bird sings. Its vocal chords vibrate and set the air around them vibrating as well. The vibration (sound waves) travel from the bird's beak through the air, all around in all different directions. Your ear picks up the vibrations and the vibrations make your ear drum vibrate. No. of key elements present: 4
	2	Option selected: (iv) (i) It doesn't explain how you hear the sound. (ii) You don't have to concentrate to hear noises. (iii) The sound waves travel FROM the gong TO your ear. NOT the other way round. (v) It doesn't explain how the noise gets to your ears. (vi) Doesn't mention how the noise gets to your ears so you can hear it.
	3 (i)	Yes, water carries sound waves better than air does. So you could hear the engine.
	(ii)	Yes, the steel particles would vibrate and carry the sound along to your ear.
	(iii)	Yes, because the string is tight the sound waves can travel along it.
	(iv)	No, the sound waves would hit the wall and go quieter. Making the sound hard to impossible to hear.
	(v)	No, because there is no air for the sound waves to travel through.
	(vi)	Yes, you can hear noises from around you not just in front of you (sound can travel long distances).
3(I)	1	The bird will let out a sound that will vibrate – by hitting the air and the vibrations will pass through the air and hit the ear drum. No. of key elements present: 3.5 [student has not said specifically how ear receives the signal, although she appears to understand the transmission process very well]

	2	Option selected: (iv) (i) It says nothing about <u>how</u> you hear it – it just states what happens. (ii) You don't have to concentrate to hear sounds – it happens naturally. (iii) This is true, but it doesn't say how it passes through the air. (v) This says nothing about air vibrations travelling through the air and it hitting the ear drum. (vi) How do we hear it? Again, it doesn't say how we hear it – vibrating through air etc.
	3 (i)	No, the water blocks the sound waves.
	(ii)	Yes, the vibrations through the steel girder can travel through and be heard.
	(iii)	Yes, the vibrations travel through the strong [<u>sic</u>] and the can microphones the noise.
	(iv)	No, the wall acts as a barrier and stops it.
	(v)	No, there is no air for the sound waves to vibrate in.
	(vi)	Yes, it will be quieter but you will still hear the siren, because there is still air for the waves to go through.
6(I)	1	The bird in the tree makes a noise by its voice box vibrating and then these vibrations hit air particles in the air and they go on hitting another and another in a domino or wave like fashion until the air particles vibrating reaches the child. The childs ears then pick up the vibrations from the air particles onto the childs ear drum. No. of key elements present: 4
	2	Option selected: (iv) (I) You don't just hear the echoes around the room, but the actual sound made by the vibrations. (ii) There is no need to concentrate and listen to sound the vibrations will reach your ear drum invoulantarily [<u>sic</u>]. (iii) The sound waves travel from the gong where it is struck to your ears not vice versa. (v) You do not hear it with your ears, but you hear with your brain and ear drum. (vi) You don't just hear the vibrating of the gong, but the sound of the gong being struck.

	3 (i)	Yes, because water particles around the engine propeleor [sic] would be set vibrating by the movement and the water particles would vibrate in waves through the water to the person.
	(ii)	No, because the steel girder is unable to vibrate so your ear drum cannot heer [sic] the vibrations.
	(iii)	Yes, because the vibrations of your voice on the air particles would resinate [sic] in the tins and vibrate along the string and be amplified in the other persons tin to be heard by the person.
	(iv)	No, air particles are unable to go through the wall so the sound cannot reach your friend.
	(v)	No, because there are no air particles in the jar for the vibrations to travel on so you cannot hear it and it is on a foam piece so the vibrations on the table are unable to be heard.
	(vi)	Yes, because the vibrations in the air will only have reached you by then.
13(I)	1	The air travelling through the birds voice box vibrates it producing sound. This then travels through the air in sound waves. The waves reach the boys ears and vibrate his ear drum. No. of key elements present: 3.5
	2	Option selected: (iv) (i) no comment (ii) Concentration is not required to hear the sound of a gong as it is very loud. (iii) The sound waves travel from the gong to your ear not the other way round. (v) no comment. (vi) no comment.
	3 (i)	Yes, the engine sends vibrations through the water.
	(ii)	No, the vibrations are absorbed by the brick wall.
	(iii)	Yes, the vibrations travel along the string.
	(iv)	No, because the sound waves cannot pass through a wall if they are not strong.
	(v)	No, there is no air for the alarm to vibrate.
	(vi)	Yes, sound waves are still travelling in all directions.

15(I)	1	When the bird sings, the sound is carried by vibrations on sound waves towards the boy's ear. Inside the ear, the vibrations resonate and the sound is processed by the brain. No. of key elements present: 2.5 [no mention of air]
	2	Option selected: (iv) (i) The sound echoes around the room because the air is vibrating and travelling on air/sound waves. (ii) Incorrect because you do not have to concentrate to hear the sound. (iii) Air doesn't leave your ear, pick up the sound and then return back to your ear so you can hear it! (v) There is more to it than just hearing it with your ears. It involves vibrations and sound waves. Explanation is too simple. (vi) This explanation is too simple. The gong vibrates and so too does the air around it.
	3 (i)	Yes, the water can vibrate enough and allow sound to reach you.
	(ii)	No, the solid brick wall would absorb all the sound, not enough vibrations would get through.
	(iii)	Yes, the vibrations can run along the string and the sound waves would reach you.
	(iv)	No, the air vibration would be trapped by the density of the wall and sound wouldn't reach you.
	(v)	No, because there is no air, the vibrations cannot travel.
	(vi)	Yes, because the air still vibrates.