# SOME PRECONCEPTIONS BROUGHT TO THE STUDY OF SOUND BY STUDENTS IN GRADE EIGHT.

by

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## Abstract

This study is a natural history of ideas brought to the study of sound by a sample of Grade Eight students. The topic of sound was chosen partly because of the technical background of the researcher and partly because of the lack of previous research combining sound and Junior-Secondary students. The research technique used was a Piaget-style interview lasting approximately fifteen minutes in which the students were encouraged to physically explore various apparatus and to explain why that apparatus made sounds. The interviews were recorded on audiotape and the tapes were then transcribed. The typescripts were then analysed to create a set of conceptual profiles. The analyses were then considered in terms of de Bono's Levels of Understanding. Furthermore, certain difficulties, particularly with concepts related to waves and difficulties related to language, were discussed. Suggestions were made for further research.

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# CHAPTER ONE

# THE PROBLEM AND ITS CONTEXT

## 1.00 OVERVIEW OF CHAPTER ONE

This chapter is concerned with this researcher's reasons for attempting this study, both personal and professional. Then it moves to a review of possible problems created, in part, by curricular needs for a standard product as opposed to differences in the perceptions of students tackling that curriculum. The chapter goes over difficulties in finding and in formulating research questions and the research techniques necessitated by those difficulties. Finally it reviews some limitations of the study.

## 1.10 REASONS FOR DOING THIS STUDY

This researcher chose this topic for these reasons:

1. The researcher had had a very strong background in the interactions of sound and persons. This stemmed from his training and experiences as an electronics technician, ranging from VHF radio-telephony to ultrasonic detection and location of hostile submarines (Royal Air Force 1983);

2. During that time the researcher had become interested in differences in conceptual ecologies, exemplified by curiosity as to why a well-trained wireless mechanic had cleared a small aircraft to fly from Scotland to Norway despite a defective radio compass;

3. As a student of Bronowski (1973), Kuhn (1970), Popper (Magee 1974) and Toulmin (1977), this researcher was aware of the importance of social and societal factors in the development of physics instruction and learning;

4. This researcher sees physics as an act of the imagination and the understanding of sound requires the exercise of imagination; even something as simple as Kundt's tube needs the hypothesis of waves to relate the stroking of the rod to the resultant positions of the grains of powder;

5. As a classroom teacher, the researcher is aware of at least two current paradoxes stemming from Chapter 9 of Science Probe Eight, the current science text. One paradox is that the approach to understanding sound in the text appears to require reasoning characteristic of Piaget's Formal Operations; yet it is reasonable to expect most students in Grade Eight to be in the Concrete Operations stage (e.g. Cowan, 1978, p. 278). The other paradox is that sound, a longitudinally-waved phenomenon, is usually represented on an oscilloscope as a transverse-waved display.

## 1.20 EDUCATIONAL SIGNIFICANCE OF THE STUDY

Professor Jeff Thompson was the chairman of the Science Task Group on Testing, reporting to the Department of Education in London, England. He stated that a paper delivered by Rosalind Driver to the annual conference of the Association for Science Education had left him with a "humdinger" of a problem. Driver's research shows that children do not acquire scientific knowledge and understanding in a "straight line" as it were. Sometimes they move sideways or even backwards, as experimental work and new concepts illuminate each other (Sunday Times, 17/1/88, page not known).

Traditionally, the student who did not repeat on the year-end examination just what the teacher had said to him during the year was said to have failed science. This grading made certain assumptions about relationships between the student and the material. One of those assumptions is that students receiving the same teaching should produce similar results; in turn this assumes that all students bring the same inputs to the course. This researcher is doubtful that a teenager who spends vacations commercial fishing in the Gulf of Alaska has the same ideas about waves as the peer who spends vacations in the Chilcotin. A few days ago, students at a Miltown school were taken to the theatre for a live show;

when his view of the stage was blocked, a Kindergarten boy complained that he could not see the T.V. (M.L. Aspden, personal communication, Fall 1991).

This kind of misapprehension is not limited to children; recently a highly intelligent, well-trained shops teacher told the staff room that: "Fishing in winter is the pits! Those aluminum boats really pull the cold out of the sea!" ( Langley, personal communication, 1988). On an English examination a mature student was asked a question about Higgins in Pygmalion. Even though that student had played Pickering in many performances of that comedy, he could not clear his mind of the Higgins of My Fair Lady and so produced an answer which needed a very understanding examiner (W.E. Aspden, personal experience, 1965).

The above examples demonstrate that students--even students with successful previous training--do not always bring the same or even the expected ideas to academic work. Thus the assumption that all students bring the same inputs to the course is blatantly false. With that falsehood made overt, it becomes necessary to find out more about the inputs those students really bring to the academic study of sound, in the hope that the teacher can either build on the students' present knowledge or arrange, perhaps, demonstrations which will encourage the students to consider the possibility that their beliefs are erroneous.

Therefore, by exploring and airing some of the beliefs brought by Grade 8 students to the academic study of sound, it is hoped that this study might help learning become clearer and more efficient.

## 1.30 STATEMENT OF THE PROBLEM

The purpose of this study is to expose some of the preconceptions which students bring the study of sound.

On reviewing the literature available on the topic in 1987, this researcher found nothing relevant to the expected course of this study. Still in 1987, this researcher commissioned a search by a professional UBC librarian; this search turned up nothing relevant to the study of sound by students in the intermediate or junior-secondary grades. In 1989 a research assistant in the Education Faculty of UBC searched the literature; again, nothing relevant was found.

Faced with such a paucity of research data, the researcher had to create his own study of the field of sound. He started by taking the relevant concepts from a variety of physics texts and created a number of concept maps in the style of Novak (1984). From those maps, he synthesised six major parts of the topic; those parts are: Perception; Vibration; Frequency; Pitch; Transmission and Echoes.

## 1.40 SPECIFIC RESEARCH QUESTIONS

In the absence of published previous research, this researcher could find no specific hypotheses to be studied. In fact the researcher suspected that formulating such hypotheses from the researcher's knowledge of formal physics might taint students' answers with the researcher's preconceptions, expressed unconsciously in such ways as tone of voice and body language.

By combining the researcher's understanding of the scientist's perception of sound with the requirements of the provincial curriculum and the researcher's experiences in teaching that subject, this general question arose:

How do students conceptualise sound phenomena ?

In turn, this question can lead to several others. They include:

As the students come into the grade eight sound course, what are their ideas about human hearing, sound as energy, relationships between pitch and loudness, vibration, how we respond to frequencies, how musical instruments work, the role of air as a transmission medium and the formation of echoes? Do the students "read" an oscilloscope trace in the same way as does the teacher? Does the port-dwelling students' understanding of sea waves affect their perceptions of sound waves?

Therefore the researcher chose to create an exploratory study. The most obvious problem in a verbal study is the tendency of students to shade their answers to what they think the teacher wants. This has been attested to in publications ranging from Goldsmith's Deserted Village: " ... to trace the day's disasters in his (the school master's) morning face" to the insurance salesman's technique of nodding and of asking questions requiring a "yes" answer in order to train the customer to agree that the latter should sign the contract.

To reduce the researcher's effects on the student's explanations, the researcher chose to have the student physically explore various apparatus--some from a science department, some specially-made, some store purchased--and vocalise what the student was thinking. In turn, these comments and actions led the researcher to ask questions of clarification and extension. Therefore the specific research questions depended on the individual student's responses to the equipment.

However, a completely unstructured conversation could go anywhere; to keep the interview on track, the interviewer used the six major topics from his understanding of the physics of sound (Perception, Vibration, Frequency, Pitch, Transmission and Echoes) as waypoints in the interview.

Therefore, the research questions were developed to elicit students' mental constructs on these six major topics and to explore the students' elaborations of their answers.

## 1.50 METHOD OF STUDY

The researcher chose the individual interview as the technique for gathering data on student preconceptions.

The interview was guided in outline by the researcher's sense of the parts of the study of sound and in detail by student actions, comments and responses.

Interviewees were self-selected. Students at a junior-secondary school were offered the opportunity to earn a dollar for about twenty minutes' work during the noon hour. As students came, they were interviewed.

During the early seven interviews, a table in the researcher's laboratory had various sound-producing apparatus put on it. Three interviews did not use any apparatus. Four interviews used a door harp as the stimulus.

The interview was usually in three parts, Introduction, Research, Closure. The Introduction by the researcher ensured that the student was aware that the interview was intended to help the researcher with a university course; that the interview was absolutely voluntary and that the student had the right to leave any time; that the interview would have absolutely no effect on the student's future at the junior-secondary school or at university; that the interview was being taped. If the student accepted those conditions, the interview was continued.

The early interviews started with the interviewee being shown the apparatus on the table, being asked to try out the items of equipment and to tell the interviewer about them. Sometimes it was necessary to start by asking the student close-ended questions about a specific piece of apparatus, in order to get the student to speak freely.

The later interviews used a door harp. This apparatus was chosen because, at the time, few students had seen one and so student exploration was more likely to be influenced by student concepts of sound than by previous experiences with similar items. The particular shape of door harp was chosen because it seemed most dissimilar to many stringed musical instruments such as guitars.

The final part of the interview consisted of thanking the students for their efforts, by informing them that the researcher's findings would be published as a book and by asking if they had any questions.

Because the interviews were carried out during the thirty-five minute noon break, they were limited in time to about fifteen minutes each. Some interviews were shorter than others because the student had run out of ideas and one or two interviews took almost thirty minutes because both the student and the interviewer became fascinated by the topic.

Many more interviews were carried out than are cited; five were lost during a transfer of documents from one site to another; three were carried out with Grade Nine students as practice for the interviewer; three had to be aborted for various reasons, such as excessive interruption from the school PA system.

## 1.60 LIMITATIONS OF THE STUDY

The researcher cannot be certain that the sample of students was quite random, for he deliberately refrained from asking interviewees why they had volunteered.

Miltown is isolated; one cannot leave the district without riding a ferry or a plane. Suburbs of Miltown are parochial; for example a student in the suburb of Berrypatch has told this researcher that students in the suburb of Ferryview (less than a kilometre away) are snobs (Gr. 6 student, personal communication, 1985).

Miltown's industry is the oldest pulp mill on the coast; this researcher was informed that until recently the Miltown Mill took about two hundred employees to do what Cariboo Pulp did with twelve employees (M. Stubbs, personal communication, 1978). Therefore it could be argued that many social perceptions in Miltown are more appropriate to an agriculturally-based, rather than to a technically-based, culture.

This community has a very strong musical tradition; the childrens' chorus and orchestra have toured Europe and the Soviet Union. Miltown hosts an international music festival every other summer. Therefore, if any preconceptions of sound exist, then they might well stem from experiences of music.

Miltown is dominated by the sea. Few students have not had their perceptions of wave phenomena affected by ferry rides and salmon fishing.

The interviews noted represent about five percent of the Grade Eight population of one school in an isolated community.

Given this context, the researcher cannot claim that the sample studied represents the Grade Eight population of

British Columbia. However, this research might provide a source of testable hypotheses.

## 1.70 SUMMARY OF CHAPTER ONE

This chapter has explored some of the researcher's reasons for choosing this topic, outlining some of the researcher's relevant experiences. The purpose of the study is to learn more about the ideas about sound which students bring to the academic topic of Sound in the Grade Eight Curriculum.

Because of the dearth of published research on the interactions of students and sound at the time this thesis was started, there were few obvious hypotheses to test. Therefore this research became a type of natural history, trying to get some idea of how students think of sound. The technique for research was to invite volunteer students to look at various items of equipment, to have a student manipulate the equipment and to have the student verbalise, spontaneously or by open-ended questioning, what the student was thinking. Although the interviews were exploratory, they were focussed around six key ideas.

The interviews were audio taped and the tapes transcribed to typescript. The researcher then reviewed the typescripts en masse, looking for consistencies, anomalies and patterns.

It is far from certain that this research can be generalised to a population of grade eight students, since it was carried out in one school in an isolated community which has an international reputation for music.

# CHAPTER TWO

# THEORETICAL AND PRACTICAL PERSPECTIVES

## 2.00 INTRODUCTION

There seems to be a dearth of research into the interactions of Junior Secondary students with the academic study of Sound. Therefore, to find an academic context for this research, it was necessary to review the historic background of this kind of research. However, during the same period that this research was being carried out, two others were researching similar fields, one for elementary students and the other for university students. Some findings are noted at the end of this chapter.

In this chapter the related literature will be reviewed in three frameworks, two theoretical and the other methodological.

### 2.01 Two Theoretical Frameworks

This research is about how students reason about sound. One way to describe the interactions of people and the natural world is to look at systems of belief. One system is that the Universe is, and that humans must try to understand it (the subject-oriented perspective). The other system is that the universe is a product of human thought (the student-oriented perspective). This part of the paper first looks at the subject-oriented perpective historically from the Ahmes Papyrus to Heisenberg's Uncertainty Principle and exposes serious problems with that perspective. Then it looks at the student-oriented perspective historically from Adelard of Bath to Linder, and exposes some technicalities of this study.

## 2.02 A Subject-oriented Framework

Although the student-oriented view, known as "Constructivism" in science instruction is not perfectly identical with that view in mathematics instruction, this researcher found that, to understand traditional reasoning in physics, one must go into mathematics, for as Feynman writes:

> The strange thing about physics is that for the fundamental laws we need mathematics. (1965, p. 36)

and Bronowski writes:

> The exact fit of the numbers describes the exact laws that bind the Universe (p. 161).

Herodotus (quoted in Turnbull, p. 1) suggests that mathematics as we know it originated in Egypt, where flooding of the Nile changed the sizes of individual farmer's fields and so changed the amount of tax the farmer had to pay. Therefore the King's overseers had to devise means to measure the amount of land each farmer had. Aristotle claims that mathematics originated with the leisure class of Egyptian priests; his view was confirmed by the Ahmes papyrus (Turnbull, p. 2).

According to Turnbull (p. 4), a Greek merchant, Thales, transferred Egyptian rules of earth-measuring (geometry) to Greece and abstracted the concept of a space. The study of spaces seemed to be the study of the Universe, for an object is a space filled with matter and a vacuum is a space devoid of matter. By further abstraction the Greeks classified geometric ideas by points. A place could be defined as a single point, a line as the connection of two points, a plane as the relationship of three points and the simplest solid, the tetrahedron, as the relationship of four points.

Since a point has position but no dimension, the Greek study of geometry became more and more idealised until there developed the idea, ascribed to Plato, that a figure such as a circle drawn by an earthling was a tawdry attempt to mimic a perfect circle in existence beyond human experience. Turnbull quotes (p. 27, 28) that to the question "What does God do? " Plato replied, "God always geometrizes." Therefore geometry became a search for perfection.

Bronowski (p. 156) reminds us that another Greek, Pythagoras, discovered that by dividing a vibrating string into integer numbers of lengths, the harmonics of the ground note could be produced; a non-integer division produced discord. This practicality confirmed the theoretical view that geometry was the way to understanding the Universe.

The view that the Universe had a static, geometric perfection persisted until the time of the Renaissance, when perspective painting developed. To quote Bronowski :

> The perspective painter has a different intention. He deliberately makes us step away from any absolute and abstract view. Not so much a place as a moment is fixed for us ... ; a point of view in time more than in space (p. 180).

The intention of these painters was to create a sense of movement in space (Bronowski, p.179); this movement became scientifically important when Kepler, using the more precise measurements of Brahe, found that the position of Mars was too far off the position expected (by about eight minutes of arc) (Feynman, p. 16). Therefore Mars did not go in a perfect circle, but in an ellipse. Newton used geometry to learn more about the paths of planets but found that the stasis of geometry prevented further analysis. Newton developed a new analysis based on rates of change; this new analysis, calculus, became the most important mathematical tool for exploring both astronomical and terrestrial phenomena in scientific terms (Bronowski, p. 184-6).

Newton's development of calculus stemmed from his assumptions that space and time were absolute, rectangular and passing immutably (Bronowski, p. 241). These assumptions became rules to live by; the work of the next couple of centuries was to develop knowledge for economic benefit; the paradigm of the geographer hacking his way through the jungle to learn everything about, say, Africa, was matched by that of the scientist in his laboratory hacking his way into learning everything about, say, heat. However, those explorations were to ruin the very assumptions on which they were based.

Celestial navigation was vital to reliable maritime transport. Creating the tables of numbers needed to guide reliable navigation required a colossal number of repetitive arithmetical operations. Pascal had demonstrated that numbers and operations could form patterns (Turnbull, p. 90); the power loom performed dozens of repetitive movements every minute and the embroidery on the cloth could be changed by changing the loom control cards in the Jacquard system. Babbage tried to develop a Pascal design into a machine which generated tables of numbers much as a loom generates cloth; the numbers generated would depend on the human's choice of

Jacquard-type cards. Babbage never got the machine to work as he wanted it to, but he created a mechanical system which, apparently, could take a load of axioms and data and figure out every possible combination.

Babbage's machines raised questions at the overlaps of mathematics and philosophy; those questions included:

a) Could every statement in mathematics be proven or disproven?

b) Was mathematics consistent, in that the same axioms could not generate both $a = b$ and $a \neq b$ ?

c) Was there some machine-capable method to decide the truth or falsity of a mathematical statement?

(Taken from Hodge, p. 91)

In exploring these questions, Kurt Godel demonstrated that:

> ... any such precise mathematical systems of rules and procedures whatever, provided that it is broad enough to contain descriptions of simple arithmetic propositions and provided that it is free from contradiction, must contain some statements that are neither provable nor disprovable by the means allowed within the system
>
> (Penrose, p. 133).

Thus Godel, in 1931, by showing that a reasoning technique as simple as arithmetic could contain statements which were impossible to classify as true or false by axiomatic means, showed that the perfection envisaged by the Greeks and searched for through millennia by philosophers and scientists, was a chimera.

Since physics needs mathematics for fundamental laws (Feynman, 1965, p. 36), then clearly Godel had shown a serious flaw in scientific reasoning. Was it then possible to be guided by the Bronowski quotation (p. 161) and find the exact fit for the numbers in order to find the exact laws of the Universe? Alas, no.

In 1881 Michelson and Morely tried to find the speed of the Earth through the ether (a hypothetical fluid which accounted for the propagation of light). Instead, they found that, in normal dimensions:

> It appears to be impossible to alter the speed of light in space by sending it in different directions. In fact the speed of light in space is found to be the same by all methods of measuring it, even if the observer and the light source are in relative motion with constant velocity (Buesche, p. 27).

This conclusion seems to be absurd. To illustrate its absurdity, consider this example. An observer is driving the freeway at 80 km/h. Car A is travelling in the same direction at 50 km/h; the observer, perhaps using Doppler, will sense himself to be passing car A at a relative speed of 30 km/h. Meanwhile, car B is travelling in the same direction as the observer at 100 km/h; the observer will sense a relative speed of 20 km/h. Car C is in the opposite lane going in the opposite direction at 90 km/h; the observer will sense a relative speed of 170 km/h. The above makes sense and is experienced in reality. Yet if cars A, B and C are replaced by flashes of light, then the observer will experience them all at the same relative speed, that of light, according to Michelson and Morely.

To overcome this absurdity, Lorenz suggested that an object shrinks in the direction of motion (Feynman, 1977, p. 1:15:5). This contradicts one assumption at the heart of post-Newtonian physics, that space is absolute (see previous quotation), for it means that an object such as a metre stick filling that space will change its length according to its direction of travel. Therefore, no measurement of distance can be taken at face value.

In an attempt to deal with the above absurdities it was suggested that time itself depends on relative speeds. This has been tried; when two identical, very accurate, clocks were synchronised and one kept stationary whilst the other was flown round the earth on a commercial jetliner, the clocks were found to be out of synchronisation after the flight. Thus time cannot be held to be absolute. Therefore no time measures can be taken at face value. Both the length and time absurdities can be handled mathematically; yet Godel had demonstrated that mathematics is badly flawed.

What, then, of microscopic dimensions? To quote Feynman:

> (Heisenberg's Uncertainty Principle) says that if we try to pin down a particle by forcing it to be at a particular place, it ends up by having high speed. Or if we try to force it to go very slowly, or at a precise velocity, it "spreads out" so that we do not know very well just where it is (1977, p. 6.10).

Thus the Greek ambition to find an objective, perfect structure of the Universe by the use of reason and of measurement was doomed by the imperfections of reason found by Godel and by the impossibilities of perfect measurement found by Michelson and Morely and by Heisenberg.

Therefore, it is fallacious to believe that there is a perfect truth in the natural world, both independent of humans and intelligible to them. On a more practical level, many scientists and mathematicians regard the Differential Calculus as the key to post-Newtonian physics:

> In (the differential calculus) mathematics becomes a dynamic mode of thought, and that is a major mental step in the ascent of man
>
> (Bronowski, p. 187).
>
> Once the basic ideas of differential calculus have been grasped, a whole new range of problems can be grasped without great difficulty. For two hundred years after the discovery of the differential calculus, the main advantages lay in applications of it (Sawyer, p. 121).
>
> If we go back to our chequer game (physics) the fundamental laws are the rules by which the chequers move (Feynman,1965, p. 36).
>
> .. the Newtonian scheme translates to a precise and determinate system of dynamic equations. ... This form of determinism, as satisfied by the world of Newtonian mechanics, had (and still has) a profound influence on philosophic thought (Penrose, p. 217).

The curious point about this most valuable mathematical tool and philosophic viewpoint is that it is inexact. The key to calculus is to have the term *dx*2* which has a magnitude, albeit tiny, equated to zero (Dakin and Porter, p. 42). Therefore this profoundly influential technique is based on inexactitude, that is, imperfection. Therefore any structure of the world perceptible to man must come from man himself.

The view that mathematical entities exist only if they have been (mentally) constructed by man is the core belief of the philosophy of constructivism (Flew, 1979). This researcher would argue that one can substitute "physics" for "mathematics" in the above statement.

## 2.03 The Student-oriented Perspective

This thesis has already referred to Thompson's reference to Driver's research. That research indicated that children do not acquire scientific knowledge and understanding in a "straight line" as it were. Sometimes they move sideways or even backwards as new work and new concepts illuminate each other (Sunday Times, 17/1/88).

To understand how such research can surprise one of the eminences of science education in England, it is appropriate to look at a history of the viewpoint which stimulated that research.

The earliest reference this researcher has been able to find which hints at a personally constructed universe is that of Adelard of Bath, who, in the twelfth century, said that:

> It is through reason that we are men, for if we turn our backs on the amazing rational beauty of the universe we live in we should indeed deserve to be driven therefrom.
> (Goldstein, p. 88).

A more recent quote comes indirectly from Feynman:

> If one cannot see gravitation acting here, he has no soul
> (Marion, p. 94).

William Shakespeare wrote that :

> there is nothing either good or bad but thinking makes it so ... (Hamlet, II,ii,250).

B.L. Whorf wrote that:

> We dissect nature along lines laid down by our native languages. The categories and types that we isolate from the world of phenomena we do not find there because they stare every observer in the face: on the contrary, the world is presented in a Kaleidoscopic flux of impressions which has to be organised in our minds.... We cut nature up, organize it into concepts, and ascribe

> significances as we do, largely because we are parties to an agreement to organise it this way--an agreement that holds throughout our speech community and is codified in the patterns of our language
> (quoted in Rheingold,1988, p. 5).

Davis and Hersh (1981) state that:

> The constructivist's argument ... is that mathematical truth is time-dependent and is subjective, although it does not depend on the consciousness of any particular live mathematician (p. 373).
>
> Intuitive means lacking in rigor, and yet the concept of rigor is defined intuitively rather than rigorously (p. 39).
>
> A related meaning of "intuitive" is what one might expect to be true in this kind of situation (p. 391).
>
> Intuitive means relying on some physical model or on some leading examples (p. 392).

Kant claimed that:

> there must be some forms of all possible experience or, as he called them, the forms of intuition, which we impose on everything that we are in contact with; and that, since we are capable of attaining organised and

> intelligible information about the world, we must have within ourselves the organising principles. Our minds structure and interpret the observations of our senses.
>
> (Popkin and Stroll, p. 135)

That so many disparate thinkers have produced ideas as similar as those quoted above strongly suggests to this researcher that there might well be considerable truth in the idea that the apparent organisation of the outside universe comes, in reality, from the organisation of our senses; if that is so, then the outside world does not "impact upon our senses" but our senses and the outside world interact. However, a consideration of the anthropic principles of cosmology would be beyond the scope of this study.

However John Locke stated that our knowledge comes to us through our senses and we have no innate ideas. He believed that a neonate's brain was a "white paper, void of all characters, devoid of all ideas". Locke thought that we get our ideas of objects because several simple ideas constantly appear together and always seem conjoined, so we presume that these ideas belong to one thing (Popkin and Stroll, p. 193).

Key ideas of present day constructivism appear to stem from Kant's view that there must be principles or concepts by which we organise the general content of any possible experience in order to reorganise it as a coherent datum.

Jean Piaget is credited with developing the technique for exploring an individual's principles and concepts. He was originally a biologist who had worked on standardising tests of children's abilities with Theodore Simon in the laboratory of Alfred Binet (Piaget 1977 preface; Thomas 1979, p. 289). He described his work as Genetic Epistemology, which means that the central question guiding his investigations is not, "what are children like?" but, "How does knowledge develop in humans?" Or, more precisely, "How does the relationship between the knower and the known change with the passage of time?" (Thomas, p. 289).

## 2.10 THE PIAGETIAN VIEW

### 2.11 Background

According to Piaget himself, the subject of his investigation is:

> What conceptions of the world does the child naturally form at the different stages of his development?
>
> (Piaget, 1982, p13).

In turn, the above becomes two questions:

> What is the scheme of reality which prompts this thought?

and:

> What use does he make of the whims of cause and of law? ... (What is) the child's notion of causality?

Piaget points out that:

> the content may or may not be apparent and varies with the child and the things of which it is speaking. It is a system of ultimate beliefs and it requires a special technique to bring them to the light of day
>
> (Piaget, 1982, p. 13).

If Piaget is right in stating that the content varies with the child, then he contradicts the "tabula rasa", the belief of Locke that:

> at birth a child's mind is a void, an unmarked page or tabula rasa on which the contents of the mind are sketched by the child's experiences as she grows up.
>
> (Thomas, p. 32)

The relative merits of these views are very important indeed to the subject teacher, because the key assumption of a provincial, state or national curriculum to be tested at the end of the year assumes that the same experiences will generate the same products; in turn this assumes that the input materials--the students--are homogeneous. That is like saying that if a workshop puts wood through a chair-making machine, the end-product will be the same whether the wood put in is teak or is balsa. This possibility requires that the subject teacher investigate whether or not all his students think alike on a certain topic and whether or not the students think in the ways expected by the curriculum designers.

One example of how students bring different ideas to science courses is demonstrated by my experience as science teacher in a coastal town who found my students were well aware of the semi-diurnal nature of the tides, neaps, springs, full and half moons, tidal currents and, in particular, tidal effects on the locations of salmon. I took my niece (of about the same age as my students) from Quesnel to look at the Small Boat Harbour in Miltown. It was low tide. The child looked at the ramp and asked: "What's this for?" "So people can walk down to the boats." When she asked, "Is it always this steep?" I said, "No, sometimes it's almost horizontal." "Then why do people walk on it when they will fall off the end?"

Clearly I had included a factor, the change of the sea level, of which the child was not aware and I, and my students, were too familiar; therefore the assumption that children from interior communities bring the same concepts of tide to class as do students from coastal communities is clearly dubious. Indeed Haggerty has found that a student can have two conflicting beliefs about a phenomenon and change from behaviour appropriate to one belief to behaviour appropriate to the other according to the social situation (Haggerty, personal communication, 1986).

Piaget's view of knowledge is that it is:

> A process of acting--physically and/or mentally--on objects, images and symbols that the child's perceptual lens has cast into patterns that are somewhat familiar to him.... The objects are found in the world of direct experience, whilst the images and symbols can be derived not only from the "real world" but from memory as well (Thomas, p. 294).

From the above quotation it is clear that if the teacher wishes to produce predictable results from the objects, images and symbols that the curriculum imposes on the child, the teacher must be aware of the "perceptual lens" which the student brings to the course. A synonym for "perceptual lens" might be "preconceptions brought to the course".

A key concept in Piaget's writings is the scheme:

> A scheme is the structure or organisation of actions as they are transferred or generalised by repetition in similar or analogous circumstances
>
> (Piaget and Inhelder (1969) in Thomas, p. 295).

> The child reshapes events of the world somewhat to fit the pattern of her existing schemes (Thomas, p. 298).

Therefore, to match the student and the curriculum more exactly, the teacher should be aware of what schemes the student brings to his studies. Such is the purpose of this study.

2.12 Piaget's Interview

The clearest statement of the relevant technique is given by Thomas:

> During the adolescent years, children are more often given verbal problems and asked about how they arrived at their conclusion.
>
> ... Piaget has not limited himself to asking each child a preconceived set of questions. Rather, after beginning the interview with a standard question or two, he has felt free to create, on the spot, additional questions for the child, designed to probe the thought processes that produced the initial answer (Thomas, p. 290).

An example of the technique comes from Piaget himself. A child is given two rulers, each about six inches long and shown that they are of the same length. One ruler is then slid about three inches along and the child is asked if the length of the moved stick is still equal to that of the other. Only 15% of children aged 5 years believe it is; 70% of eight-year-olds believe it is; 100% of eleven-year-olds think it is. Yet the same sticks' lengths, if they are placed obliquely to each other, are more accurately estimated by younger children than by older (Piaget, 1977, p. 76-9).

Such evidence belies the idea that children are little adults; children have ways of perceiving appropriate to their ages and their experiences. Constructivist researchers have found and published many examples of children's surprising concepts in physics; just one text (Driver, Guesne, Tiberghien (1985), subsequently abbreviated to DGT) shows students' "unscientific" conceptual understandings of such "scientific" material as:

> Various models of a simple electrical circuit (p. 36);
> students who think that mixing water at temperature a with water at temperature b will increase the mixture's temperature to (a+b) (p. 62);
> students who think that objects will fall off the Earth if dropped in the Southern Hemisphere (p. 180).

It is not adequate to assume that a successful idea will be held by the student forever more; for instance Strauss (1981) (cited in DGT, figure 4.2 right) suggests that a student can hold an idea about the temperature of mixtures at age 4, lose it at age 6 and have it again at age 9.

2.13 Piaget's Precautions

However, this method of obtaining insights into students' thinking is not without difficulties. The content of their thinking may or may not be apparent and varies with the child and the things of which it is speaking. "The method is difficult and tedious and needs one or two years' full training"

(Piaget, 1982, p. 14).

The researcher should vary the questions, make counter suggestions and respond to student answers rather than to the researcher's schedule. The form of the question can influence the answer; if the researcher were to ask, "What makes the sun move?" this might well indicate to the child that some sort of machine or animal is required for the answer.

Open ended questions are intended to bring out the child's ideas, no matter how unexpected those ideas may seem.

The researcher's unconscious body language can stop the child in midanswer or even give the child clues about the kind of answer the researcher wants (p. 16). The validity of the answer should be assessed by reviewing the spontaneous questions of children of the interviewed age or younger.

The child might well think of itself as immature and its ideas unworthy of serious discussion. One way of handling this possible issue is to treat the student as a peer and to assure the child that answers will not be attributed to him or her. Self-censorship can appear when the child is jolted into self-conciousness; therefore the researcher must consciously work to keep the conversation smooth (p. 19).

Recognizing patterns of response is certainly an important aspect of research, but mere summaries of the type "x children mentioned phenomenon y" are misrepresentative. Instead the researcher should note and perhaps publish the actual phrases used by the child (p. 20).

It is dangerous to assume that a child's answers will be on the same level throughout the interview. A student might be deeply engaged intellectually by one question and amused by the triviality of another (p. 21).

## 2.13 Piaget's Classification of Student Reactions

An uninterested child might reply to a question with the first thing that comes into its head; Piaget describes this as a random answer (Piaget,1982, p. 21).

Sometimes a child might give an answer in which it does not really believe; such is romancing (p. 21).

When the child gives an answer suggested by the question, or to please the questioner, such is called suggested conviction (p. 22).

When the child draws the answer from his or her own schemata after reflection, such is called liberated conviction. Although it is from the child, it is very possible that this answer is fine-tuned to fit the child's perception of the question.

When the child produces an answer from his or her own reflections which, in turn, have resulted from previous cogitations in the same mental area, such is said to be spontaneous conviction. It must be noted that liberated and spontaneous convictions can masquerade as each other (p. 22).

## 2.20 THE RESEARCHERS' PERSPECTIVES

As Piaget wrote (Piaget,1982, p.16, 21), there is some danger that the child's answers will be influenced by the researcher's schemata; therefore it is vitally important that the researcher endeavour to keep his conceptual ecology hidden. However, if the researcher has no mental structures with which to guide the interviews and their analysis, he will be like the proverbial horseman, galloping off in all directions.

This researcher's mental structures stemmed from five sources. They were first his training in sonics phenomena as an apprentice at Number One Radio School, Royal Air Force, Locking. The next influence was the content of the Science Teacher's Course at the College of Education of the University of Hull. The third influence was the Teacher's Guide To Grade Eight Science. The fourth influence was de Bono's Levels of Understanding. The fifth influence was the paper by Posner, Strike, Hewson and Gertzog (1982) (subsequently abbreviated to PSHG), on the conceptual ecologies of the typical person.

## 2.21 This Researcher's Training in Acoustics and Ultrasonics

This researcher was trained as an electronics technician by the Royal Air Force. The relevant parts of the course included: microphones and telephones, aircraft intercommunication equipment, testing and servicing components, VHF equipment, UHF equipment, HF communications equipment, beacon location, sound, introduction to wireless communication, amplifiers. Additionally, he was trained by RAF Yatesbury in the use and servicing of equipment used to locate submarines by sound. As a serviceman with Coastal Command, he was introduced to sonobuoys and spent some time as an observer on antisubmarine patrols, practices and research flights.

The researcher used this background, and that from his coursework at Hull, to organise the topic of Sound into six key ideas, Perception, Vibration, Frequency, Pitch, Transmission and Echoes.

## 2.22 Concepts from Science Probe Eight, Teachers' Resource Guide

Page 9-3 of this Guide gives the lists of goals and of key ideas with which Grade Eight students of sound would be faced.

This researcher reviewed the typescripts of the interviews with those goals and key ideas in mind, to get an idea of the relevant schemas used when the child thought he was engaged with the questions developed from the six-topic list.

## 2.23 de Bono's Levels of Understanding

One example of a Piagetian task and its products comes from Edward de Bono. He showed a thousand people a black cylinder standing alone on a white table. Suddenly, without warning or apparent reason, the cylinder fell over. Each member of the audience was asked to try to understand what had happened and to write down his or her explanation on a file card. Ten minutes later, the cards were collected

(de Bono, p. 18).

de Bono then reviewed the cards and found that the answers displayed five levels of understanding. They were (summarised from chapter 3):

Simple Description:- for example, it changed position suddenly..

Porridge Words:- for example, the cylinder had a mechanism in it that made it fall over after a certain time; here the names are used to mark unknowns.

Give it a Name:- for example, it fell over. Reason? Gravity. Here the word is chosen which is seen as the most appropriate.

The Way It Works:- for example, Overbalanced due to a slow shifting of contents.

Full Details:- A combination of "Give it a Name" and "The Way It Works". For example, "The tube was unstable but was stuck to the table by adhesive which eventually gave way"

(taken from p. 31).

This researcher found de Bono's categories very helpful indeed when thinking about the children's comments during the interviews.

## 2.24 A Model of Mental Organisation

PSHG (1982) produced a model for a conceptual ecology which this researcher bore in mind during the reviews of the interviews. Features of the model include:

Analogies and Metaphors:- parallels and similarities with other ideas which reinforce and stabilise the present mental structure;

Anomalies:- weaknesses in an idea's structure of which the person is aware;

Explanatory Ideals:- the criteria the person believes are needed for a satisfactory explanation;

Epistemological Views:- criteria such as elegance, economy and permanence of knowledge;

Metaphysical Beliefs:- such as in the orderliness of nature;

Metaphysical Concepts:- such as the stability of time and distance;

Knowledge from other fields.

The authors had demonstrated that for a concept to be accepted into a person's conceptual ecology, it must be intelligible to that person, it must be plausible and verifiable by that person's standards, it must appear fruitful to that person and the idea's competition must be shown to have strange or unacceptable results.

## 2.30 CONSTRUCTIVISM IN PRACTICE

The above has been strongly oriented towards academia. What evidence is there that such material is relevant in real life teaching? In this section this researcher looks at M.L. Johnson Abercrombie's experiences of teaching at the Universities of London and Birmingham. Her book, Anatomy of Judgement, clearly displays the effects of personal schemata on the perception of "objective truth".

In addition, this section will look at some research on sound in the recent science education literature.

### 2.31 Johnson Abercrombie's Findings

M.L. Johnson Abercrombie (subsequently abbreviated to JA) taught anatomy and zoology at the Universities of Birmingham and of London.

She found that scientific ways of thinking did not stem automatically from learning the facts of science. Consequently she started teaching by discussion so that her students would become aware of some of the factors that had affected their judgement in scientific matters. JA regarded judgement as ignoring some of the bombardment of information, seizing on the rest and interpreting it in the light of past experience (p. 14). More to the point of this research, she wrote that:

> during discussion, students were mutually testing and modifying their schemata and as a result of reorganising their store of experience were able later to make more valid interpretations (p. 21).

JA's essential message is:

> We are unaware of the extent of our personal involvement in the act (of forming judgements about received information), tending to regard the information as given (p. 172).

She cites as examples of the effects of past experience the chimpanzee who had been born blind then had its sight restored; it could not recognise a feeding bottle by sight, but recognised the bottle when it touched the chimpanzee's cheek (p. 47). Another example was of the human adult whose sight was restored surgically several years after being born blind; even after thirteen days' training the person could not differentiate between a square and a triangle without counting the corners (p. 46-7).

She found that the earlier a schema had formed, the harder it was to verbalise (p. 95) and that the student was not aware of using (such early schema); because the student was not aware of them he did not question the validity of using them on a particular occasion, and therefore tended to use them inappropriately and so failed to gain information of predictive value (p. 95).

Those of her students who were told that a Breughel painting was of a wedding saw joy and musical instruments; those who were told it was of a fight saw anger and weapons (p. 38). She refers to the schematic assumptions involved in certain optical illusions. It might be assumed that such schemata as health, disease and x-rays are relatively stable; yet JA found that in an experiment involving the reading of x-ray pictures, radiologists were found to disagree <u>with themselves</u> in twenty percent of their cases. In that experiment, a radiologist was shown an x-ray and made a diagnosis. Some weeks later, the doctor was shown the same picture and asked to make a diagnosis, unaware that he or she had done so previously. Several such pairs of diagnoses were then compared (p. 108).

JA studied the reactions of several groups of students to various topics; amongst other things, she found that what was a fact to some students was an inference to others (p. 103); that a fact was relevant to some and a red herring to others (p. 103); the name given to an object affected its perception (p. 104), and even burette readings tended towards the expected values (p. 105). She found that students tended to think that things that were alike in some respects would be alike in all respects (p. 141). She found that expectation controlled inferences; for example larger cards were thought of as nearer; expanding balloons were seen as approaching; radiograms of human hands were assumed to have been taken at the same distance, so that a larger image was thought to be that of a larger hand; larger and smaller sizes of hands' images were ascribed to age differences; few students looked at the wrist cartilages to verify those inferences (p. 102-3).

Students were astonished to learn that their conceptual ecologies affected how they viewed documents. The factors involved were:

the status of the writer,
the repute of the journal,
the student's knowledge of the writer's background,
the student's level of scepticism (p. 145).

Students were surprised to learn that they had so many, and so different, meanings of the word "normal". Many students were disturbed to find such "objective" measures as consistency, suitability and agreement were, in fact, subjective (p. 147). JA summed up her influence on this thesis thus:

> Everything we are trying to teach can be learned only if it is compatible with the student's present attitude, or if his attitude can be so modified as to incorporate it (p. 159).

2.32 Bruner's Autobiography

Bruner cited research done by "Smitty Stevens" but gave no citations by which this researcher could find the original research papers. Therefore these notes come directly from Bruner (1983).

The purpose of the research was "to find out how the . .. ear ... represented the world of impinging stimulation." (p. 72). The research claimed that there were four basic attributes of tone:- pitch, loudness, density and volume. There are only two physical properties of pure tones: the amplitude and the frequency of the simple sound wave which produces them. However, there is also a reference to Fourier's Analysis (p. 73) and a reference to resonance (p. 74).

According to Stevens, pitch is produced by resonance at a specific place in the cochlea. Changing the amplitude, whilst holding the frequency constant, can slightly shift the peak of resonance. Loudness can be described as the number of neural fibres in the cochlea that can be fired around the peaking point. Density is related to the concentration of neural fibres near the resonance site which fire. Volume is related to the number of fibres in the cochlea which fire (p. 74).

Bruner writes that, "(The above) may be totally irrelevant with respect to how sounds are actually experienced:" (p. 74). Yet he writes of how a colleague compressed the tune of "Yankee Doodle". At first, the compressed version sounded like the repetition of one note, but after a few sessions, "Yankee Doodle was coming through loud and clear." Indeed the real Yankee Doodle sounded gross! (p. 75).

> In the estimation of physical magnitudes, both the physical and time separations were found to be important (p. 75).

Bruner also wrote that:

> We discovered what "primitive" painters had known for many centuries: significant objects in a picture become accentuated in appearance--in size, colour, saturation, clarity--however (p. 75).

He further wrote that:

> The psychophysics of sensory attributes is much too winding a road into the study of perceptual filtering (p. 75).

2.33 Gustafson's Findings

Gustafson carried out research into the teaching of sound involving five students in a Grade Four classroom in Alberta. As part of her research she asked students for their ideas about sound prior to the course being taught. The relevant views are summarised below.

Children perceive a difference between learning and understanding. Understanding means self-constructed, self-satisfying explanations (p. 109), whilst learning appears to refer to "only memorisation or the ability to repeat terminology or observations" (p. 124).

The struggle for personal understanding is not linearly progressive; instead, children display many reversals of direction, make surprising observations and construct webs of ideas which are intelligent and personal (p. 109). Replies to the question of how sound is made included:

All five said that things must move to make a sound.

Some things, for example timers, stereos, photocopiers and airconditioning systems make sound without moving.

Four children recognised that sound could be made louder by putting more energy into the sound maker.

Some children recognised that different keys on musical instruments produced different notes.

One student noted that higher notes sounded louder.

Replies to the question of how sound travelled included:

Sound can travel through a solid if it is not too thick;

Sound can be heard through liquids;

We hear better in air than in water;

Echoes used big spaces with walls for your voice to bounce back to you.

Two children spoke of sound travelling in waves or vibrations, but one had taken the idea from cartoons.

Reasons why we hear things included:

We hear things because they are close;

> Sound is attracted to ears like one magnet to another; Sound waves are invisible and can't be felt; their existence is proved by the fact that we hear them.

Discussing the reception of sound, most of Gustafson's students knew that ears are involved:

> that some people have difficulty hearing, so must use aids or have people speak up;
>
> that some animals hear better than others, and there is some disagreement on effects of ear size.

2.34 Linder's Findings

Linder (1989) worked with ten physics graduates from a physics teacher education program to find out how they thought about and made sense of the phenomena of sound (p. 43).

He found four qualitatively different ways of thinking about sound: one as an entity which is carried by individual molecules through a medium and the other as an entity which is transferred from one molecule to another through a medium (p. 45). He referred to the above two views as "microscopic". The two "macroscopic" views were that: sound is a travelling bounded substance with impetus, usually in the form of flowing air; sound is a bounded substance in the form of a travelling pattern (p. 51).

The concept of sound formed by blending microscopic with macroscopic perspectives became:

> the concept of sound is linked to the concept of waves, as part of some universal, mathematically abstract, physics modelling system (p. 146).

In reference to the speed of sound, student conceptualisations included:

> The speed of sound is a function of the physical obstruction which molecules present to sound as it navigates its way through a medium.
>
> The speed of sound is a function of molecular separation (the closer molecules are to each other in a medium, the faster the propagation, and vice-versa).
>
> The speed of sound is a function of the compressibility of a medium (the more compressible a medium is, the faster sound can travel through it, and vice-versa) (p. 146).

## 2.40 SUMMARY OF CHAPTER TWO

This chapter looked at the literature guiding the ideas behind this research.

The historical study went from the practical problems caused by the flooding of the Nile to the Greek search for the perfection of the Universe. This search dominated physics until the twentieth century, when Bohr, Einstein, Godel, Heisenberg and Michelson and Morely demonstrated that even if such exists, no person cannot comprehend so perfect a Universe; consequently, any comprehensible structure must come from the human mind. The other part of the historical study moved from Adelard of Bath in the twelfth century to the problems, exposed by Rosalind Driver, to be faced by the Ministry of Education of England in the 1990's. Driver demonstrated that students neither conceptualise nor mentally operate in ways predicted by scientists' analyses of scientific topics. The idea that students are "blank sheets" on which the teacher "paints" the scientific topic is the idea from which a province-wide curriculum stems. Yet glances at medical students' optical illusions show that what we think we see is often not, in fact, what is there. Many experiments have demonstrated that what we think we see is governed by what we expect to see--that is our memories and mental habits.

Jean Piaget created a technique by which a learner's underlying concepts could be brought to consciousness and looked at by the student, the teacher and, perhaps, by the learner's classmates. This chapter explored techniques and pitfalls of the Piagetian interview and looked at examples aired in texts such as Children's Ideas In Science and Anatomy of Judgement.

This chapter looked at some concepts held by this researcher, and their sources. It looked at previous work in the study of student preconceptions about sound; one set of findings from Grade Four and the other from post-graduates. Therefore it is hoped that the historical review has laid the theoretical framework; that the work on Piaget, de Bono, Gustafson and Linder has laid the methodological framework of the research which follows.

# CHAPTER THREE

# METHODS OF STUDY

## 3.00 INTRODUCTION

This chapter deals with the technique of data collection. The reasons for, and some limitations of, the data collection techniques are given. It relates the data to the provincial curriculum. It describes the tasks, techniques and apparatus used in the interview. It describes the analytical procedures used by the researcher to make sense of the data.

## 3.10 PURPOSE

The purpose of this research was to find out what, if any, preconceptions students in Grade 8 brought to the study of sound.

### 3.10.1 Researcher's Profile of Topics in Sound

From the scientific study of sound and the researcher's experience, one profile of topics in sound included

PERCEPTION

VIBRATION

FREQUENCY

PITCH

TRANSMISSION

ECHOES

3.10.2 Profile of topics from the Teachers' Guide

From: Bullard et. al. (1985) p. 9-3, another set of topics in sound included:

ENERGY

PITCH

LOUDNESS

AUDIBLE FREQUENCIES

FREQUENCIES

AIR AS TRANSMISSION MEDIUM

ECHOES

WAVE MOTION

COMPRESSIONS AND RAREFACTIONS

USE OF OSCILLOSCOPE

Yet another set of topics comes from the the B.C. Ministry of Education's optional learning outcomes from the current science curriculum:

C70: Understand the nature of sound transmission;

C90: Understand common applications of light and sound.

Possible activities suggested by the curriculum guide include the following:

have students use an oscilloscope to observe various musical instruments and note wave patterns;
Use slinkies and/or Kuntz's tube to demonstrate the compressional wave patterns of sound;
Have students explain how sound is used in echo-location.

The Ministry has prescribed the use of the text Science Probe 8 as one means of assisting students to achieve the above learning outcomes. The goals of the Chapter on Sound include:

1. Know that sound is a form of energy;
2. Know the difference between pitch and loudness;
3. Realise that only certain frequencies are audible;
4. Know what frequency means;
5. Appreciate how different frequency sounds are produced in musical instruments;
6. Understand the nature of sound transmission--realise that sound requires a medium in which to travel, and will not travel through a vacuum;
7. Know what an echo is;
8. Realise that sound is carried by wave motion, and that sound waves consist of compressions and

rarefactions in the particles making up the medium carrying the sound;

9. Be familiar with the display of several different kinds of sound on an oscilloscope screen. (Bullard, Baumann, Deschner, Gore, McKinnon and Sieben, 1985)

As well as goals, the chapter has key ideas (KI). They include:

1. All sounds result form vibrations of some sort;
2. Sound is a form of energy;
3. The frequency of a vibration is the number of vibrations completed in one second;
4. One vibration per second is called a Hertz;
5. Pitch depends on frequency of a sound. The pitch of a sound is your brain's subjective interpretation of frequency;
6. Every object that can vibrate has a natural frequency at which it will vibrate;
7. Musical instruments depend on natural frequencies;
8. Audible frequencies range from 15Hz-20 KHz for young people with good hearing;
9. Infrasonic sounds have frequencies below the audible range;

10. Sound requires a medium in which to travel; unlike light it cannot travel through a vacuum;
11. Sound travels in a form of wave motion. The type of waves is called compressional;
12. Sound travels at different speeds in different media;
13. An echo results from sound waves reflecting from a barrier near the source of the sound;
14. The oscilloscope can be used to display sound characteristics such as frequency, loudness and quality. (Bullard et. al.,1985)

Since this thesis is concerned with preconceptions based on previous experience and thinking, the researcher removed from consideration goals 3 and 9 and key ideas 4, 8, 9, 12, 14; consequently, the remaining goals and ideas were organised into these topic areas:

1. Human Sound Perception ;
2. The Energy of Sound;
3. Pitch versus Loudness;
4. Perception of Pitch;
5. Audible Range of Frequencies;
6. Vibration;
7. Responses to Vibration Frequency;
8. Frequency and Musical Instruments;

9. Air as Transmission Medium;
10. Echoes;
11. Waves Without Oscilloscope; Compressions and Rarefactions;
12. Student Perception of Oscilloscope Trace.

The only relevant research on these aspects of sound of which this researcher was aware of in 1987 was that quoted in Bruner (1984, p. 73-4).

## 3.20 THE STUDENT SAMPLE

Interviewees were self-chosen. The researcher and the other science teacher asked their Grade 8 science classes for volunteers who wished to earn a dollar for an interview during the Noon Hour. Usually a half-dozen children per year volunteered, from about ninety students. A colleague has suggested that so few volunteered because word got round the student body that a student would be asked questions to which he did not know the answer, and the dollar was small reward for such discomfort. Eventually approximately twenty students were interviewed.

The volunteer pool was from Grade 8 of a three-grade Junior Secondary school in Miltown. It is difficult to classify the students; the school is in the wealthy suburb, yet draws some students from the remnants of a 1960-70's hippy commune. Levels of achievement were not studied; neither were innate academic abilities.

The school is located in an old mill town. The city is geographically isolated; although the loom of Vancouver's lights can often be seen from this city, a minimum of five hours' surface travel separate the two. The next adjacent city is two hours away by ferry. This city has a very strong choral tradition. A childrens' choir toured Poland and the Soviet Union a couple of years ago, and the city hosts an international summer choral festival.

## 3.30 THE CLINICAL INTERVIEW

The interviews were developed and carried out much in the style of Piaget and de Bono, in that unusual apparatus was presented for the interviewee's exploration and questions and answers were developed from that exploration.

In the early interviews, apparatus from school stock was used (see list in section 3.50); however an unusual apparatus was found by chance and used in the later interviews. The apparatus used was a Door Harp (see figure 2), made by Langen's Laminations of Victoria B.C. The researcher had thought that the apparatus was relatively unknown in Miltown, yet in late November and December 1988 a local store sold about 100 units. The shape, the whale, was chosen by the researcher because it was unusual and did not give the sort of clues an interviewee might gain from a familiar shape such as that of a guitar or a piano.

Since the interviews were, in some sense, affected by the apparatus used, it was thought appropriate to carry out a few interviews without apparatus.

A conceptual profile for the Science Probe 8 chapter on Sound was developed and questions were based on that profile. The questions were intended to be open-ended in order not to restrict the range of answers. In turn, the researcher felt free to explore any line of answers which appeared potentially fruitful. Since no video camera was available, the interviews were recorded on audiotape. As there was little research on Grade 8 students' understanding of sound it became an exploratory study.

The interviews were carried out in a Science Room of a Junior Secondary School during the noon hour. This time was chosen so as to avoid interference with instructional time, pre-school help to individual students and the need to catch buses immediately after school. Interviews were frequently interrupted by PA announcements, but, since the PA was the medium by which fire and earthquake warnings were given, it was thought unwise to switch it off.

## 3.40 INTERVIEW METHOD

The key condition for permission to carry out this research in the school was that the research in no way affect the operation of the school; therefore, the usual technique of taking students from classes for prolonged interviews was impossible. Because of the limitations imposed by the school bus schedules, interviews had to take place during a thirty-five minute noon hour, including time for administrivia, bathrooms, lunch and gossip. Therefore the interviews were limited to about fifteen minutes each.

The research topic was restricted to grade 8 students so both science teachers called for volunteers from their classes. Appointments were made with the volunteers, with the researcher making absolutely clear that the interview was entirely voluntary and that it, or withdrawal, would have no effect on the student's program or grades. The student was informed that the interviewer was studying at UBC and had the homework assignment of finding out what students knew about sound; the student was told that the researcher and the professor would publish the results as a book in a year's time. Appointments for noon-hour interviews were made with those students who wanted to go on. No attempt was made to select students; so few volunteered that the researcher was concerned to garner enough data within the three years available. In all, about twenty usable interviews were carried out.

When the student came to Science Room III for the research interview, the student was asked to sit at the bench with the equipment on it. The student was shown the recording equipment and reminded that the interview was completely voluntary and that he or she had the right to leave at any time.

When the researcher felt that the student was comfortable with the situation, the interview was started with a statement and question along the lines of, "I'd like to find out what you think about sound. Just what do we mean by the word 'Sound'?" The student was then introduced to the equipment and asked to tell the researcher about it. The researcher might ask the student questions for clarification and/or to lead to other points. The researcher asked as many open-ended questions as possible; however he sometimes had to ask a close-ended question to encourage a response. Appendix (1) shows the typescript of a typical interview.

When the researcher felt that the student had told everything, or the student was getting tired or time intervened, he closed the interview by thanking the student, asking if the student had any questions, stating that the interview would be typed up in a way so that no one would be able to recognise who had said what, and handing over the interview fee.

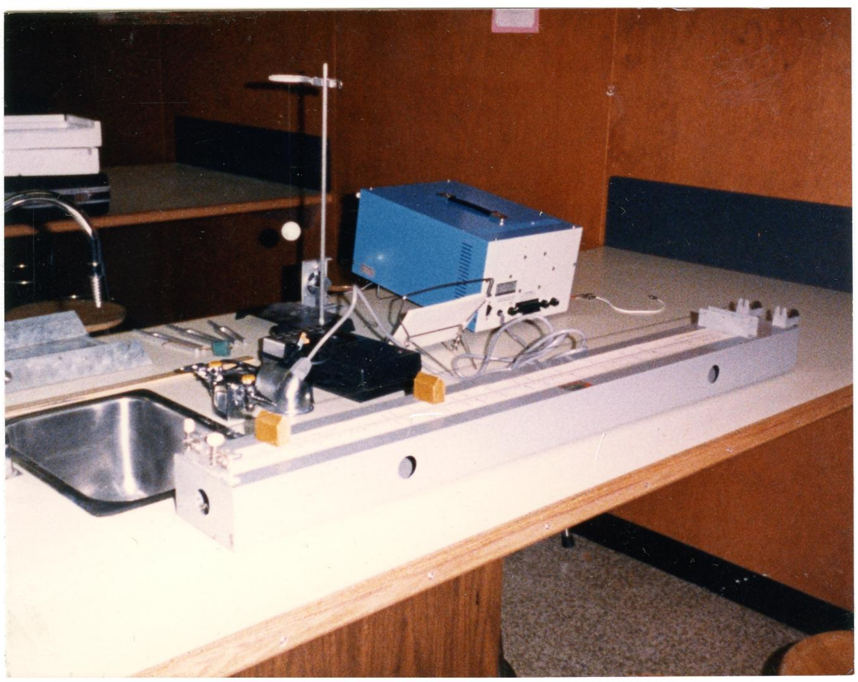
The interview tapes were sent en masse to a Vancouver secretarial company where they were transcribed into Microsoft Word 3.0, on 3 1/2 inch disks. After some problems with the combination of program and computer the researcher reviewed the transcripts and tried to use the computer to create a glossary of statements for each of the key concepts. In turn, each glossary was to be scrutinised for important evidence and patterns of student conceptualisations about sound.

## 3.50 DESCRIPTION OF TASKS

A sound exists for a relatively short time and so it cannot be studied at leisure as can, say, the forces involved in two weights pulling a mass. During the early interviews, an array of sound equipment was laid out and the interviewee was asked what s/he thought and predicted as the equipment was manipulated by the interviewer. The key items of equipment were as follows:

1. Click Wheel, locally manufactured, intended to probe student understanding of frequency;
2. three tuning forks of differing sizes, to explore any effects of source dimensions on sound;
3. A ping-pong ball on a thread, to look at forces from the tuning forks;
4. Metrestick and clamps, to explore effects of length on predicted notes;
5. Sonometer to explore effects of force and length on predicted note;
6. Oscilloscope to explore student perceptions of amplitude and pitch.

Figure 1. Two views of apparatus used in the earlier interviews

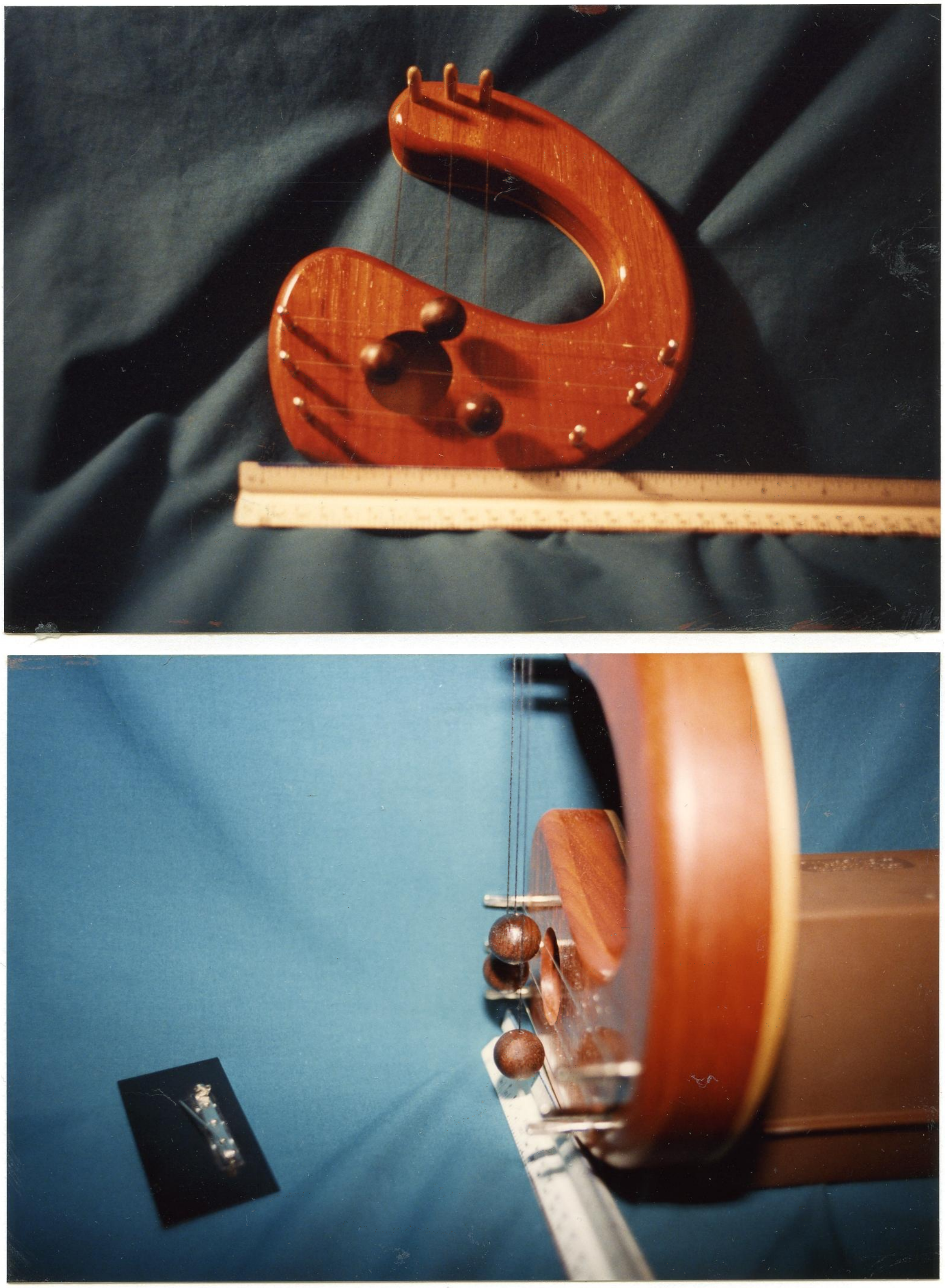


During a subsequent conversation with the thesis supervisor, it was agreed to concentrate on one apparatus and explore the student perceptions of that. A Newton's cradle was used in an informal exploration but did not produce worthwhile results.

By chance, the researcher came across an apparatus called a DOOR HARP. The middle of this instrument looks like a guitar, with a wooden box, a hole and three strings of different lengths and sizes, across it. However, it does not have a neck and frets as does a guitar; instead it has three similar wooden balls hanging by threads, which strike the strings as the harp is shaken normal to both the strings and the threads. Thus it looks like a strummed instrument such as a guitar, but is in fact a percussion instrument like a piano. Sound came not from striking keys or plucking strings but from moving the whole instrument. About 100 door harps had been sold in Miltown (conversation with store owner). Only one interviewee had seen a door harp.

It was felt that the unusual nature of the harp and its rarity would be a fertile sources of student ideas about sound.

Figure 2. Photographs of the Door Harp used for this Study



The interviewee was led to each apparatus in turn and asked about it. The interviewer tried to give as few verbal clues as possible--often referring, for example, to the door harp as a "gizmo"--as to the real use of the apparatus, so that the student's perceptions would be less likely to be tainted by those of the interviewer. The interviewer felt that the most difficult part of the interview lay in avoiding teaching.

As stated previously, this is a naturalistic form of research and it is the only research with Junior Secondary students in the field of Sound of which the researcher was aware. Therefore there were no specific hypotheses to be tested. Consequently, the exploration was more like a conversation than a formal interview. The interviewer used open-ended questions and interrogative paraphrases to explore these questions:

What do we mean by sound?

How does sound travel?

How do we hear things?

What do we mean by vibration?

How do the dimensions of an object affect its sound?

How is sound produced?

How are echoes produced?

The interviewer had a list of appropriate topics during the interview and tried to keep to that list. However he felt free to explore promising lines and cut off others; for example he had a long interview with a student clarinettist on how reed instruments work, and the interviewer shut down one interview when he began to suspect that the interviewee was deliberately giving answers that the student thought the teacher wanted.

In quoting from interviews, "I" refers to the interviewer; "S" refers to the student.

An example of a student trying to please the teacher:

i I Can we make sound point like that?
S Yes.
I We can?
S No

This researcher felt some difficulty in shifting from one topic to another without telling too much about either. Here are examples of such shifts:

ii I... How do we hear things?
S With our ears.
I Tell me more about what your ears do.
I How do you know when you are hearing something?
S I don't know.

Examples of circularity in descriptions:

iii I Let's see. The drawing on the board, are you hearing that drawing?

S. you can hear the different sounds.

iv I Great. What I want to ask you is this: What do we mean by the word "sound"?

I How do you recognise what is a high note and what is a low note?

S High notes are pitched a lot higher. They are shrill. Low notes are like a trombone or something.

I How do you recognise high notes?

S The pitch. You can tell high notes because they are like a shriek. They are higher-pitched. It would be like a woman screaming.

I How do you recognise a woman shrieking as opposed to a man bellowing?

S Your ears just pick it up.

### 3.51 Researcher's Subsequent Actions

Interviewing took place from May 1987 to February 1989. Interviewing ceased at that time because the biology teacher needed to teach 'Sound' in order to enhance his students' study of the human ear, and because the time available to complete this thesis was running out.

During Summer 1989, the Supervisor and the researcher agreed to computerise the thesis. The interviews' audiotapes were sent to a firm in Vancouver to be transcribed on to 3 1/2" discs. The researcher intended to take questions and answers from the disc and assemble them in the appropriate blocks. Unfortunately, a computer glitch developed in September 1989 which wasted five months.

The data was finally sorted out when the researcher took the typescript of the interviews into isolation and spent three weeks in Summer 1990 reading the data base, classifying the comments and entering relevant comments on 8x5 file cards. All the questions and comments about a particular topic were placed on one card then that card was reviewed using the conceptual profile from Bullard et. al. (1985).

When the research had been sorted, it was reviewed using de Bono's criteria to get a feel for the depth of student understanding of the topic of sound.

## 3.60 LIMITATIONS OF THE DATA

Only one field researcher was involved and so the study might well have been coloured by the unusual nature of the researcher's knowledge of sound and related phenomena.

The research apparatus were those commonly available in the school; for example, the oscilloscope was the only electronic item explored. The sample was drawn from only one community, one which is rather isolated. The community's industry has been primitive, requiring an unskilled labour force. The community has a very strong tradition of music, with international ramifications. The sample was drawn from only one school. No attempts were made to discover students' motivations for volunteering. The interviews took place in only one room and at only one time of day. The interviews had to be rushed. No attempt was made to measure or even to estimate the effects of fatigue on the participants.

# CHAPTER FOUR

# RESULTS OF THE STUDY

## 4. 00: OVERVIEW OF THIS CHAPTER

The purpose of this study is to identify some of the beliefs that children bring to the study of sound. The interview scripts were analysed to look for common responses to interview questions.

The analysis was organised around the major concepts of perception, vibration, frequency, pitch, transmission and echoes. These concepts formed the framework of the exploratory interviews.

When the researcher analysed the students' responses, he found that their classifications did not quite match either of the two profiles discussed in section 3.10. Therefore, he put together the findings in a profile based on student understandings; that profile, along with illustrative components, forms Section 4.20.

## 4.10 USE OF PROFILES

From a scrutiny of Science Probe 8, supplemented by his own academic studies in the field, this researcher arrived at a list of six topic areas which provided a basic framework for use in each interview. The six-topic list is located in Section 3.10.1 of this thesis.

During the interviews, the researcher had a paper with the topic areas before him, to be used as the framework for each interview. In practice, the actual substantive issues raised in each interview depended on what equipment was in use. With that in mind, there were three interview types: the early one in which students explored apparatus ranging from a ball on a thread to an oscilloscope; the middle, very productive, interviews in which the researcher and the student just talked about sound; the third interviews based on the door harp.

Because the research was about what students thought, the subconcepts of the above profiles came from the students' answers. The sum of the responses in the thesis would not be the same as the number of responses on tape, because many responses overlapped categories, so that one response could involve two or more subconcepts.

## 4.11 A Conceptual Profile of Students' Understanding of Sound

1. Human Sound Perception
2. The Energy of Sound
3. Pitch versus Loudness
4. Perception of Pitch
5. Audible Range of Frequencies
6. Vibration
7. Responses to Vibration Frequency
8. Frequency and Musical Instruments
9. Air as Transmission Medium
10. Echoes
11. Waves Without Oscilloscope; Compressions and Rarefactions
12. Student Perception of Oscilloscope Trace.

## 4.20 ANALYSIS OF DATA

Since this appeared to be the the first research in the field of Junior Secondary students' perceptions of sound, the researcher tried to keep his perceptions out of the interviews and, particularly, out of the interpretations of interview data. A key problem, of course is that despite what John Locke (and some of the researcher's friends) have said, the researcher's brain is not a blank slate. One of the key problems of measurement is that the instrument affects the measurement; therefore one can only minimise such an effect, not obliterate it. To reduce the effects of the researcher's input, he tried to isolate the comment by the student and to include the interviewer's question or comment only where it was needed to clarify the student's comment.

Therefore the database of interview typescripts was regarded as a source of student statements about sound rather than as a record of conversations.

Subsequent to the interviews, the researcher reviewed the database and copied each student statement about, say, "pitch" onto an eight-by-five card dedicated to "pitch"; eventually he had 148 statements about "pitch" on eleven cards. Each statement on the card was coded with the student, the apparatus in use and the page of the database where the statement was to be found. This procedure was carried out for each topic on list 3.10.2.

When the cards had been made up, each card or set of cards dedicated to a topic was reviewed again to find patterns or consistencies among the statements. These categories became the topic list noted as 4.11. Once this topic list had been assembled, the statements associated with each topic were scrutinised for key beliefs about that aspect of sound.

When the researcher had found patterns from the students' topic profile, he reorganised them into the profile noted as 3.10.2.

The symbols in brackets after each quotation e.g "(123)" gives the page of the database where the quotation is to be found.

1. Human Sound Perception.

Major Research Question: How do students think we hear?

Subconcepts: (A) Air as Medium

(B) The Role of the Ear.

A. Air as Medium

Of the thirty-three relevant responses, only two describe sound as a property of air. Most other responses indicated that sound travels from source to receptor without involving the air between them. Examples of this kind of response include:

i I: How do you think sound is getting from the (tuning) fork to your ear?

S: By the hit of the two ends which make it vibrate.

I: Did you say something vibrates between the fork and the ear?

S: The vibration of the two ends.

I: And how does the vibration get from there to our ears? Any ideas?

S: No. (30)

ii I: How does sound travel?

S: I'm not sure. Probably, once you make the noise,it travels in sound waves. I don't know how to explain that. (14A)

B. Knowledge of the role of the ear.

There was a wide range of knowledge ranging from:

I: Tell me more about what our ears do.

S: I don't know. (6A)

to:

S: The noise goes into your ears. It goes in the inner ear, the eardrums, and there are bones in your ear. They vibrate. (9A)

<u>2 The energy of sound</u>.

Major Research Question: Do students recognise that sound is a form of energy ?

A child recognises energy merely as movement. Therefore, in exploring students' ideas about sound as energy, this researcher looked for links between sound and movement.

Subconcepts: (A) Local movement, as in the tines of a tuning fork.

(B) Translational movement, as in how far a sound is audible.

A. Local Movement

Of approximately eighty responses relevant both to sound and to movement, thirty said that sound was caused by hitting; tines hitting air, balls hitting wires and so on. Examples of this kind of response include:

i I: What could that ( the differences in sound of two differently-sized tuning forks) be due to?

S: The longer one is hitting more of the air.

(2)

ii I: How do they make music?

S: They hit the metal.

(4A)

iii S: Kind of things like that, wires and hitting them. (45A)

B. Translational Movement

Thirteen responses related sound and distance; they include:

i I: What do you notice when I pull the (sonometer) string quite a long way down, compared with when I pull it a tiny way down?
S: It's a lot louder when you pull it all the way down.
(6)

ii S: Higher notes have higher speeds.
(3)

iii S: Loud noise has a larger volume.
(52)

iv I: ... with the ping-pong ball. What do you think should happen when we hit it with the 320E tuning fork?
S: It shouldn't go as far.
I: What's happening?

S: It goes further.

I Why do you think that is?

S: Because it goes slower so they can make more distance. (27)

3. Pitch versus Loudness.

Major Research Question: Do students perceive the amplitude and the pitch of sound as two separate factors, or are those two factors perceived as one?

Subconcepts: (A) Frequency

(B) Amplitude

(C) Together

A. Frequency

Only one comment mentioned frequency spontaneously; therefore the researcher looked for synonyms. Examples of relevant comments include:

i S: Smaller fork can give out a higher note because the tines move faster. (5A)

ii I: What do you mean by tone?

S: Whether it is a high or low tone. Its volume is another way I recognise (sound) iii I: What do you mean by higher and lower?

S: Well it does not have any effect on how loud it is.

I: Give me an example of a high sound.

S: A piano. If you go further up the scale it gets higher.

I: Can you make a high sound then a low sound?

(Student demonstrates properly)

(9A)

iv I: When some thing is vibrating fast, how does that sound to us?

S: High-pitched and it hurts your ears a bit. Hard to listen to. (46A)

B. Amplitude

Few comments mention amplitude in isolation; examples include:

i S: The noise gets louder when the wire is pulled a lot. (22)

ii S: As the working length of the string is reduced, the noise gets louder. (36)

iii S: If we made the click wheel go faster, the sound would be louder. (23)

C. Many comments integrated amplitude and frequency; examples include:

i S: The note (from the sonometer wire) is higher when you pull it a little bit compared with when you pull it a big amount. The noise gets louder when the wire is pulled a lot. (22)

ii S: Smaller fork can give out a higher note because the tines move faster. When the sonometer wire goes quickly, the sound gets louder. (5A)

iii S: The lower the note, the more power it should have. (27)

iv Whilst observing the oscilloscope:

S: The higher the note, the longer the lines go.

I: Try this.

S: They are much shorter.

I: Shorter up and down or shorter across?

S: Up and down. They seem longer.

I: Longer up and down or longer across?

S: Longer across. Shorter up and down.

(33)

v S: The waves seem to widen as you bring the tuning fork closer.

I: Wider across or wider up and down?

S: Up and down.

(35A)

vi I: What would you say about the width of the waves?

S: As they go up, they increase up and down. They seem to get wider.

I: They seem to get wider across the screen?

S: Yes.

(25A,26A)

4. Perception of Pitch.

Major Research Question: Do students perceive pitch strictly as a phenomenon of frequency?

Subconcepts: (A) High notes

(B) Low notes

(C) Causes

Of the over 140 comments about pitch, only a few related the phenomena of high and low notes to rapidity of vibration. Most students recognised high notes by analogy with another phenomenon, such as a shriek. In addition some comments, particularly those relating to pull, force and pitch seemed paradoxical; for example one would expect the strength of the pull on a sonometer string to have an effect on the amplitude of the note rather than its pitch. Examples of this kind of response include:

A. High Notes

A surprising feature of replies in this category was the number of circular descriptions; examples include:

a. Recognition

i S: High notes are high-pitched, like a shriek. (39)

ii S: High notes are pitched a lot higher. They are shrill. (39)

iii S: High pitch is squeakier. (2A)

b. Characteristics

i S: High notes travel at high speeds. (3)

ii S: Higher note lasts less time. (27)

iii S: High sound vibrates quickly. (quoted by four students)

iv S: Small fork or ruler gives high note. (quoted by seven students)

v S: High-pitched sound is like choppy water. (55)

vi S: A twang is a high note. (40)

B. Low Notes

a. Recognition

i S: Sound is low. I can't really explain it. (26)

ii S: Voice and ocean are both called deep,because both are low down. (2A) iii S: Low notes are like a trombone. (38)

b. Characteristics

i S: Deeper notes take longer to stop. (21)

ii S: Deeper note has further-apart waves. (28)

iii S: Lower-pitched note has more stretched-out waves. (29A)

iv S: Low notes have a space. (10A)

v S: Deeper notes have more power. (27)

C. Causes

i S: Recognise a flute in a dark room by high notes. (39)

ii S: High note caused by tines hitting harder. (3)

ii S: Tone higher because less wire vibrating. (6)

iv S: Long fork makes different sound because it needs more space to vibrate in. (17)

v S: Smaller pull on sonometer wire causes higher note. (22)

vi S: Clarinet's low pitch is caused by letting less air inside. (45)

vii S: Longer clarinet tube gives longer note. (51)

5. Audible Range of Frequencies.

Major Research Question: Are students aware that some sounds are inaudible?

Subconcepts (A) Audible amplitude

(B) Audible Frequency

Examples of this kind of response include:

A. Audible amplitude

i I: (looking at oscilloscope) is there a time when you cannot hear the tuning fork but you can still see a wave?

S: Yes, right now.

I: What does that suggest about the way we hear things?

S: Our ears don't pick up all the sounds.

(28)

B. Audible Frequency

i S: Some animals, like dogs, can hear pitches that people cannot hear. (9)

ii S: The high note can pierce a dog's ear. Most humans can't get up that high. (60)

6.Vibrations

Major Research Question: what factors, of which students are aware, control the frequency of a vibration?

Subconcepts: (A) Longer vibrator gives lower notes

(B) Tine thickness affects vibration rate

(C) The vibration rate of a string is controlled by its dimensions

(D) Cavity Resonance

A. Longer vibrator gave lower note

Fourteen of the seventy or so relevant statements generated agreed with this. They included:

i S: Tine length lowers sound because it needs more room to vibrate. (17)

ii I: Suppose you had several tuning forks. How could you predict what notes they would give out?
S: By the thickness and length of them. (18)

iii S: (With ruler overhang extended from 60cm to 70cm) the note is way lower and way slower. (35)

B . Tine Thickness is important in controlling the rate of vibration.

Four responses agreed. They included:

i S: Thickness of tine does not let fork vibrate slowly enough. (18)

ii S: Thinner tine gives deeper note. (25)

iii S: Shorter fork gave out deeper sound because the handles were longer. (28A)

C . The vibrations of a wire are controlled by its dimensions.

Eight responses agreed with this statement. They included:

i S: Sonometer tone is higher with closer bridges, because less of the wire is vibrating. (6)

ii S: because (the string) is not as long, they can't vibrate as much so it is higher. (12A)

iii I: Why do you think (a thick wire) would give out a deep note?
S: Because it would make it vibrate slower.
I: Why do you think it might vibrate slower?
S: Because it is thicker and not so easy to bend. (45A)

D Cavity Resonance

Although only a couple of students referred to this, their comments suggest some difficulties with perceiving air as an oscillator; examples of such include:

i I: Tell me how a clarinet works... what do the holes do?

S: They cut off air to certain keys. Every key you put your finger on makes the note lower and lower...

I: How does this make the note lower?

S: Less air is getting inside. (45)

ii I: What does opening and closing the hole do to the length of the clarinet?

S: Nothing. (47)

iii S: You need a vibration to get a note.

I: ... if you get different notes from blocking different holes,you must get different notes from different holes. Is that true?

S: I am not sure. I don't think so. ...

I: The longer the tube the longer the note. Is that what you are saying?

S: Yes....

I: How do you think that changing the length of the tube in the clarinet changes the vibrations?

S: When you blow into it, it vibrates from the reed, it vibrates through the tube, and it vibrates out and it spreads. (51)

iv I: Is it possible to have two flutes the same shape and size but blow different notes?

S: Yes, ... by making the tube longer or shorter.

(28)

v I: What is in the tube?

S: Air.

I: What do you think the tube is doing to the air to make the sound more concentrated?

S: I don't know. (47A)

vi I: How does a clarinet have those vibrations?

S: As its travelling through the air, travelling through, it's blowing against it and the keys that made it. (59)

7. Responses to Vibration Frequency.

Major research question: Of four ways to look at frequency (rate of change of field intensity, tally of cycles completed every second, as the cause of pitch or characteristic of vibration) which do students perceive? CAVEAT Since only one student used the word "frequency" spontaneously in about four hours of interviews, this researcher looked for synonyms, such as vibration, pitch and tone.

Subconcepts: (A) vibration
(B) pitch
(C) tone

A. Vibration.

a. It is clear that vibration is a familiar concept, since many students mentioned it spontaneously. Examples of this kind of response include:

i I: What do you notice about the overhanging ruler?

S: It vibrates. (22A)

ii S: The harp vibrates when (the ball) hits it. (36A)

iii S: When a person speaks, the vocal cords vibrate. (41A)

b. When asked to define vibration, students' concepts seemed to agree with with those of the science texts consulted by the researcher. Although the texts did not define vibration per se, they implied that vibration is a movement about a point, regular both in distance and in time. Examples of student concepts include:

S: Motion going back and forth. (40-41)

S: A movement, basically side-to-side, or up and down (54) c . Some responses gave the researcher the feeling that students perceive sound as something carried by the vibration but not produced by it, much like a surfboard carried by a wave. Examples include:

i S: It makes sound because of two forks vibrating. (17)

ii S: (a guitar) creates sound from vibration on the strings.. (40)

iii S: A little vibration would hit the other strings and and make a sound. (40-41)

iv S: Speech and noise create sound. (37)

B. Vibration and Pitch

Vibration was frequently used as a cause of pitch, particularly that a higher pitch was a consequence of faster vibrations. Examples include:

i S: (The sound of the clickwheel) will get a higher pitch as the wheel goes faster. (24)

ii S: It would go higher...because it vibrates more. (37A)

However, many descriptions seemed almost circular:

i    I: How do you recognise a high-pitched note?
     S: It is pitched a lot higher. (39)

ii   S: Sound is the noise something makes. (60)

     I: What do you mean by higher and lower (pitches)?
     S: Higher is, well, it does not have any effect on how loud it is. It is a higher sound. (9A)

C. Only two students referred to tone, one as pitch (54) and the other as loudness (29A-30A)

8. Frequency and Musical Instruments.

Major Research Question: What do students know of the production of sound by musical instruments?

Subconcepts:(A) Sonometer
(B) Door Harp
(C) Clarinet

Only five of the fourteen interviewees had worked with musical instruments. Instruments included clarinet, flute, guitar, piano and voicebox. A megaphone was mentioned by one student. Each student mentioned vibrations in explaining how the instrument worked.

A. Sonometer

Some ideas unexpected by the researcher were related by students. Examples include:

i I: Why do you think the tone sounds higher when the distance between the bridges is shorter?

S: Less of the wire is vibrating.

(6)

ii S: You pull (the sonometer string) a tiny bit and the note is higher than if you pull it a big amount.

iii I: Which part of the wire would you say is vibrating the most?

S: The part of the wire on the far side of the bridge from the finger. (36)

iv I: ... ( the pitch of the note) seems to go up when?

S: When you pull the bridges apart, the pitch goes up.

I: So what happens when I bring them in?

S: They go lower.

(25)

v I: Which instrument does the sonometer remind you of?

S: The oboe.

(32A)

B. Door Harp

Although this instrument was new to many students, they seemed to recognise that it worked by percussion. Examples include:

i I: And what do the balls do as they hit the string?

S: They make music.

(4A)

ii I: What do you mean by vibrate?

S: It goes through the whole piece of metal.

I: What does?

S: When it hits, it goes straight through.

(4A)

iii S: If you turned them (the keys) you could tighten the strings or loosen them and probably change the pitch. (11A)

iv I: What do you think the tightness does to the wire to make it give off this noise?

S: It stretches it.

I: How does stretching make it give off noise?

S: I don't know.

(36A)

C. Students who play the Clarinet or the Flute.

The wind instrumentalists produced some variations which surprised this researcher. The first two examples appear to demonstrate inconsistent ideas:

i I: Is it possible to to have two flutes the same shape and size but blow different notes?

S: Yes.

I: How would you do that?

By making the tube longer or shorter.

(28A)

ii I: What does opening and closing the hole do to the length of the clarinet?
S: Nothing.

(47)

iii I : How does (covering the holes) make the notes lower?
S: Less air can get inside.

(45)

9. Air as a Transmission Medium.

Major Research Question: Do students recognise that, in everyday life, air is needed for the transmission of sound?

Subconcepts: (A) Air must vibrate to transmit sound.
(B) Sound cannot usually be transmitted in the absence of air.

A. Air must vibrate to transmit sound.

Many students recognise the need for vibration in the air. Examples of this kind of response include:

i The longer (tuning fork) is hitting more of the air. (2)

ii S: Vocal cords make sound in air by vibrating. (42A)

iii S: It is important that the clarinet reed vibrate the air.

(42A)

B. No air means no transmission of sound.

Some students, however, do not recognise that the absence of air causes the absence of sound. Examples include:

i I: Why is there no sound in space?

S: Can't hear in space because it is too far away. (34A)

ii I: Could two people sitting a metre apart in space hear each other?

S: Probably.

I: How?

S: The same way.

I: Explain it to me.

S: if someone is talking you can
hear him down here and you could
probably hear him in space. (35A)

iii I: Tell me. If we were in space would we
be able to talk like this?
S: Not unless we were in an enclosed room.
I: What would that do for us?
S: It would probably make the sound echo
louder.

(16A)

10. Echoes.

Major Research Question: How do students think of echoes?

Subconcepts: (A) Sound can bounce off objects
(B) Some effects of those bounces.

A. Sound can bounce off objects.

Most students were aware that an object is needed to bounce a sound back. Examples of this kind of response included:

i S: Echoes come from mountains when sound bounces off something and comes back to you.

(13A)

ii S: An echo is where you make a noise and it would hit somewhere, the noise would probably bounce off something and it would come back to you and you would hear it again.

(18A)

B. Some effects of these bounces

Some students recognised that the time for which a note was heard might involve echoes. Examples include:

i S: Sound bounces back and repeats itself as it gets louder.

(13A)

ii S: Noise of the door harp string could hit the end (stops?) and bounce back.

(18A)

iii I: Do you know anything of the wood of the door harp ?

S: It's hollow. It gives a better sound ... because the sound goes through it and back out ... the box echoes the sound.

(40A)

iv S: The echo box is like an amplifier.

(40A)

<u>11. Waves. Compressions. Rarefactions.</u>

Major Research Question: How can the teacher in Miltown expect his students to think of sound waves?

Subconcepts: (A) Sound travels in waves

(B) Sound waves are alternate zones of compression and refraction

(C) Ocean surface waves as a model for sound waves.

A . Sound travels in waves;

This seemed to be well understood. Examples include:

i S: Vibration is caused by sound waves in the air.

(7A)

ii S: Vibration and waves are linked, because both help sound travel.

(16A)

iii S: Sound waves carry sound to our ears. When noises are made, they go off. I guess they go into the air or wherever and you can hear them.

(56)

B. Sound waves are alternate zones of compression and rarefaction.

No student described sound waves as alternate zones of compression and rarefaction. There were however, student perceptions which could be developed from the idea of hitting into that model. Such perceptions include:

i S: Sound is made as nails hit paper.

(1)

ii S: Continuous clicking would make a musical note.

(1)

iii S: Sound gets from fork to ear by hit of two ends.

(30)

C. Ocean surface waves as a model for sound waves

Only two students compared sound waves with ocean waves. Examples include:

i S: Sound is like waves in the ocean. (55)

ii S: Sound is soft and wavy. (55)

iii S: If it is high pitch, it will go like choppy water. (55)

iv I: You said (ocean) waves travel in ripples.
S: The sound waves would travel in individual lines. Any kind of motion that would make the sound travel towards the earth. (15A)

12 Student Perceptions of Oscilloscope Trace.

Major Research Question: Does a student read an oscilloscope in the same way as does the science teacher?

Subconcepts: (A) Do students recognise the height of the waveform as proportional to the amplitude of the sound?

(B) Do students recognise the width of the individual wave as proportional to the pitch of the note?

A. Do students recognise the height of the waveform as proportional to the amplitude of the sound?

There are few clear examples where the height of the waveform is ascribed to amplitude. Examples include:

i S: Harder strike produces waves of the same horizontal distance apart but higher. (22)

ii S: The louder the talk, the taller the waves get. (31)

iii S: Waves seem to widen up and down as tuning fork brought closer. (25A)

B. Do students recognise the width of the individual wave as proportional to the pitch of the note?

There were only two examples :

i S: Wave crests are closer with a higher-pitched note. (5)

ii S: Lower frequency gives wider-across waves. (26A)

## 4.30 SUMMARY OF CHAPTER FOUR

This chapter has reviewed the topic lists involved in the research and has organised student comments about those topics so that the researcher has been able to deduce possible patterns of preconceptions held by students about sound.

The results are discussed more thoroughly in chapter five.

# CHAPTER 5

# CONCLUSIONS AND DISCUSSION

## 5.00: INTRODUCTION

This chapter summarises the study, states its general conclusions, draws educational implications from those conclusions, suggest further research and attempts to put the study into a perspective from a classroom.

## 5.10 SUMMARY OF THE STUDY

The purpose of the study was to attempt to obtain a better understanding of the beliefs about sound held by students in grade eight prior to formal instruction. The literature of science education was searched extensively for material on sound; in 1987, when this study was started, no relevant literature was found, and so this study became a natural history of student perceptions about sound. Details of the techniques and the findings of the study were given in chapters three and four. As this study was being carried out, studies by Gustafson (1988) and Linder (1989) were published;

these studies were reviewed to seek commonalities with this study.

## 5.20 CONCLUSIONS OF THE STUDY

### 5.21 Broad Patterns of Student Beliefs about Sound

Since this study is intended to be for the use of classroom teachers, it is appropriate to arrange the broad patterns of belief in the format of the topic list from Bullard, Baumann, Deschner, Gore, McKinnon and Sieben, (1985).

Using the goals and key ideas of Chapter Nine, Sound, from Science Probe Eight, presented in section 3.10 of this study, the following broad patterns of student belief about sound were identified:

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1. Know that sound is a form of energy.

Thirty responses in eighty suggested that sound was caused by hitting; tines hitting air, balls hitting wire and so on.

Thirteen responses related sound and distance. Higher notes had more energy and were ear-piercing, travelled faster and were caused by the tuning-fork tines going faster.

No student mentioned the Kinetic Molecular Theory.

That no student cited the Kinetic Molecular Theory in connection with sound strongly suggests that students either have not been introduced to the theory or do not relate it to sound. Both suggestions are surprising, since the theory has been introduced to the students and sound is a product of molecular motion.

2. Know the difference between pitch and loudness.

In breaking this topic down to its subconcepts, it appears that most students think of pitch and amplitude as one phenomenon. Few considered pitch and amplitude separately. When the oscilloscope was used, there was considerable confusion about the terms "height " and "width". Many students seemed to think that "width" referred to the vertical magnitude of the display, whilst other students described the same separation as "height". Students seemed to have much mental difficulty in isolating a particular cycle from those displayed.

It seems, therefore, that there are semantic difficulties in this field which should be addressed when students are attempting to learn about sound; it seems, also, that there are difficulties in student observation of the typical laboratory oscilloscope. Stevens (Bruner,1984,p. 74) found that changing the amplitude, whilst holding the frequency constant, could slightly shift the peak of resonance; in short, that frequency is not independent of amplitude. This, in turn, leads to the possibly heretical conclusion that children's perceptions of sound might be more in tune with reality than are scientists'. If this is true in other fields of science, then the thrust of Constructivism might have to be reversed, so that scientists' preconceptions are brought into line with those of children.

3. Realise that only certain frequencies are audible.

Students were aware that some animals can hear pitches inaudible to humans. However, in the absence of an appropriate signal generator, the researcher was unable to explore this knowledge further. Some students realised that a sound can be inaudible because its amplitude is too low, yet still be visible on the oscilloscope display. One can conclude, therefore, that (in the terms of Gustafson's students) an oscilloscope could be used to develop "learning" about inaudible sound into "knowledge".

4. Know what "frequency" means.

Only one student used the term "frequency" spontaneously. However if that term is changed to vibration, then many students appear well-acquainted with the phenomenon, since many students used the term without prompting. Of the seventy or so relevant responses, fourteen indicated that longer vibrators gave out lower notes. Four responses indicated that the thickness of tines partially controlled the rate of vibration. Some students were aware that the length, thickness and tension of a wire controlled the note it gave out.

If "pitch" is substituted for "frequency", then faster-moving tines or wires cause higher pitches. In many comments, pitch and amplitude were either integrated or confused. High notes were described circularly, for example, "Higher notes are higher-pitched" and low notes were described as having more power or harder to stop. Vibration was frequently described as the cause of pitch.

A rather more serious conclusion might be drawn from the contrast that, whilst "frequency" was used extensively by the text authors, it was used only once by students; the conclusion is that some curriculum designers and writers are not in touch with student thinking.

5. Appreciate how different frequency sounds are produced in musical instruments.

The musically-experienced students thought of a musical instrument as a rod with holes. Each student regarded vibration as the cause of the notes. This researcher could not elicit the student view of an instrument as a tuned resonant cavity. Students did not explain why changing the hole configuration changed the output note.

If the sonometer is accepted as a paradigm of stringed musical instruments, then one can conclude that students are aware that the dimensions of the string affect the note given out. Comments about the door harp suggest that students are aware that the box of the instrument can affect the note given off.

6. Understand the nature of sound transmission--realise that sound requires a medium in which to travel, and will not travel through a vacuum.

In describing the act of hearing, only two responses of more than thirty described sound as a property of air. As stated previously, no student invoked the concept of air as a molecular material. Most other responses indicated that sound travels from source to receptor without involving the air itself.

Many students recognised the need for vibration in, not of, the air in sound transmission. Indeed, no student who had been asked thought that air was needed for sound transmission.

7. Know What an Echo Is.

Most students were aware that a transmitted sound can bounce off a large object and be received by the sender. Some students recognised that sound can bounce off the ends of a sonometer wire and thus prolong the wire's reverbration time. Students who looked at the door harp were aware of the role of the echo chamber in enhancing the harp's sound. Indeed, one student compared the chamber to an amplifier.

8. Realise that sound is carried by wave motion, and that sound waves consist of compressions and rarefactions in the particles making up the medium carrying the sound

One can conclude that the idea that sound travels in waves seems to be well learned, if not well understood; however, few students seemed to have a clear idea of the structure of a sound wave. One student compared sound waves to ocean waves, with high pitches being like choppy water.

No student referred to compressions or rarefactions, although many referred to oscillators "hitting" the air.

This researcher felt that a student's conception of sound waves is that they pass through the air without affecting it, just as a light ray goes through a piece of glass without, apparently, changing the glass.

9. Be familiar with the display of several different kinds of sound on an oscilloscope screen.

As stated previously, there seem to be some semantic difficulties with terms such as "high', "wide" and "deep" to describe the appearance of the traced part of the screen. There was considerable difficulty, perhaps because of the fluctuating nature of the display, in drawing the form of a particular wavelength to the attention of the student; thus one can conclude that the popular oscilloscope needs to be re-designed in order to ease the student's observational tasks.

10. Key Ideas.

As well as goals, the chapter has key ideas listed in section 3.10.2. They need no repetition here.

Notes on Key Ideas

Most key ideas are parts of the patterns already mentioned in this section. However, this researcher deliberately refrained from using terms such as "Hertz" and "Infrasound".

There was no opportunity to compare speeds of sound in different materials; however one student suggested that high notes travel faster.

Students demonstrated awareness of natural frequency in such statements as "shorter tines vibrate faster", but no attempt was made to generalise that awareness.

Summary of Section 5.21

In this researcher's opinion, the most troubling of the students' preconceptions (not in any particular order) are:

Students use the term "wave" to describe sound yet few have an image of a wave.

Students imagine sound travelling through air but not involving that air.

Students do not invoke the idea of air being in particle form.

Students perceive pitch and amplitude as one phenomenon.

There is considerable semantic confusion about phrases such as "a high note"; it is unclear whether the height refers to the frequency or to the amplitude.

5.22 Conclusions of the study - General

In considering the merits and otherwise of the techniques used for gathering data in a natural history, it seems that the Piagetian interview, with its open-ended questions, is a technique preferable to a formal, paper-pencil questionnaire. This is so partly because the latter is both too deeply organised by the researcher's conceptual ecology and so can taint the student's mental processes by encouraging--if not demanding--both answers at random and suggested conviction (Piaget,1982, p. 21-2). The Piagetian interview avoids the complications of the student's possible reading and writing difficulties, and can give information to the interviewer by body language. However, as Piaget himself pointed out, it takes at least a couple of years for the interviewer to become reliably perceptive, for many signs are subjective and difficult to put into a form available to outside scrutiny. This researcher did not feel confident enough in his observational skills to include them in this study.

The analysis of the typescripts yielded much data; however the validity of that data is open to question, since this was a first study and there is little or no comparable data to inform one of researcher bias, effects of musical training, ideation specific to this isolated coastal community or even if some subtle condition, to which the researcher was oblivious, was controlling the sample self-selection.

In view of the commonalities found by three different investigators of student perceptions of sound (mentioned in sections 5.32 and 5.33), in widely different locations and age cohorts, it is reasonable to accept, for the time being, that the interviewing and analysis techniques carried out in Miltown were appropriate.

The most relevant of the student perceptions found by this research include:

1. Sound travels through air, but is independent of it.
2. Students use scientific words with some fluency, but with little clear ideas of their meanings (de Bono might refer to these terms as "porridge" or "give-it-a-name" levels).
3. Waves are seen as surface phenomena; little structure is implied.
4. Words are used ambiguously, for example "high" can refer to frequency or to amplitude.
5. Students appear unaware of inconsistencies of belief about the same phenomenon, such as bringing a sonometer's bridges closer will make the note lower--a few minutes later the same student says the same action will make the note higher.
6. Students did not spontaneously relate the phenomena of sound to the Kinetic Molecular Theory.
7. Few students recognised cavity resonance; this implies that they perceive the wood of the clarinet as matter, but not the air inside it as matter.

8. Some students seemed unaware of the circularity of their descriptions.

9. Many students did not relate the compressibility of air to the phenomena of sound.

10. Students were able to make sense of an oscilloscope trace, although there was the expected semantic confusion about, for example, the word "high". No attempt was made to find out if students were aware of the effects of timebase selection on the display.

## 5.30 EDUCATIONAL IMPLICATIONS

### 5.31 Implications By Category

#### 1. Know That Sound is a Kind of Energy.

Student lack of awareness of the Kinetic Molecular Theory suggests that greater efforts should be made to ensure that students are well aware of the theory before they embark on the study of sound. One way in which to do this might be to regard sound as heat made coherent; this would imply that a teacher should attempt to tie the study of sound in with the study of heat rather than, as is traditional, with the study of light.

Another problem is that "energy" is not taught until Grade Nine on the " Science Probe " scheme; therefore, in calling sound a form of energy, the teacher might well be relating the unknown of sound to the unknown of energy! The fuzziness of such a relationship might go far to explain why some students, even at university, confuse motion with energy (recall that even kinetic energy needs mass!).

2. Know the difference between pitch and loudness.

Although many students recognised a high (frequency) note, and several students were well aware of vibration, only a few students related the two. Instead, several descriptions of high pitch resorted to analogy, such as "like a shreik"; this might tie in with Johnson Abercrombie's finding that the earlier a concept forms the harder it is to bring to consciousness. If children form their ideas of pitch whilst learning to speak, then those ideas might well be too hard (or even too far separated in time) to relate with ease to such relatively new concepts as vibration.

Many students seemed to think of amplitude and pitch as an integrated phenomenon. This researcher can think of at least four hypotheses why that should be:

1. Steven's finding that resonant frequency can be shifted by amplitude change (Bruner,1984, p.74);
2. they are, in fact, part of the same phenomenon in everyday life, for example, the phrase, "come here, you

little monster" will be phrased differently, both in pitch and in amplitude, depending on whether the teacher is speaking to a student or to a lover;

3. it might be an example of the difficulty some students have in the late concrete operational stage in manipulating two variables simultaneously;

4. it might be semantic confusion over the use of the words "high" and "low" , as in, " Lower your voice when you talk to me", and, "Sopranoes, try to sing a semi-tone lower".

One way to deal with the confusion might be to use an oscillator set to a certain frequency and change the amplitude of its output, then set the amplitude and change the frequency. Of course this assumes that the human ear has a linear response to frequency changes and a linear response to amplitude changes. This researcher's recollection from his training at Locking is that the ear does not have a linear response to amplitude.

3. Realise that only certain frequencies are audible

If this concept is to be developed "scientifically" then the most likely technique will involve both a variable oscillator and an oscilloscope. The oscillator is likely to be a

" black box", with its workings taken on trust, and the student perception of the oscilloscope ( as was seen in category 9) is not quite as simple as could be expected.

4. Know What "Frequency" Means.

As stated previously, the term has at least four meanings. Only one student used the word spontaneously. There was some difficulty in having the student concentrate on one waveform among the many on a rapidly-changing display. It has been suggested that the latter problem could be overcome with the development of an oscilloscope with a liquid crystal display; however, such a machine would be restricted to audio frequency, since the minimum reverse time for its elements is one millisecond.

The term "vibration" is more familiar to these students than is the term "frequency" and so it might be more productive to use the former term in discussing the phenomena of sound.

5. Appreciate how different frequency sounds are produced in musical instruments

The students who were familiar with musical instruments were aware that changing the hole configurations changed the notes produced. None of those students thought of the air in the instrument oscillating on its own, yet were happy with the idea of the wood vibrating; this researcher feels this could be a product of a possible student belief that, whilst wood is matter, air is not. This implies that the teacher should be careful to ensure, perhaps by demonstration, that students know that air is matter.

6. Understand the nature of sound transmission--realise that sound requires a medium in which to travel, and will not travel through a vacuum.

Since no student described air as a molecular material, it appears that this is a point to be emphasised when starting the unit on sound. Aspden's interviewees echoed Linder's in regarding sound as a phenomenon which passes through air but is not a phenomenon of air itself. This would appear to demand that the teacher demonstrate that air is needed for sound to be heard.

7 .Know what an echo is.

Since most students seem to be aware that an echo can be created when sound bounces off a large object, this topic, in itself, needs no unusual emphasis. However, some students perceived sound as bouncing off the ends of the sonometer wire; this might prove a fruitful way in which to introduce the concept of cavity resonance, needed to describe how musical instruments work.

8. Realise that sound is carried by wave motion, and that sound waves consist of compressions and rarefactions in the particles making up the medium carrying the sound.

The idea that sound travels in waves seems to be well known. What is not so clear is the student's mental picture of a wave. A couple of students mentioned waves on the surface of the ocean; yet such waves are transverse, whilst sound waves are longitudinal. It would seem appropriate, therefore, to include a lesson on the various kinds of wave, based, perhaps on the demonstration in the chapter on earthquakes in Science Probe 10.

No student referred to compressions and rarefactions, although the idea of tines hitting the air might be a useful lead in. Newton's cradle might be another lead; however, there might be some difficulty in persuading a student that steel balls are elastic.

9. Be familiar with the display of several different kinds of sound on an oscilloscope screen.

As stated previously, when observing and describing the trace, and relating it to heard sound, there is some ambiguity about ideas such as "high" or "wide". Such ambiguities might be resolved by science people agreeing to a convention about the use of such words; as an interim measure, science teachers might seek the advice of English teachers on such language. This researcher feels that much of the problem stems from the fact that an oscilloscope trace is visually unstable when it displays sound in real time; consequently, it is very difficult to draw a student's attention to an aspect of the display such as the shape of a particular wave. One suggestion to overcome this difficulty is that an oscilloscope strictly for sound demonstrations should be designed; such an instrument might have a liquid-crystal display, fed from a digital sampler and memory of the input signal. One problem with such displays is that an element takes approximately a millisecond to cut in or out; however, elements of the human eye take more than a centisecond to change, and so the display change time would be imperceptible to the human eye. Such a design would let the teacher select and manipulate a specific waveform, simply by manipulating the input memories.

5.32 Commonalities with Gustafson's Study

Both Gustafson's and Aspden's students thought that movement was needed for sound. Some students in each group related the loudness of a sound to the energy going into it. Some students in each group recognised that manipulating the keys of a musical instrument manipulates the notes given off by that instrument. Students in both groups recognised that echoes need big walls and large spaces. Some of Gustafson's students and many of Aspden's stated that sound travels in waves.

5.33 Commonalities with Linder's Study

Both Linder's and Aspden's studies found students who thought of sound as travelling through, but not an organised movement of, air. Linder's subjects recognised the compressions of air needed for sound, but Aspden's subjects did not.

5.34 Thoughts with de Bono in Mind

When this researcher used de Bono's Levels of Understanding to estimate depths of student understanding, he became aware that many expressions seemed to be used glibly, with little understanding on the part of the student. This implies that far more probing should be done of students' answers; such seems obvious to most teachers but some curricula seem to base much of their contents on dictionary-type definitions.

Use of such strictly lexical material would go far in explaining why many descriptions tend to be circular, such as "High notes are pitched a lot higher" and why students appear to be unaware when they contradict themselves when explaining how an apparatus works. It might also go far in explaining why a student can hold a belief in one situation and contradict it in another. One way to move away from the dictionary and to make students aware of their standards and of their inconsistencies might be to move towards the kind of course exemplified by Johnson Abercrombie. However, her course was taken by adults and introducing students to techniques of civilised disputation might cost more time than the science curriculum can spend. However, in clarifying observations, definitions, theories unifying disparate phenomena and matters of fact, inference and opinion, Johnson Abercrombie's techniques of group discussion might well be implemented. In turn, this might be objected to by those who regard scientific theories as divine truths to be heard in reverential silence; in turn this view ignores the practicality that "scientific" information doubles every few years, so no lecture series can be expected to cover the next several years' discoveries.

5.35 Apparatus

From the curriculum planner's point of view, there might be another reason for the confusion of words in reference to amplitude and frequency.

Perhaps the semantic confusion stems from the student's difficulty in ascribing a quality such as "high" to two simultaneous presentations, such as amplitude and frequency. If it is important that students be able to differentiate between frequency and amplitude, then equipment which can be used to produce such differentiation should be available in schools. At the least, audio-frequency oscillators, amplifiers and transducers and oscilloscopes will be needed. However, such equipment is likely to be complex and, consequently, expensive. For example, the current oscilloscope which will demonstrate "the display of several different kinds of sound", "sound quality" and overcome the visual difficulties mentioned previously in observing rapidly-changing waveforms is The Fast Fourier Transform Analyser made by *Bruell and Kjaer* at a price of about forty thousand dollars each (Dow, personal communication, April 23 1992, Powell River). Few schools would be able to afford a class set of those!

Even the digital oscilloscope mentioned in section 5.31.9 would not be inexpensive.

Therefore it is unlikely that individual students would be able to explore such phenomena as amplitude and frequency separate from each other. Without opportunities to generate personal knowledge, the science classroom becomes merely a place to paint students with facts, rather than a community intended to encourage them to construct their own knowledge.

## 5.40 SUGGESTIONS FOR FURTHER RESEARCH

With such a dearth of research in the field of student perceptions about sound, the field is wide open. It might be fruitful to fill the gaps in the Gustafson-Aspden-Linder age spectrum in order to find out how age-specific is the development of the concepts associated with sound. Gustafson worked with Grade Four students; Aspden worked with Grade Eights and Linder worked with physics post- graduates. Such research could be commercially important, for communication seems to be getting more personal. For example, Plato's ideal city had a population of 5040, the crowd he felt could be addressed by one speaker; in the nineteenth century, newspapers were tailored to particular segments of society; in this century, T.V. has addressed groups of one or two; the telephone and the personal camcorder have made communication one-to-one. A major use for personal communication is, of course, commercial advertising; so any thing, such as a deeper knowledge of people's responses to sound, which makes communication more successful is likely to be financially rewarding.

More work needs to be done on word usage in science instruction. One has only to compare the different meanings of words such as "significant" and "integrated" in physics and in other fields to recognise that word usage is often a barrier to communication. The study of sound might be a fruitful way in which to look at such ambiguities formally; in fact, rather than restrict the study of sound to Kundt's tubes, waves and the like, the study could be used as the core of a course on "communication by sound", ranging from rhetoric to music to electronics to psychodynamics to noise pollution.

It might be worthwhile to use the apparent ambiguities of description of amplitude and pitch to explore brain functions at a biological level. One might consider that both Freudian Analysis and Genetic Epistemology have much in common, with conversation exposing deeper mental structures, parallels between concepts such as "schemata" and "complex", and "ego-defences" and "classifications of student responses".

A group instrument could be created to measure both the strengths and frequencies of concepts needed for the academic understanding of sound phenomena; this would give the teacher a far tighter grasp of instructional requirements--and of irrelevancies.

The digital oscilloscope might be worth developing for school use.

## 5.50 A LAST WORD

When this researcher looks back at his cited reasons for undertaking this study and asks himself what he has found, he can now say that he has found that the mechanic was quite normal; the fault lay in the assumption that a person's conceptual ecology is always perfectly consistent and logical to another person.

Comparing ideas for the Literature Review has convinced this researcher that the physics of sound stretches the imagination--perhaps in relating the person's voice to the display on the oscilloscope--just as much as does the poet who relates "my love" and the "red, red, rose". Both are ways to develop and extend persons' knowledge of both themselves and their environments.

As Storr put it so aptly:

> . . . in discovering more about our environment we create internal patterns or schema. By doing so, we reduce the need to pay equal attention to every impinging stimulus, and only need to take notice of those stimuli which are novel . . . ( Storr, 1990, p. 170)

This researcher's suspicions about the confusing aspects of an oscilloscope display appear to have been confirmed.

Whether this research, done primarily from the researcher's private library and using local students, is adequate is not for this writer to say.

The ideas behind this thesis can be summed up thus:

> Mystery and disorder spur man to discovery, to the creation of new hypotheses, which bring order and pattern to the maze of phenomena. But mystery and disorder pertain to our own natures as well as to the external world. I venture to suggest that, just as it is inconceivable that all the laws of Nature will ever be discovered, so it is equally impossible to believe that the complexities of human nature can ever be grasped in their entirety. (Storr, 1990, p.172-3).

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Appendix 1. (Interview with a student )

I: I would like to interview you, (student's name) as to how we hear things. Now suppose you tell me as loudly as you can, how do we hear things?

S: With our ears.

I: Tell me more about what your ears do.

S: I don't know.

I: How can you tell when something is making a noise?

S: You just hear it.

I: How do you know that you are hearing something?

S: I don't know.

I: Let's see. The drawing on the chalkboard, are you hearing that drawing?

S: No.

I: How do you know what is on it?

S: I can see it.

I: There is some air blowing in the room. Do you hear it?

S: Yes.

I: How do you know that you can hear it? That you are not seeing it? Tell me, if you saw a man standing by a woman, what differences would you expect in their voices?

S: The man would be deeper.

I: In what way would those voices be different?

S: The pitch would be different.

I: What would you notice about the pitch of the man's voice from the pitch of the woman's voice? Which would be which?

S: The woman's would be higher.

I: How would you know that the pitch was higher?

S: You can hear it.

I: What do you mean by a high pitch? Which of these is a high pitch and which is a low pitch?

S: The first one.

I: How can you tell it was a high pitch? How did it sound?

S: It sounded squeakier.

I: OK. How could you tell this was a low pitch?

S: It goes deeper.

I: Why do we use the word deep? What else do we call deep?

S: The ocean is deep.

I: Why do we say that the ocean and the voice are both deep?

S: Lower down, I guess.

I: Why do we think of a voice like this as down from a voice like this (high)? Why do you think that one is downer than the other?

S: Because it sounds lower.

I: It sounds lower? OK. Give me a high pitched sound. Just do it as if you were singing. Come on, we are friends here, I won't bite you. I have just had lunch.

S: I can't.

I: OK. Can you imitate the sound of a foghorn? Come on, give it a try.

S: (No response).

I: You are a bit embarrassed eh? OK. Next question. What do you call it when you hear a sound then you hear it a second time? I clapped my hands, and could you hear other claps coming off the walls? What do we call that?

S: Echoes.

I: What causes echoes?

S: When you are closed in a space, or something.

I: Those are pretty good answers. Let me just show you something. Have you seen one of these things before?

S: Yes.

I: I call it a gizmo. What is its real name?

S: A door harp.

I: Do you have a door harp at home?

S: Yes.

I: Can you tell me how this thing works. Just talk and tell me how this thing works. First of all, what do you notice about its shape? How would you describe its shape?

S: Like a C.

I: What material is it made of?

S: Wood.

I: I tell you what. You play with it and tell me what you are doing and see if you can get it to work. That's pretty good. OK. Now what is happening, what is going through your mind when you tried to make it work?

S: This hit the strings.

I: What hit the strings?

S: The balls.

I: And what do those balls do when they hit the string?

S: They make music.

I: How do they make music?

S: They hit the metal.

I: OK. When they hit the metal what do the balls do to the metal?

S: (No response)

I: Let's see. Why not touch one of these metal pieces very gently and see what happens when the ball bangs into them.

S: It vibrates.

I: How can you tell it is vibrating?

S: I can feel it.

I: What do you mean by the word vibrate?

S: It goes through the whole piece of metal.

I: What does?

S: When it hits, it just goes right through.

I: How can you tell that it is going right through?

S: By the bell.

I: How can you tell that the vibration or whatever it is, is going right through to the other end?

S: If you put your hand there.

I: Which vibration do you think is greatest? The vibration at the end or the vibration in the middle?

S: In the middle.

I: How would you check? Can you try touching it?

S: By the back of it?

I: You are just about at the middle. Try the top one, it's easy.

S: At the ends, I guess.

I: OK. Let's see. If I hit this pencil, it moves away in one direction, doesn't it? When the ball hits the wire, does the wire just go in one direction?

S: It goes back and forth.

I: OK. Can you tell me anything about how quickly it goes back and forth compared with the sound it makes?

S: When it goes really quickly it gets louder.

I: Anything else?

S: There is more vibration.

I: What do we mean by more vibration?

S: You can feel it more.

I: Does it make more vibration in the wire moving back and forth, or is there more vibration in the wire going quicker? Which do you think?

S: Going back and forth.

I: Yes, but going back and forth slowly, or quickly, or a long distance or a short distance?

S: (No response).

I: OK. I think that is too difficult a question. Suppose we hit the string with the wire but really hard, what do you think is happening to the wire?

S: The vibrations keep getting longer.

I: How can you tell?

S: Because it's less time.

I: OK. Suppose I hit it very gently like that?

S They would be quicker then.

I: It dies away quicker. OK. What do you notice about the pitch of the wire? The note, if you like, in the wire? That one there, or that one here?

S: The second one is softer.

I: Do you mean higher or lower? Or louder or softer? Which?

S: Lower and softer.

I: OK. Now we will have to go now, so let me thank you for your efforts. I really enjoyed working with you. I'll be using your interview but I will change the names around and add it to other interviews. Thank you for your efforts and here is your dollar.