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FIRST YEAR UNIVERSITY STUDENTS' CONCEPTIONS OF ATMOSPHERIC PRESSURE

a
RESEARCH REPORT

submitted by
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in partial fulfillment of the
requirements for the degree

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ABSTRACT

This qualitative research project investigated the ideas of a small group of learners in the first year physics course at the University of the Witwatersrand in the area of atmospheric (air) pressure. These ideas constitute the prior knowledge with which these learners enter physics education at tertiary level. Clinical interviews were conducted with an initial sample of three (3) respondents, and the main study consisted of seven (7) first-year physics students. Data obtained during the course of the interviews was audio-taped and transcribed, and from an analysis of the transcripts a picture was obtained of the content of the knowledge held, and of the epistemological and ontological views that respondents entertained. What renders this work important is the argument that teachers are unable to assist the learning process without engaging actively with what their learners already know and believe. The first step in setting up learning experiences which can assist learners to become fluent in the construction of sound scientific explanations for phenomena and to become competent at weighing evidence is to determine the state of learners' prior knowledge. The findings of this limited case study may be summed up as follows: There is very little indication, in the sample investigated in this study, that any meaningful learning has occurred in the areas of pressure, atmospheric pressure and the kinetic theory. These concepts have little or no explanatory power for learners in attempting to account for natural phenomena and technological applications in which atmospheric pressure is at work.

DECLARATION

I declare that this research is my own, unaided work. It is being submitted for the degree of Master of Science in Science Education in the Faculty of Science of the University of the Witwatersrand, Johannesburg. It has not been submitted to any other university.

……
J. S. Small
18 February 2005

DEDICATION

To my beloved daughters,

Shelley and Astrid,

because they were the smartest class I have ever taught.

And to my dear wife,

Kathy,

whose forbearance made it possible.

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I wish to thank my supervisor, Mr Mike Stanton, of the Department of physics of the University of the Witwatersrand, for his expert advice, solid support and encouragement to enable me to complete this research report. With his help I have been able to organize and print this report on time. I am also indebted to him for allowing me the use of books and other resources.

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CHAPTER 1

ORIENTATION TO THE RESEARCH

1.1 INTRODUCTION

This report investigates research undertaken into the knowledge and understanding of pressure and atmospheric pressure held by a small group of first year physics learners at the University of the Witwatersrand. These ideas constitute the prior knowledge with which these learners enter any further physics education at tertiary level.

A qualitative study was carried out using clinical interviews on a sample of ten (10) respondents. Data obtained during the course of the interviews was audio-taped and a complete transcription of the interviews was made. The transcripts are appended to this report (Appendix 1). These transcripts have been examined carefully and analysed in the light of research into "children's science" (Gilbert, Osborne & Fensham, 1982), into the contrast between "meaningful" and "rote" learning (Novak, 2002), into the nature of scientific knowledge and the epistemological views that students hold (Désautels & Larochelle, 1998), and into the ontological categories identified by Chi, Slotta and DeLeeuw (1994, quoted by She, 2002, by Lee & Law, 2001, and by Matthews, 1998). The reservations of McClelland (1984) with respect to the interpretation of the evidence provided by respondents' answers to interview questions have been carefully noted.

Fundamentally, this is not a piece of classical misconceptions research. It is a review of the state of respondents' knowledge and understanding of the concept of pressure and the phenomenon of atmospheric pressure. "Knowledge" here refers to respondents' declarative knowledge (the knowledge of the content of the concepts under discussion) as well as their procedural knowledge (knowledge of how the concept can be applied, that is, used to account for natural phenomena or to explain how technological applications work). This distinction is borrowed from the writings of Gilbert Ryle (quoted by Novak, 2002). An attempt has been made for respondents to call on their strategic knowledge (Duschl & Osborne, 2002), that is, their metacognitive capacity, or their ability to think about the explanations they were attempting to construct as they were constructing them. "Understanding" refers to respondents' ability to connect formal physics concepts to one another, to the natural phenomena and technological applications that illustrate them, and to other concepts in

physics. Also at stake here is the ability of respondents to transfer knowledge, that is, to apply knowledge constructed in one context (such as the classroom) to another (such as the airfield, a mountain summit, or other relevant context) (Novak, 2002).

1.2 STATEMENT OF THE PROBLEM

This project is concerned with the nature of the prior knowledge in the area of atmospheric pressure that learners in the first year physics class will take into their further studies in physics.

1.2.1 The first question: What do learners know?

The first priority is to determine what views the learners studied hold on the concept of pressure and on the phenomenon of atmospheric pressure. An attempt is made to establish subjects' familiarity with these terms, and to explore their understandings of the origin of atmospheric pressure, and to probe their ability to use basic theory to explain certain natural phenomena associated with it and its technological applications.

1.2.2 The second question: Do learners have any epistemological commitments?

Next, the study will seek to determine the views that respondents hold on a range of epistemological questions. These include their opinions on the following questions:

- How useful is physics theory (in this study, the example of the kinetic molecular theory of gases was used) to respondents in explaining natural phenomena with which they are familiar? In this study, attention is paid to the phenomenon that a mountaineer experiences difficulty breathing at high altitudes.

- Additionally, how useful are such theories in respondents' efforts to understand certain familiar technological applications that exploit knowledge of atmospheric pressure? The example used in this study is the phenomenon of heavier-than-air flight (the example quoted is of a large jet passenger plane taking off and flying through the air). This relates to the way in which learners think about the concepts and propositions related to the pressure exerted by the atmosphere. Leach and Scott (2003, p.92) refer to the Piagetian notion that "intelligence organises the world by organising itself". The implication of this is that, in the world of students' experience, they do not

consider different phenomena to be disparate and unconnected. Organising the world surely means making some attempt to classify phenomena, to apply the principle of cause and effect to new situations, to relate or attempt to relate new information and observations with existing knowledge. The present study sought a glimpse into that process. The question was: How do respondents think (ask themselves questions and arrive at meaningful or logical conclusions) about the phenomenon of atmospheric pressure?

- What is the relationship between models of the molecules comprising air and the molecules themselves? How believable or useful are models that are adopted by physicists to explain natural phenomena? Along with this, do respondents believe our knowledge of atmospheric pressure to be tentative or not, that is, finally determined or subject to change?

1.2.3 The third question: Do learners assign the correct ontological categories to the concept of pressure and the phenomenon of atmospheric pressure?

Researchers such as Chi *et al.* (1994, quoted by Lee & Law, 2001) have concluded that when learners' views are at variance with accepted scientific views relating to a phenomenon, the origin of such a mismatch is to be found in the assignment of the relevant phenomenon to an incorrect ontological category. These researchers identify three ontological categories, namely "matter", "process" and "mental state". An important subcategory of "process" is "constraint-based interaction", where a defined system behaves according to the principled interaction of two or more constraints (She, 2002). Therefore, in this study an attempt is made to identify the ontological categories of respondents' views on atmospheric pressure.

Here is an example of how a learner may mistake a "mental state" for a "constraint based interaction". When asked to define atmospheric pressure, the learner may state that "atmospheric pressure is when . . . ", and go on to mention the surprising result of some demonstration, such as that a cup that is filled with water, covered with paper and then inverted, does not allow the water to fall to the ground. Here a fairly complex concept, atmospheric pressure, is confused with an event that merely serves to demonstrate it. Atmospheric pressure has built into it aspects such as that the earth has an atmosphere, the properties of its component gases, the concept of pressure, the force of gravity, and causality (atmospheric pressure being pressure due to, or caused by, the atmosphere). That being the

case, atmospheric pressure should be assigned the category of "mental state", that is, a definition, a mental construct, a product of the fertile imagination of a human scientist, a concept made up of a number of simpler concepts and propositions (Novak, 2002), and that can be fruitfully applied to the task of solving a wide range of problems in physics and technology. As for the demonstration, the water in the cup does not escape because the force of gravity (weight of the water in the cup) is far less than the force exerted by the surrounding atmosphere, which is the explanation of a process, or "constraint based interaction".

Désautels and Larochelle (1998) explain that learners at junior-college level (a cohort similar in age to the sample to be studied in this project), when probed on their conception of a "particle", for the most part likened it to golf balls and tiny ball bearings. Most of the views expressed by these learners were an attempt to transpose scientific knowledge (of a tentative nature) into the world of everyday materiality (relating to things that are concrete and tangible). This reveals a tendency on the part of novices to scientific thought to assign a scientific concept (in this case the notion of a "particle") to the ontological category "matter".

In summary, there are three important issues to note:

1. Learners have vague, confused and incoherent views on atmospheric pressure, its origin, natural phenomena associated with it and its technological applications;

2. Learners' epistemological commitments related to atmospheric pressure and connected concepts are incoherent, contradictory and inconsistent;

3. There is a substantial mismatch between learners' ontological categorisations and those of accepted science.

1.3 BACKGROUND TO THE PROBLEM

As will be demonstrated in the explication of the background to the problem, the state of learners' prior knowledge is a key indicator to teachers of the learning that is likely to occur in this subject area.

In explaining the background to the research problem outlined above, two questions will be addressed:

1. Why does this project emphasise the nature of learners' prior knowledge?

2. Of what importance or interest is the choice of the phenomenon of atmospheric pressure?

1.3.1 The value assigned to prior knowledge from a social constructivist perspective

1.3.1.1 Vygotsky's "zone of proximal development"

The overall orientation of this study is a social constructivist perspective based on the work of Vygotsky, and that of his contemporaries Leontiev and Bakhtin, work that has in more recent years been further developed by neo-Vygotskians such as Wertsch. A central pillar of Vygotsky's theory of learning and development is his definition of a "zone of proximal development", essentially the space between the learner's prior knowledge and his or her conceptual understandings after the process of learning has occurred, mediated by a teacher or more capable peer. (Vygotsky, 1979; Vygotsky, 1986; Wertsch, 1984; Scott, 1998)

From Vygotsky's (1979) perspective, the teacher's role is to assist students to progress from their present developmental level, as measured by what problems they are able to solve unassisted, to a higher level that they have the potential of attaining. The teacher's role may be viewed as both mediator (guiding students en route to the higher level) and facilitator (setting up conditions that are conducive to students successfully negotiating the gap).

From the Vygotskian perspective, as described by Wertsch (1985), the classroom is a site of much social interaction between teacher and students, as well as among students themselves, with teachers guiding students through their individual "zone of proximal development". To Vygotsky, knowledge first exists in the interpsychological plane, that is, it is the possession, and an integral part, of the culture and the community of which students are members. From there, scientific knowledge is internalised by the individual student. For a student, a teacher (by virtue of her subject expertise) can be a precious resource. Peers are an important resource, too. In fact, in my view a very good test of whether one really understands something is that one is able to explain it convincingly to one's peers. This means that one has achieved shared meaning with one's peers. Miller (1989) reminds us that unless this is achieved no learning or teaching is possible.

Other resources that may be available are books, magazines, videos or useful information obtainable on the internet. I believe that even such an apparently private learning activity as reading a book also involves the internalisation of concepts from the interpsychological plane

(where the reader is in the company, and engaging with the thoughts, of the author) to the intrapsychological plane (where the reader appropriates the ideas in the book). A similar point is made by Cobb and Bowers (1998) in connection with a trainee accountant learning the tax code in solitude.

1.3.1.2 Theoretical progress in the twentieth century

Duschl and Osborne (2002), in a comprehensive review paper on research into the creation of learning environments that enable dialogue in science classes, draw attention to the progress that has been made in the science education research community's understanding of how knowledge grows and develops. The authors note how, during the course of the twentieth century, theories of learning, mind and knowledge have progressed **from**:

- behaviourism (Trowbridge & Bybee, 1990),
- belief in *tabula rasa* (Gilbert, Osborne & Fensham, 1982), and
- the notion that knowledge grows in a steady, cumulative fashion,

to:

- an emphasis on the cognitive and social nature of thinking,
- the notion that children may have innate capacities (such as language syntax), and
- recognition that knowledge is often reconfigured, adapted and even abandoned.

In contrast to the behaviourist model of learning and teaching, constructivism accepts that learners are human beings and that a teacher's preoccupation should not primarily be the management of learners' behaviour. It makes nonsense of the view posited by behaviourists, namely that the learning-teaching enterprise may be approximated to the training and conditioning of dogs, cats and rats. (Trowbridge & Bybee, 1990)

Additionally, it reflects awareness of an important insight when a teacher acknowledges and treats the learner as an active participant, rather than as one who arrives in class carrying an empty bowl (akin to the notion of a clean slate, or *"tabula rasa"*), hoping to have it filled with offerings of knowledge delivered by the teacher and to be passively received. The issue here is whether the human mind is a vessel to be filled, or, as Plutarch suggested, a fire to be

lighted. The going-out point is that no learner ever tackles the learning of a new concept in science from scratch, that is, from a state of total ignorance. The *"tabula rasa"* assumption, namely that a learner has no knowledge of a topic before being formally taught it, has been convincingly demonstrated to be invalid (Gilbert, Osborne & Fensham, 1982).

In the light of such theoretical progress as has been outlined by Duschl and Osborne (2002), as mentioned earlier, curriculum planners and teachers have been offered such advice as to try to:

1. Centre classroom instruction around the learner's active learning, taking into account research findings that demonstrate that the learner's prior knowledge is a significant factor affecting learning;

2. Focus on procedural and strategic knowledge (metacognition), and not merely declarative knowledge.

1.3.1.3 Constructivism foregrounds the role of learners' prior knowledge

The central tenet of constructivism is that the learner is not the passive recipient of knowledge but actively works to construct or acquire knowledge of the subject being studied. However, there are a wide variety of perspectives that are labeled "constructivism" (Geelan, 1997). Constructivist models that value and foreground learners' prior knowledge promote a humane (learner- and teacher-friendly) classroom environment and dialogic as opposed to authoritative classroom discourse (Scott, 1998). Such models support the provision of scaffolding, that is, teaching interventions that are sensitive to, and contingent upon, learners' needs. They also dignify learners who may be struggling to master new concepts in physics (Wood, 1991). The point about "contingency" is that the teacher's actions and interventions depend on what learners bring to the classroom. This renders learners' prior knowledge extremely important to the outcome of any teaching-learning activity.

The cognitive learning models of Jean Piaget and David Ausubel, while at substantial variance with one another, have this in common: both theories foreground the knowledge that learners possess prior to any formal education. Piaget's "genetic epistemology" emphasises assimilation, accommodation and equilibration of new concepts into existing cognitive structures formed in the process of maturation, while Ausubel's assimilation is of new concepts into existing sets of interlocking concepts that form propositional hierarchies in the

thinking of learners. Be that as it may, a constructivist's view of learning is dominated by two key considerations:

1. The need to take learners' prior knowledge into account when devising learning experiences;

2. The call to diminish the traditional reliance on, to devalue and move away from, meaningless (rote) learning and instead to pursue and encourage meaningful learning, that is, learning that involves actively linking new concepts with prior views held by the learner (Piaget, 1964; Novak, 1977).

The constructivist call to learners to "take responsibility for your own learning" is not synonymous with a call on teachers to abdicate their teaching responsibilities. Taking responsibility for one's learning is akin to taking responsibility for living one's own life. It goes without saying that a serious and responsible learner will try to obtain needed assistance with matters that are beyond the reach of his or her present knowledge and ability. It is really up to the learner to engage with the subject matter under discussion, to make personal (that is, to construct) the public knowledge being considered in class, and to that end to exploit the totality of resources available, including tapping into the teacher's experience and knowledge of the subject area.

An important reflection when analyzing the interview transcripts in the present study was the question of whether or not respondents had actually engaged with the idea that the atmosphere exerts pressure, and whether or not any of the public knowledge related to pressure, atmospheric pressure, the kinetic molecular theory and its applications had been internalized or assimilated (that is, constructed).

Every learner has some prior knowledge, no matter how limited or "thin" that knowledge may be (the term used by Geertz, quoted in Miller, 1989). In the language of Vygotsky (1986), learners start out with "spontaneous concepts" (commonsense, or everyday word meanings) and learn "scientific concepts" (systematised knowledge) by strenuous mental application, with the help of a teacher or more capable peers. It is the aim of this study to determine the nature of the "spontaneous concepts" that learners hold in the area of atmospheric pressure. Gilbert *et al.* (1982) emphasise that "[i]t is the interaction of children's science and their teacher's science that will have profound implications for the outcomes of teaching" (p.628).

It may seem, on the face of it, wrong to speak of determining “spontaneous concepts” in the case of 18- or 19-year-olds, the target age group of the respondents in this study. After all, how could it possibly be the case that these learners hold, after at least 13 years of attending formal science classes, “spontaneous concepts” in a learning area such as pressure and atmospheric pressure, topics that enjoy much attention in the syllabus during both GETC (General Education and Training Certificate) and FETC (Further Education and Training Certificate) phases of the K-12 education system in South Africa. In answer it must be noted that knowledge passes from the “spontaneous” to the “scientific” stage only on condition (and to the extent) that the learner actually equilibrates or internalizes it.

According to Pines and West (1986), constructivists do not recognize that meaningful learning has occurred when a learner, after attending a lesson, is able to state or repeat some fact to which he or she was exposed during that lesson, that is, “some piece of public knowledge”. In the words of these authors, although this ability may represent a change of behaviour, it “may not count as meaningful learning or a change in understanding for the constructivist . . . ” The reason for this is that “[s]uch changes in knowledge that constitute rote memorization or an ability to regurgitate propositions verbatim do not exemplify learning or understanding; more often, they exemplify the lack of meaningful learning and understanding” (all quotations in this paragraph are taken from page 583).

If, therefore, the learners who were subjects in the present study did indeed, over a period of years, attend formal lessons in science at which the relevant topics have been covered, then they have been exposed to “public knowledge” in this area. Did that “public knowledge” become constructed knowledge? This question will of necessity be answered differently in the case of each individual learner. There is evidence from the interviews conducted in this study that some learners have a very clear personally constructed conception of the definition of pressure. And in the case of a minority of respondents, there is evidence of some ability to use the definition in accounting for phenomena and constructing explanations related to applications.

1.3.1.4 Effective teachers know about what their learners already know

Let it be assumed that a teacher of physics intends for his or her learners to achieve the following broadly stated learning outcomes:

- To learn and appropriate new concepts as these are currently accepted by the scientific community;

- To become scientifically literate (that is, to understand the way science is done, and the way(s) in which scientists do their work);

- To understand and accept the epistemological assumptions implicit in the learning and practice of physics (that is, to gain some insight into the nature of science, a sense of the truth value of the knowledge claims of science, and the way(s) in which science has advanced historically).

From a social constructivist standpoint, the first step in devising a teaching sequence is outlined by Scott, Asoko, Driver and Emberton (1994, p.201) as follows: "We argue that decisions relating to planning and teaching for conceptual development require the teacher to consider first the nature and status of students' existing ideas and understandings . . . ". In a similar vein, Carr, Barker, Bell, Biddulph, Jones, Kirkwood, Pearson and Symington (1994, p.150) state that "[i]f students come to lessons with ideas about their world which already make sense to them, then teaching needs to interact with these ideas, first by encouraging their declaration and then by promoting consideration of whether other ideas make better sense."

The social constructivist perspective assigns a high value to the provision of scaffolding, that is, teaching interventions that are sensitive to, and contingent upon, learners' needs (Wood, 1991). If teachers were made aware of their learners' prior knowledge, they would be well-placed to provide their classes with learning experiences that would use that knowledge as a going-out point, very much the way any extension or renovation work planned for a building necessarily takes the existing structure as a going-out point.

Cayhadi and Butler (2004, p.569) state that "getting students to recognize flaws in their mental models helps them develop their understanding" and that "[a] student's system of beliefs, observations, and understandings — whether correct or not, relevant or not, and correctly applied or not — are brought by that student to lecture, laboratory, and problems class."

Leach and Scott [2003, p.92] refer to the Piagetian notion that "intelligence organises the world by organising itself", and explain that "[a]ccording to this perspective, in order to

predict how learners will respond to attempts to teach science it is necessary to understand the knowledge that students bring to a given teaching situation".

Therefore, from a constructivist perspective, this prior knowledge is a key determinant of what learning is likely to occur in this learning area. It therefore seems important to determine the nature of the knowledge held by the respondents in the present study. This study seeks to describe the epistemological views of the sample studied, that is, the nature of the scientific knowledge held. A further goal is to attempt to determine the ontological assumptions made by subjects in this study, that is, to explore what they perceive the atmosphere to be, to consist of, as well as what they believe would account for the observation that the atmosphere exerts pressure on the bodies it surrounds. In the process, it may be possible to discover aspects of such prior knowledge that need to undergo a process of conceptual change in the learners studied, a process designed to align their understanding with accepted scientific views of the topic.

1.3.2 Why investigate atmospheric pressure?

1.3.2.1 Atmospheric pressure explains a wide range of familiar phenomena

A wide range of phenomena occur by virtue of the pressure exerted by the atmosphere on any object that is in contact with air. There are many natural phenomena and technological applications that learners come into contact with in daily life that are only comprehensible with reference to the concept of atmospheric pressure. A few examples are mentioned below:

- A metallic tin containing a little water that is boiled away and its screw-top tightly shut will collapse in on itself as it cools down;
- A mountaineer at high altitudes has trouble breathing;
- Water boiled at high altitude is lukewarm;
- Heavier-than-air flight, thought by some early physicists (Lord Kelvin being a notable example) to be impossible, is a multi-billion rand per year industry
- Weather forecasts are based on the presence of and changes to low- and high-pressure cells in the atmosphere

In the science classroom, certain properties of fluid pressure are exploited when we measure atmospheric pressure experimentally. Some questions arising from this include:

1. Are these properties known to learners and are they understood?

2. Are learners aware of the possibility of measuring the height of a tall structure (mountain or building) by applying the concept of atmospheric pressure?

3. Are they aware of the make-up of the atmosphere, that is, its fundamental components or building blocks?

4. And are they able to use this knowledge to explain the origin of the pressure exerted by the atmosphere?

Many present-day applications of hydrostatics principles cannot be properly understood in the absence of a thorough grasp of the fundamentals of atmospheric pressure. Among these are the functioning of such apparatus as the pneumatic drill, pneumatic pump and the air compressor. In the field of human physiology, it is impossible to explain the functioning of the human lung without reference to the concept of atmospheric pressure. In the present study it is not the intention to undertake an exhaustive investigation into all of the above phenomena and to attempt to answer all of the questions raised. These are listed merely to try to illustrate that atmospheric pressure as a topic offers a rich opportunity for researchers wishing to explore the state of the knowledge and understandings held by physics learners. Novak and Gowin (1984) offer the advice that for interviews to be manageable, they should not last too long. These authors give the guideline of between 15 and 30 minutes for each interview. For the present study, therefore, it was decided not to attempt to cover too much ground.

1.3.2.2 Learning about concepts in science versus learning about natural phenomena

In this study one-on-one conversations took place between the researcher and ten respondents. In undertaking an analysis of the content of those conversations it is necessary to try to explain, or to give an account for, the nature of the answers given. If the interviews conducted were designed to open a window into the thoughts of respondents on the concepts under discussion, the question has to be what the “open window” is revealing. McClelland (1984) sounds a cautionary note against the automatic assumption that novices necessarily hold alternative frameworks, that is, a self-consistent stock of interlocking concepts with which

they attempt to make sense of phenomena but that is out of harmony with accepted scientific explanations. The point is that learners may not have **any** framework of preconceptions. (McClelland talks about child learners, but I shall apply the arguments made to learners in physics, that is, novices to the field.) Why, then, have the respondents in the present study provided such unconvincing answers? What accounts for the difficulties their answers reveal?

Respondents have not constructed knowledge related to atmospheric pressure. They have, for whatever reason, not engaged with this phenomenon in the sense that they have not applied their minds to the task of relating theory (such as the definition of pressure and the assumptions of the kinetic molecular theory of gases) to the natural phenomena that may be explained by means of that theory. The following considerations flow from this observation:

- Have the respondents in this study not thought it worth their while, or have they not found it necessary, to engage with the phenomenon of atmospheric pressure?

- If the answer to either alternative is in the affirmative, does this possibly reflect badly on our assessment practices? (The achievement of good results in examinations and other assessments is clearly the foremost consideration to any undergraduate student!)

A fine distinction drawn by McClelland (1984) has to be respected, namely that between learning about a concept in science and learning about a natural phenomenon as part of the content of a physics course. This author argues that "[p]henomena are not the content of science but the vehicle for learning it, that is, for learning theories". A scientific concept, such as "pressure" is a theoretical construct. It is formulated so as to be as inclusive as possible. Thus, the definition "pressure is force per unit area" (expressed mathematically as $P = F/A$) depends in turn on the definitions of "force" and "area", and there is the need to clarify precisely what force and what area are intended. The concept of pressure is additionally defined in such a way that it can be used to discuss widely disparate phenomena, involving:

1. all phases of matter;

2. every branch of physics;

3. natural phenomena spanning every scale from the sub-atomic to the astronomical;

4. relatively simple and straightforward problems, as well as extremely abstract, complex and advanced theories.

The formula $P = F/A$ applies to the pressure exerted by **solids**. By way of explanation, the formula $P = F/A$ can be applied, in the area of mechanics, to the simple case of a solid rectangular block of wood resting on a table top. By virtue of its mass it exerts a downward gravitational force on the table, and the ratio between that force and the area of the portion of the block that is in contact with the table surface is defined as the pressure exerted by the block on the table.

The formula $P = F/A$ also applies to the pressure exerted by **liquids**. In the area of hydrostatics, the formula $P = F/A$ is applied to the problems experienced by a diver at a particular depth due to the pressure exerted by the surrounding water. The formula $P = F/A$ is applied in the derivation of the formula for liquid pressure $P = \rho gh$.

The formula $P = F/A$ also applies to the pressure exerted by **gases**. In the study of gases, and in particular when we apply the kinetic molecular theory to the derivation of the ideal gas law $PV = nRT$, the fundamental definition used for the pressure P is $P = F/A$, where F is the vector sum of the forces exerted by the molecules in a gas sample on the total area of the walls of the gas container (A).

The point of the above account is that the definition that is succinctly captured in the simple formula $P = F/A$ is widely applicable. This inclusivity is a key requirement for acceptable definitions in science. Physics is not the *ad hoc* description of a wide range of disparate phenomena in nature, but it is an organised and systematic enquiry into such phenomena.

1.4 AIM OF THE PROJECT

In line with the foregoing statement and background to the problem, it is clear that the aim of this project has to be threefold:

1. To determine what conceptions the learners studied hold on atmospheric pressure, its origin, natural phenomena associated with it and its technological applications;

2. To determine and attempt to categorise the respondents' epistemological commitments related to atmospheric pressure;

3. To clarify and attempt to categorise the ontological assumptions made by learners in their thinking about atmospheric pressure.

Although the identification of misconceptions is not the primary aim of this study, it is inevitable that an analysis of learners' views will reveal areas that need to undergo a process of conceptual change (Posner, Strike, Hewson & Gertzog, 1982). While it is acknowledged that some instruction will have been given to respondents at some point during the first-year physics course, such instruction is often provided hastily (given the time pressure involved in covering an overfull syllabus). Atmospheric pressure represents a very small part of the overall programme of instruction. This non-interventionist study seeks to probe for deeper understandings than what instruction generally allows students to cultivate, and this may be done irrespective of any instruction provided.

1.5 THE RESEARCH QUESTION

The primary research question is:

What is the nature of the knowledge that first-year physics students have about atmospheric pressure?

A more accurate description of this knowledge would be that it is presently held knowledge that will in turn serve as prior knowledge in any further studies in physics.

Linking to the aim of the project, the research question can be resolved into three sub-questions:

1. What views do learners hold on atmospheric pressure and related concepts?
2. Do learners understand the concept of pressure and the natural phenomenon of atmospheric pressure well enough to be able to use these in explaining familiar or unfamiliar phenomena and technological applications?
3. How does this prior knowledge fit into recognisable epistemological categories?
4. How may this prior knowledge be organised into recognisable ontological categories?

1.6 LIMITATIONS OF THE STUDY

This project represents a case study of limited scope, and makes no pretensions to generalisability. The hope is to identify some general difficulties that learners experience in thinking about the concept of atmospheric pressure, but no widespread claims or generalisable conclusions will be made.

1.7 IMPORTANCE OF THE STUDY

It may be re-emphasised that the study is very relevant, because of the place of atmospheric pressure in physics syllabi at primary, secondary and tertiary levels. It is hoped that the results will be of interest to secondary and tertiary level teachers, and that it may provide insight into the needs of learners for exposure to teaching sequences that recognise and acknowledge the prior knowledge with which they come to class, and that promote conceptual change.

The report now turns to a review of the research literature on the knowledge held by learners in the area of pressure and atmospheric pressure.

CHAPTER 2

LITERATURE REVIEW

2.1 EARLY WORK ON LEARNER CONCEPTIONS OF ATMOSPHERIC PRESSURE

The present study is an investigation of the views of young adults, that is, university students in their late teens. For this reason, in undertaking a review of the research literature in the area of learner conceptions of atmospheric pressure, an effort has been made to limit the review to studies done on subjects within an age range that was similar to the ages of the subjects in this study.

Séré (1985, in Driver, Guesne and Tiberghien, 1985, p.105–123) explains that even though *"air is all around us and is an intimate part of our everyday environment, yet . . . its properties are taken for granted and rarely appreciated or consciously considered"* by learners. Of particular interest for the purposes of the present study is Séré's account of the interpretations given by young learners about the forces exerted by gases. (The notion that the atmosphere exerts pressure is untenable without giving consideration to the idea that the air can exert forces.) She reports three problematic ideas that learners hold, namely:

1. A gas exerts a force only when it is set in motion. Hence, on a still day the atmosphere does not exert any force on objects with which it comes into contact, but if the wind should be blowing, the atmosphere does exert pressure. Another example of this idea at work is that when blood pressure is being taken using a sphygmometer, the air would be pushing, exerting or producing a pressure while it is being pumped up. As soon as the flow of air is stopped, while the armband is still compressing the patient's arm, no pressure is being exerted. This is a manifestation of an Aristotelian idea that associates force with motion.

2. A gas exerts a force only if it is subjected to a force, a push, or if it is heated. Learners who hold to this view believe that an external cause is necessary for a gas to exert a force.

3. A gas exerts a force in one direction only. This is a corollary of the "force causes motion" view. Many young learners do not believe that an enclosed gas exerts

forces against the inner sides of the container. If a compressed gas forces a plunger or piston (that is free to move) in an outward direction, the idea is that the gas exerts a force on the plunger in that (and no other) direction. In this kind of reasoning priority is given to the observable effect.

Séré's study involved English secondary school pupils aged 12–16. At the upper end of this age range, Séré's subjects would be merely a year or two younger than the subjects in the present study. In connection with the views that young learners hold on atmospheric air, the following ideas were identified as the main reasons advanced for answers that were given:

1. The atmosphere exerts a pressure which is observable only when there is a pressure difference;

2. The atmosphere exerts a pressure on surfaces;

3. Vacuums suck or exert pressure;

4. Spaces must be filled;

5. Pressure of air inside sucks or pulls.

It is not necessary, and indeed beyond the scope of this research report, to detail at length the specific phenomena and demonstrations that were explained using the above-mentioned reasoning, but suffice it to say that all of these are aptly described by Novak (2002) as "limited or inappropriate propositional hierarchies". "Limited" in that they reflect naïvete, incompleteness and oversimplification, "inappropriate" in the sense of being out of line with the accepted explanations given in physics texts.

Nussbaum (1985, in Driver, Guesne and Tiberghien, 1985, p.124–144) reports on four studies carried out by himself and his co-workers on learners' understanding of the particulate nature of gases. In an interview study done in Israel in 1978 on a sample of 150 14-year-old learners from nine urban schools, the following findings were reported in connection with key assumptions of the kinetic molecular theory of gases.

With reference to the notion that a gas is composed of invisible particles, it was found that 64% of pupils were able, without prompting, to state that air consists of particles. When asked to choose a picture which best represented the structure of air, 78% chose the particle

diagram. However, one out of six of the "particulate" learners could not accept that gas particles are evenly scattered in an enclosed space, that is, they could not shake off the entrenched preconception that air is continuous. Only 35% of the sample could accept the idea that there is empty space between the particles of which air is composed. Of those learners who accepted that air is particulate, only 50% suggested that the particles have intrinsic motion.

The point of this review is that a significant proportion of the sample were unable to internalize, or equilibrate, key aspects or assumptions of the kinetic molecular theory of gases. This is significant from the point of view of the present study, because here respondents were probed, not on whether they could recite the assumptions of the kinetic molecular theory off by heart, but on whether the theory was in any way useful to them. That is, did it have explanatory power for them? This will be commented on in the analysis of the interview transcript.

Importantly, given the fact that the sample of respondents in this study are all university students, in a 1981 cross-age study done in the USA involving 576 learners that included university students, it was also found that a majority of respondents accept the particle nature of air, but approximately 50% are not persuaded that there is a vacuum between the component particles (molecules), and approximately 60% do not believe that these molecules have intrinsic motion.

Very important work on establishing the nature of learners' prior knowledge on the properties and behaviour of gases (including air) was also reported by Driver, Squires, Rushworth and Wood-Robinson (1994). These authors report that even the most mature group (at age 16) of learners studied experience serious difficulties with concepts that are well-established in physics. For example, Driver *et al.* (1994, pp.108–109) report that, of all the learners that were interviewed, *"[a] third appreciate that the Earth's atmosphere changes with distance from the Earth's surface"*. What do the remaining two-thirds believe, particularly in an era where the re-entry of space vehicles into the Earth's atmosphere has become a common and widely publicised occurrence? These authors state that *"[h]alf recognise that air is a mixture of components"*. What, then, do the other half believe? Further, *"[t]wo-thirds consider that air has negative weight or no weight"* and *"less than a quarter consider that air has weight"*. What do the majority think?

2.2 WORK DONE LOCALLY

An electronic search of the literature on the topic of student conceptions in physics reveals that atmospheric pressure has been treated very sparingly in comparison with topics in mechanics, which have enjoyed much attention. A search through the tables of contents of proceedings of various South African (SAARMSE and SAARMSTE) conferences on science education during the decade of the 1990s turned up not a single title that includes atmospheric pressure.

Rollnick and Rutherford (1990) report on a piece of misconceptions research — work done on the ideas held by primary school teachers-in-training in Swaziland on some concepts about air and atmospheric pressure. An initial sample of 21 volunteers were interviewed (13 of these were individual interviews, and two were group interviews with four respondents per group). Then, a test was administered to three groups each of approximately 30 primary school teacher trainees at a teacher's college. The majority of these respondents had the equivalent of grade 10 (junior certificate). The aim of the research was to establish their ideas before instruction on the topic. A comparison was made between the results of this investigation and what was found in previous research conducted in developed countries.

Overall there was close agreement between the results for the Swazi sample and the misconceptions reported in the literature. However, the exceptions pointed out were:

1. The idea that air pushes out other things to occupy space.

2. The almost complete absence of ideas related to the particle nature of air.

3. The use of the concept that air occupies space to explain ideas about air pressure.

The main conclusion of the study by Rollnick and Rutherford (1990) was that many of the misconceptions held by young children on air and atmospheric pressure may stem from misconceptions held by their teachers.

2.3 WORK DONE IN THE ORIENT

She (2002) made a careful examination of the perceptions of 20 learners (aged 14–15) who were presented with a syringe containing trapped air. When asked whether or not the air in the

syringe could be compressed, 80% of the learners sampled felt that, for a variety of reasons, it could not. The reasons given were that: (p.986)

- *"it is full of air that has nowhere to go"*
- *"air occupies space"*
- *"there is air inside the syringe"*
- *"air pressure exists inside the syringe"*
- *"air molecules inside the syringe were already compressed to the extreme level"*

She (2002) claims that ontological category shift is a prerequisite for conceptual change, and the series of studies conducted by Lee and Law (2001) is a parallel effort to test this claim. In both studies an attempt is made to uncover respondents' ontological assumptions. The theoretical underpinning of She's study is the model of "learning as conceptual change" devised by Posner, Strike, Hewson and Gertzog (1982). Several constructivist learning models have in common the foregrounding of learners' prior knowledge as the most critical predictor of what learning will take place, and how it will occur. Therefore, if an educator has established the content and nature of the prior knowledge held by members of his or her class on the concept of atmospheric pressure, that could conceivably help to inform the design of teaching sequences to achieve the needed conceptual change in learners. The present study will not extend this far, but it is well to flag this matter as a possible subject for future research.

A serious puzzle for science educators is to find just the right things to say, to do and to facilitate the learning process, leading to the outcome that learners are well-informed and hold correct (scientifically acceptable) conceptions. The challenge is to create a learning environment that would help learners on their way, either to becoming competent scientists, engineers and technologists (in the case of the minority), or to becoming citizens that are well-informed on what science is and the role it plays in the way our world works (in the case of the majority). She (2002) believes he has found an instructional strategy that will enable learners to overcome their conceptual shortcomings in the area of atmospheric pressure.

The purpose of She's research was to investigate the process of conceptual change in 14- to 15-year-old learners in the area of atmospheric pressure. The author also wishes to

demonstrate the viability of the dual situated learning model (She, 2001) by illustrating the role it may play in assisting the process of conceptual change in the sample that was investigated. The study also seeks to lend support to the idea that conceptual change can only occur if it is recognised that individual concepts are not constructs that exist randomly in learners, but that they form part of more elaborate hierarchies of concepts, and that the higher the hierarchical level of a concept, the more dual situated learning events have to be designed and implemented to address shortcomings.

"Dual situated learning events" are teaching interventions (of no prescribed form) designed to accomplish two purposes:

1. the creating of dissonance with students' pre-existing knowledge (causing them such intellectual discomfort that they feel the urgent need for resolution, that is, for that which Piaget (1964) calls "equilibration");

2. to provide learners with the mental sets they need to resolve the dissonance and to construct acceptable scientific concepts — the term "mental sets" is used by She (2002) in the same sense, I believe, as the Ausubelian-Novakian notion of "propositional hierarchies" (Novak, 2002) — enabling the learner to view the newly presented concept as more understandable, believable, acceptable and useful than any ideas held formerly.

The present study and that of She (2002) have the following points of intersection. She posed the following six distinct research questions:

1. What is the nature of the physics concepts that must be acquired?

2. What is the state of the preconceptions with which learners come to a lesson on air pressure and buoyancy?

3. In the light of the answers to the first two questions, what are the mental sets that learners must acquire in order to achieve the needed conceptual change?

4. What dual situated learning events must be designed to simultaneously create the disequilibrium needed and provide the necessary mental sets with which learners can construct more scientifically acceptable understandings?

5. How are the dual situated learning events to be implemented, and how is this instruction received by learners?

6. If the proof of the pudding is in the eating, do learners who have been exposed to dual situated learning events subsequently predict and explain a new and challenging problem in the area of air pressure and buoyancy correctly?

Only the first of the above list of research questions is taken up in the present study, which adopts basically the same theoretical orientation as She's (2002) study. As pointed out earlier, the basic orientation of She's research is the model of "learning as conceptual change" (Posner *et al.*, 1982). Fundamentally, this entails identifying the scientifically unacceptable preconceptions that a learner holds, designing and implementing teaching interventions that expose the learner to discrepant events (disequilibrium), events designed to reduce the status of erroneous preconceptions while simultaneously raising that of scientifically acceptable understandings, making these more intelligible, plausible and fruitful than the formerly favoured preconceptions. In this process a change is effected within the learner's conceptual ecology, which is the universal set of all the concepts, understandings, beliefs, attitudes and values that the learner holds.

A further foundation of She's research is the distinction made in the literature between *"weak restructuring"* (what Posner *et al*. (1982) call *"assimilation"*, corresponding to what Pines and West (1986) refer to as *"conceptual development"*) and *"radical restructuring"* (what Posner *et al*. call *"accommodation"*, corresponding to what Pines and West refer to as *"conceptual exchange"*), either of which may occur during conceptual change.

Support is also expressed by She, drawn from the writings of Linder (1993, quoted by She, 2002) and Marton (1993, quoted by She, 2002), for the view that new ideas are related to the context in which they are used. The challenge in designing dual situated learning events therefore includes providing contexts in which the notion of air pressure is applied. The theory of teaching and learning in science known as situated cognition has gained ground and certainly is well-supported in the literature. For example, Lave and Wenger (1991, p.35 quoted by Watson, 1998) state that much learning takes place outside of the formal classroom. When learners are exposed to numerous situations in everyday life, the learning of mathematical (and I would add science) concepts and skills becomes *"an integral part of generative social practice in the lived-in world."*

It is at this point that the present study has its first point of disagreement with the theoretical underpinnings of She's research. After referring to the view expressed by Tytler (2000) that children's conceptions appear not to be theory-like but rather seem to be responses to contextual situations, the following conclusion is drawn by She: (p.982)

"This implies that conceptual change is better represented as a gradual ***accretional*** *phenomenon rather than as a Kuhnian scientific revolution."*

The present author holds a contrary view. She (2002) has designed a range of teaching interventions called "dual situated learning events" that are designed to induce in students a shift in learners' ontological views of a concept, no less! It therefore appears necessary that learners' thinking ought to undergo *"radical restructuring"*, *"accommodation"* or *"conceptual exchange"*. The term "accretion" is similar in meaning to such words as "accumulation", "build-up", "accrual", "increase", "enlargement", "addition" and "growth". None of these words seems to correctly describe the upheaval in the thinking of a student that starts off with the naïve idea that air cannot be compressed and ends up with the far more sophisticated understanding that the concept of air pressure combines elements of matter (namely that air has the attribute, invisible to both the naked and microscope-assisted eye, that it consists of tiny molecules) and process (namely that air particles are in constant motion, and that the sum total of their motions, in particular their collisions with the boundaries of the closed system in which they exist, exert a measurable and calculable pressure on the walls of their container).

Chi *et al.* (1994, quoted by She, 2002) had suggested that the real stumbling block to conceptual change is the mismatch between the ontological views that learners hold about a concept and the ontological category assigned to that concept by the scientific community. This theory has since been subjected to thorough scrutiny by Lee and Law (2001), who explored how conceptual change is promoted via ontological category shift in the case of concepts in electricity. These researchers reviewed the three important claims made by Chi *et al.* (1994, quoted by Lee & Law, 2001), namely:

- the epistemological claim that all entities in the world belong to three primary ontological categories: "matter", "constraint-based interaction" (a subcategory of "process"), and "event";

- the definition of many scientific concepts as *"constraint-based interactions" (CBI),* which is a subcategory of processes in which a defined system behaves according to the principled interaction of two or more constraints;

- the proposition that many alternative conceptions belong to the "matter" category and that learning in these instances requires a shift in the concepts' ontological status from the "matter" category to the "process" category.

The present study focuses on the question of precisely what conceptions learners hold in this area (including their epistemological and ontological views), how they understand the terminology employed in this section, and how they interpret and account for natural phenomena and technological applications that relate to atmospheric pressure. The decision to explore the concept of atmospheric pressure also acknowledges the need to make explicit the conceptions that learners hold of an omnipresent reality that is taken for granted, that is at play with every breath we take, but that is essentially unobserved and unregarded.

In the following chapter, this report will devote space to a discussion of the theoretical underpinning of this research.

CHAPTER 3

THEORETICAL UNDERPINNING

3.1 INTRODUCTION

The work of a number of researchers has been taken into account in establishing the basis of the transcript analysis. The interview transcripts have been examined carefully and analysed in the light of research into children's science (Gilbert, Osborne & Fensham, 1982), into the contrast between "meaningful" and "rote" learning (Novak, 2002), into the nature of scientific knowledge and the epistemological views that students hold (Désautels & Larochelle, 1998), and into the ontological categories identified by Chi, Slotta and DeLeeuw (1994, quoted and investigated by She, 2002 and Lee & Law, 2001).

This underpinning will now be elaborated, and the tentative nature of scientific knowledge will be explained by a brief overview of the most important schools of thought relating to the philosophy of science.

3.2 RESEARCH INTO "CHILDREN'S SCIENCE"

Gilbert, Osborne and Fensham (1982, pp.625–627) define "children's science" as the notions, beliefs and expectations which form conceptual structures that provide a sensible, coherent understanding of the world from the child's point of view. These authors highlight five distinguishing features of "children's science". These are:

1. Young learners tend to offer an account of formal science concepts using everyday language.

2. They often resort to self-centred and human-centred explanations for formal concepts, treating phenomena as personal experiences.

3. To many young learners, "nonobservables" (or that which cannot be seen or directly observed with the senses) do not exist.

4. Objects are assigned characteristics of humans and animals when learners speak of objects as having feelings, exercising their will, or performing purposeful actions. (For example: "Gas molecules try to escape from their pressurised container.")

5. Objects are often endowed with a certain amount of a physical quantity.

Gilbert *et al.* (1982) argue that it is necessary for teachers to learn about children's science, for the reason that children's views are sufficiently strong and persistent that these will interact with science teaching. Three aspects of getting to know children's science are thought to be important, namely:

- Teachers ought to know how to explore the state of their learners' views on topics to be taught and learned;
- Teachers ought to determine the content and nature of their learners' views;
- Teachers ought to consider the various ways in which children's science may, or may not, be modified by learning experiences.

The call that Gilbert *et al*. (1982) make is that a teacher ought to listen to, be interested in, and value the views that children bring to science class. Teaching efforts that fail to take such views into account are almost guaranteed to fall short of achieving even the modest objective of making learners aware that there is a viewpoint alternative to theirs, namely that of the scientific community.

3.3 THE CONTRAST BETWEEN "MEANINGFUL" AND "ROTE" LEARNING (NOVAK, 2002)

Drawing on the work of Ausubel, Novak distinguishes between rote learning and meaningful learning, Novak (2002, p.549) states that "meaningful learning involves substantive, non-arbitrary incorporation of concepts and propositions into cognitive structure". Meaningful learning, according to this view, requires a well-organised, relevant knowledge structure, also a high commitment on the part of the learner to seek relationships between new and existing concepts and propositions. Meaningful learning takes place "where the learner chooses conscientiously to **integrate** new knowledge" with existing knowledge. In contrast, rote learning takes place when learners are forced to memorise information that has little relevance, and is poorly organised. Rote learners have little or no commitment to integrate new ideas with existing relevant knowledge (this contrast is illustrated in Novak, 2002, p.552). Novak argues that all learning lies on a continuum between these two extremes.

In the present study, the above definition of rote learning was followed closely when seeking answers for the epistemological question of how respondents' knowledge was generated. It was assumed that the ways in which respondents reply to questions relating to the concepts of pressure and atmospheric pressure could provide clues as to the degree of conscientious effort put forth to connect these concepts with existing concepts and propositions. Novak (2002, p.550) reminds us that "all concepts are an abstraction, a representation of reality in our minds, not the reality itself". In this statement, the definition applied to the term "concepts" was "perceived regularities in events or objects, or records of events or objects designated by a label (usually a word)". One question addressed in the present study is whether the students interviewed showed any awareness of the abstract nature of the physics concepts under discussion, and the other is whether the degree of integration of the concepts with other knowledge might reveal whether anything other than rote learning occurred. Is the knowledge that the respondents have of the constructs "pressure", "atmospheric pressure" and the kinetic theory useful to them in the sense that it helps them to explain natural phenomena or technological applications encountered in their daily lives?

3.4 NATURE OF SCIENTIFIC KNOWLEDGE AND THE EPISTEMOLOGICAL VIEWS THAT STUDENTS HOLD

Désautels and Larochelle (1998) studied the nature of the concept of a "particle" held by junior-college students. Many of the respondents in their study tried to explain the idea of a particle by equating it to familiar objects encountered in everyday life. Put another way, "they tried to impart meaning to the 'relational world' of scientific knowledge into the world of 'everyday materiality' ". It is clear that such an endeavour would have serious associated difficulties, for the simple reason that scientific knowledge is tentative, while there is no way (and little point in trying) to make a schoolboy believe that the marbles or football with which he plays during break times, and to which he is taught to liken the scientific concept of a particle, are in any sense not real.

The tentative nature of science and of scientific knowledge has been skillfully and lucidly highlighted by a number of authorities. For example, Matthews (1998, p.995) expresses himself in the following words: "To my mind, the nature of science is best approached inductively and tentatively, not didactically". Chalmers (1994) explains that, in the philosophy of science expounded by Imre Lakatos, a scientific theory is a research

programme with a negative heuristic (a “hard core” that is assumed to be unassailable) and a positive heuristic (representing a "protective belt" of assumptions, hypotheses and initial conditions). However, over the passage of time, increasing technological sophistication and improvements in experimental methods (and the concomitant accumulation of exceptions to the rules postulated by any given theory), and a general decline in the predictive and explanatory capabilities of the theory, all combine to render the research programme degenerate. The problems experienced by the theory eventually become so many and so intractable that the protective belt of assumptions, hypotheses and initial conditions that support the theory becomes worn out, and when this occurs the hard core gradually becomes untenable. Under these conditions the theory or research programme is ultimately abandoned. An illustration of this process is the gradual change from a geocentric to a heliocentric (Copernican) view of the universe.

Désautels and Larochelle (1998) found that students often overstate the “absolute implacability of laws”, and that where models are employed, their tentative nature and the fact that a model may only facilitate understanding of a small part of a physical entity or phenomenon, is not usually appreciated by students. They quote a study by Désautels, Larochelle and Pépin (1998) that found that the views of 88 percent of participants, who were preservice science teachers, on the relationship between scientific models and the concepts they attempt to describe, ranged from specular realism to asymptotic realism. Specular realism refers to the viewpoint that models “are constructed on the basis of what was seen”, that is, a scientific model precisely and completely represents the realities it is designed to explain. On the other hand, asymptotic realism is the view that “models evolve until they produce a resemblance with this reality”. Of particular interest for the present study is the way in which students interpreted and thought about molecular models, since one of the questions in the interview schedule was precisely about the way in which pictures in textbooks that purport to illustrate atoms and molecules are viewed by respondents.

In the present study, evidence of a “misappreciation of the model-using nature of scientific knowledge” (Désautels & Larochelle, 1998, p.118) was specifically looked for. A further aim was to assess whether respondents have a sense of the tentative nature of scientific knowledge.

3.5 THE ONTOLOGICAL CATEGORIES IDENTIFIED BY CHI, SLOTTA AND DELEEUW (1994, QUOTED BY SHE, 2002 AND BY LEE & LAW, 2001)

A very useful categorization of learners' conceptions is suggested by Chi *et al.* (1994). The foundation of the system by which learners' ideas may be categorized is the ontology assigned to each conception.

The three categories are as follows:

1. Matter-based conceptualizations;

2. Constraints-based interactions (a subcategory of "processes"); and

3. Events.

Lee and Law (2001) offer examples of each that help to clarify what is meant by each of the ontological categories mentioned above. All three examples are taken from statements made by learners who talked about their understandings related to electrical circuits.

1. **Matter**. The statement *"[c]urrent comes out from the battery and is used up by the bulb"* (underlining in original, p.114) was taken as evidence that current was being viewed as something of a material nature.

2. **Constraint-based interaction**. This is a subcategory of the larger category "process". When a respondent stated that *"[t]he total resistance in the circuit is smaller and voltage is unchanged, therefore current will increase"* (underlining in original, p.115), it was regarded as evidence that the subject appreciated that current is the result of an interaction in a system.

3. **Event**. This is a second subcategory of the larger category "process". When a respondent stated that *"current flows from the positive terminal to the negative terminal"* (p.115), that is, the idea that current has an entry point at a particular instant of time and an exit point some time later, this was coded as an event.

An attempt has been made, in the process of analysing the interview transcripts in the present study, to identify the ontological categories of respondents' conceptions relating to the phenomenon of atmospheric pressure. Working in the area of electricity concepts, Lee and Law (2001) appear to convincingly demonstrate ontological category shift, in particular the

shift from “matter” to “constraint-based interaction” (that is, “process”), to be crucial in the achievement of conceptual change, provided that the learner’s attention is focused on the salient constraint at play in the study of the concept.

An investigation of how such ontological categories may shift after instruction, while of the utmost importance to the broader teaching-learning enterprise in science education, is beyond the scope of the present study. However, an investigation of what these categories are (and of how to identify them) is a necessary first step.

3.6 THE THEORETICAL LENS THROUGH WHICH THE RESPONSES OF LEARNERS WILL BE VIEWED

3.6.1 The role of model-making in science

The question of how respondents understand the relationship between a model (in this case, space-filling models) of gas molecules and the gas molecules themselves, is one that relates to the issue of the nature of science and scientific knowledge.

The relationship between scientific knowledge and the entities that are the subject of studies in physics is one that has occupied the attention of philosophers of science for centuries. Historically, in the western world, two requirements have always been considered fundamental in any epistemological discussion of knowledge. One is that "true knowledge" has to be independent of the person acquiring it. The other is that knowledge that is valid has to represent ontological realities accurately (Von Glasersfeld, 1989, 1992). Piaget (1964) defines an "operation" as the starting point for acquiring knowledge. A learner, in the process of constructing knowledge (the process of internalizing some aspect of public knowledge) performs mental operations on that knowledge, trying to assimilate new ideas into an existing scheme (or schemata), or trying to accommodate and come to terms with, or equilibrate, newly introduced ideas. So, of necessity, such knowledge cannot be a copy, or exact reflection, of some external, ontological reality. The performing of mental operations involves modifying or transforming information received, working with that information, linking it with existing knowledge, ideas and beliefs, to the point where the learner is comfortable with that knowledge.

3.6.2 The position of inductivism

An important question is whether or not science is a fixed body of knowledge. This relates closely to the question of how the body of knowledge has been acquired. Naïve inductivism is a philosophical standpoint that makes the claim that science starts with observation. Inductivists feel that observation yields a secure basis from which knowledge, that is, scientifically acceptable concepts, propositions, hypotheses, theories and laws may be derived (Chalmers, 1994). The argument is that, starting with observations of a phenomenon, a theory is then formulated by a process of inductive reasoning. There are at least two reasons why this position is not sound. First, inductive reasoning is not reliable (data gathered in the course of an experiment may be interpreted differently by two equally competent researchers). Second, signals that may be perceived by our senses in our way are not necessarily perceived in the same way by other observers. This means that observation itself is not a reliable basis on which to establish a theory. The descriptions given of whatever observational work is carried out, referred to by Chalmers (1994, p.31) as “observation statements”, are rooted in the theoretical education that the observer possesses. Observation is an activity that is personal and subjective, and is theory-laden as a result.

Put another way, if the same phenomenon were simultaneously to be replicated in laboratories all over the world, and the data gathered be studied, and inferences drawn from the results, such inferences should (from an inductivist viewpoint) be in general agreement. This would imply that science is a fixed body of knowledge, there being only one valid way of understanding or interpreting experimental results. This would suggest that all that needs to be done is to “discover” the correct interpretation by observation and inductive reasoning.

3.6.3 The contribution and limitations of falsificationism

An alternative way in which the progress of scientific knowledge has been explained is the philosophy of falsificationism, a position that sees science as a set of tentative hypotheses that are proposed to describe and explain the behaviour of the universe. To a scientist, from a falsificationist point of view, an acceptable hypothesis must be falsifiable. Karl Popper, quoted in Chalmers (1994, p.43), states that “we can learn from our mistakes . . . and shall have got nearer to the truth.” Hence the falsificationist claim is that science progresses by trial and error.

However, falsificationism is limited by the fact that observation statements, as argued earlier, are fallible. Such observation statements form the basis of the decision that a particular hypothesis has or has not been falsified. If an hypothesis appears to be refuted by a particular experimental result, this does not mean that the hypothesis has been decisively falsified and should therefore be abandoned. Experimental work is arduous, and the data obtained and the conclusions that are drawn may be contradictory.

3.6.4 The “research programmes” of Lakatos and the “scientific revolutions” of Kuhn

Imre Lakatos and Thomas Kuhn (quoted in Chalmers, 1994) interpret scientific theories, not as single hypotheses that may or may not be falsifiable by individual observation statements that contradict them, but rather as organised structures that are resistant to rejection by falsification and subsequent abandonment.

Lakatos uses the term "research programme" to describe a theory that serves as a guiding framework for present and future research. It consists of a "negative heuristic" (a set of basic assumptions on which the theory depends, its "hard core", along with the stipulation that these may not be rejected or altered) and a "positive heuristic" (guidelines on how the research programme might be developed). The "hard core" of a research programme is protected from falsification by a "protective belt" of additional hypotheses and initial conditions, a decision that allows the research programme the chance to reach its full potential. The strength of a theory defined as a Lakatosian research programme is twofold, namely its explanatory power and its usefulness in predicting new phenomena.

On the question of whether it is possible to falsify a theory that is defined as such a large and organised structure, Lakatos regards a research programme as either “progressive” or “degenerating”, depending on whether it succeeds in leading to new discoveries or it persistently fails to do so. Degenerating research programmes are gradually abandoned. This was ultimately what became of Ptolemy’s astronomy, which had led to, or predicted, no new phenomena throughout the Middle Ages. Yet, from the 16th century onward, Copernicus’ emerging heliocentric theory was developed in the face of a number of observations which seemingly had the potential to falsify it decisively. In time, however, advances in the fields of mechanics and optics made it clear that those “problematic” observation statements were themselves in need of revision. The heliocentric theory ultimately proved to be a highly progressive research programme, and is the currently accepted picture of the solar system.

Thomas Kuhn views scientific progress as occurring by revolutions. Briefly, a science arises when a single paradigm, similar to the "hard core" of a Lakatosian "research programme", becomes accepted by a scientific community. As phenomena in the natural world are examined and revealed by experimental work, over time there are sure to be difficulties and apparent falsifications that may call the theoretical assumptions of the paradigm itself into question. As such difficulties and anomalies increase in number and seriousness, a crisis develops which may lead the majority of the scientific community to abandon the old paradigm and adopt a new — a change called a "scientific revolution".

The point of the foregoing review is that the falsificationist, Lakatosian and Kuhnian accounts of the progress of scientific knowledge all provide the insight that scientific knowledge is tentative. It is neither final nor fully settled, but is always under construction and undergoing change. In analyzing the answers given by respondents in this study, a judgment will be made of whether or not learners appreciate that physics really is an attempt to enquire into the workings of the physical world, and that the answers obtained in the process of that enquiry are, at best, tentative and approximate.

3.6.5 An example of the changeable nature of scientific knowledge

A potential source of misunderstanding about the nature of scientific knowledge becomes apparent in the use of scientific models. Désautels and Larochelle (1998), in a study of the epistemological views of students, report that students have a tendency to raise the status of a tentatively proposed model unduly. In the words used by these authors, young learners are inclined “to endow scientific concepts with an ontology” (p.115). The question could be asked: Is a billiard ball a good way of representing an atom? Certainly, such a picture proved useful to John Dalton when he first proposed an atomic model of the chemical elements. When J. J. Thomson discovered the electron in the late 1890s the accepted “picture” of the atom changed to that of a currant bun. This model was, in its turn, shown to be inadequate when Ernest Rutherford revealed the outcome of his experiments with gold foil about fifteen years later, giving us a view of the nuclear atom (consisting of more than 99% empty space!). Now, in a quantum mechanical treatment an atom is viewed in terms of a probability function (a singularity in space-time).

So what is an atom after all? Answering this as a multiple-choice question, perhaps the best answer would be: none of the above. Models in science, from the standpoint of radical

constructivism (Von Glasersfeld, 1989), do not match ontological realities. Matthews (1998) states that many educators "have adopted constructivist epistemology and a constructivist account of the nature of science". All the above-mentioned atomic models say something instructive about what an atom is like, but none of them tell scientists precisely what an atom really is, nor do any of these models give a complete account of the structure and interactions of atoms. The only claim we are able to make is that we have acquired "the conceptual means to make sense of" and that is proving useful in the study of the atom (Von Glaserfeld, 1989). In the words of Davis and Hersh (1988), "a model may be considered good or bad, simplistic or sophisticated, aesthetic or ugly, useful or useless", rather than either strictly true or plainly false.

Thinking about the responses of subjects in the present study, the question that will be answered is whether or not respondents appreciate the tentative and incomplete nature of the models used in science, and indeed of scientific knowledge itself.

Davis and Hersh (1988, p.78) explain that the main purposes for constructing models include:

1. To obtain answers about what will happen in the physical world;
2. To influence further experimentation or observation;
3. To foster conceptual progress and understanding;
4. To assist the axiomatisation of the physical situation;
5. To foster mathematics and the art of making mathematical models.

However, these authors point out (p.79) that because theories in physics are subject to change or modification (the example that springs to mind is the change from Newtonian mechanics to Einsteinian mechanics in the case of systems and bodies moving at relativistic velocities), and because there may even be competing theories that are simultaneously current, there is a "pragmatic acceptance of a model as a 'sometime thing', a convenient approximation to a state of affairs rather than an expression of eternal truth". In this study, when analysing respondents' answers, an attempt will be made to determine whether these answers reflect an appreciation of the "sometime" nature of models in science.

This report will now proceed to a discussion of the methodology employed in the present study.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 INTRODUCTION

The intention of this study is to gather qualitative data on learners' understandings of atmospheric pressure by means of well-conceived and properly executed clinical interviews.

Cohen and Manion (1993) describe three purposes served by the interview, namely,

- it provides access to "what is inside a person's head" (a quotation from Tuckman, 1972), be that knowledge, information, values, preferences, attitudes or beliefs;
- it may be used to test hypotheses, or to suggest new ones; and
- it may be an explanatory device to help identify variables and relationships.

Given that the intention in this study is to record the thoughts of respondents on the subject of the pressure exerted by the atmosphere in as much detail as possible, it is clear that the clinical interview is the technique best suited to the purpose of this research. Questionnaires present rather more limited opportunities for asking additional questions, or probing for clarification (Cohen & Manion, 1993), both of which are of crucial importance to the present study.

Posner and Gertzog (1982) offer guidelines on the use of clinical interviews that this study has attempted to implement. They emphasise that clinical interviews ought to uncover and take into account the assumptions that learners make about science and scientific knowledge. Thus the interviewer endeavoured to listen carefully to transcriptions of audiotaped interviews to hear what the respondents' epistemological viewpoints are: on science, on scientific concepts (in particular, the concept of atmospheric pressure), and on the usefulness of the kinetic molecular theory of gases.

4.2 THE CLINICAL INTERVIEW

Piaget developed the "clinical method" by adapting the interviewing technique used by the psychiatrists and psychoanalysts of his era for purposes of diagnosis and the provision of therapy. He turned the clinical interview into an investigative tool for researching the nature and extent of children's knowledge. A key advantage of this technique is that it allows the

respondent to take the lead in the conversation, and to express thoughts more freely than is possible through the use of other information-gathering techniques, such as observation and testing. (Posner & Gertzog, 1982; Treagust, 1988)

Posner and Gertzog (1982, p.196) extract the following quotation from the preface to Piaget's first book, *The Language and Thought of the Child*, written in 1926:

"the clinical method . . . consists in letting the child talk and in noticing the manner in which his thought unfolds itself . . . [it] does not confine itself to superficial observations, but aims at capturing what is hidden behind the immediate appearance of things"

Schumacher and McMillan (1993) itemize the steps to be followed in constructing an interview as follows:

1. justification;
2. defining objectives;
3. writing questions;
4. deciding general and item format; and
5. pretesting.

4.2.1 Justification

The main justification for using the interview is its flexibility, the facility to probe beneath the surface of answers that may have been rote-learned, the possibility to infer ontological opinions from respondents' answers to indirect questioning, to allow respondents free rein to express their thoughts, enabling the interviewer to obtain the best possible picture of 5 Ws and H (what, who, when, where, why and how), and much more, namely the views that learners themselves hold in this area of physics.

4.2.2 Defining objectives

It is the aim of this study to determine the nature of the concepts that first-year physics students hold in the area of atmospheric pressure. The three objectives highlighted in chapter 1 of this report are:

1. To determine what conceptions the learners studied hold on atmospheric pressure, its origin, natural phenomena associated with it and its technological applications;
2. To determine the respondents' epistemological commitments related to atmospheric pressure;
3. To clarify and categorise, if possible, the ontological assumptions made by learners in their thinking about atmospheric pressure.

This non-interventionist study attempts to probe for deeper understandings than what instruction generally allows students to cultivate.

In order to meet objective 1 above, (apparently) straightforward questions on the content of learner conceptions are included in the interview schedule.

In order to achieve objective 2 above, it was necessary to elicit learners' views and opinions about the use of models and the application of theories. Further, it was decided not to directly ask them to express their views on the usefulness (explanatory power) of the kinetic molecular theory of gases. On the contrary, it seemed appropriate to do a demonstration and to make a judgment based on each respondent's ability to account for what they observed by applying the assumptions of the kinetic theory.

In order to achieve objective 3 above, a simple categorisation system was established based on the three ontological categories discussed in chapter 3, namely matter, constraint-based interaction and event.

4.2.3 Writing questions

Foddy (1993) presents both sides of the debate on the suitability, for purposes of research, of the use of open as opposed to closed questions in an interview. The purposes of the present study appear to be best served by the use of predominantly open questions. Foddy (p.127) states that *"[p]roponents of the use of open questions argue that they allow [respondents] to say what is really on their minds without being influenced by suggestions from the researcher"* (underlining added). The use of open questions, therefore, surely makes it possible to minimise bias, which Cohen and Manion (1993, p.302) define as *"a systematic or persistent tendency to make errors in the same direction".*

A second advantage of the use of open questions to the present study is that answers to open questions indicate respondents' levels of knowledge about the topic (Foddy, 1993). This may not be the case when respondents are faced with questions of a psychologically or socially sensitive nature, but such is not the nature of the questions asked in the present study. At the outset of each interview, it was emphasised that this was not an exercise designed to put any respondent "on the spot". It was stressed that the interviews would not and could not in any way affect the assessment of the respondent's performance in the Physics I course. Further, respondents could afford to be themselves because the interviewer was a student like themselves. And because the interviews were conducted under conditions of strict anonymity, they were being invited to express themselves freely and openly without fear of ever having anything they said traced back to them, for better or for worse.

4.2.4 Deciding general and item format

A methodology for exploring learners' views and understanding has been designed by Osborne and Gilbert (1980). As many as twenty situations that are familiar to the learner are depicted as line drawings on cards. (Each card has a single situation depicted on it.) The interview based on the illustrated cards is known as the "interview-about-instances", and the situations contain both instances and non-instances of the concept being explored. The pictures on the cards provide for the learner to speak freely about whether each given situation represents an instance or non-instance of the relevant concept, and to elaborate the reasons why or why not.

When these authors use such cards in an interview setting, it is to illustrate instances (examples) and non-instances (non-examples) of the phenomenon (or concept) being considered, and to get interviewees to talk about these pictures and the concepts they illustrate. Providing non-routine or uncommon examples and non-examples is also a useful way of probing for understanding. This method eliminates rote-learnable answers and definitions from the discussion and allows the researcher a window into what the learner really thinks. David Perkins, the then dean of education at Harvard University, in a lecture given at University of the Western Cape in 1988, made the remark that "rote learning is extremely fragile in the face of variation".

An alternative approach, developed by the same authors, is known as the "interview-about-events" technique. This involves conducting an individual interview with a respondent, also

seeking to explore understanding of a concept, but based on an smoothly linked series of practical demonstrations of situations to which the concept may be applied.

For the purposes of this study it was decided not to prepare a set of interview-about-instances cards as the basis for the interviews, in the manner of Osborne and Gilbert. The basis for this decision was a study done by Martínez Peña and Gil Quílez (2001). Owing to the seriousness of such a decision, some space will now be devoted to justifying this decision.

Martínez Peña and Gil Quílez (2001) pay careful attention to the quality of artwork in printed materials with which learners come into contact. Located within the "alternative conceptions movement", in which students' notions that are at variance with accepted scientific views are treated in a non-judgmental way (Wandersee *et al.*, 1994), this research was also grounded in the “assimilation theory” of cognitive learning of David Ausubel, which emphasises the role of learners’ prior knowledge in the construction of concepts and propositional hierarchies (Novak, 1977). Strongly present, too, was the influence of Vygotsky's notion of "semiotic mediation"; that is, the use of pictures, words and symbols in a learner’s construction of scientific concepts (Vygotsky, 1979).

In the work done by Martínez Peña and Gil Quílez (2001), an analysis was carried out of the illustrations in a variety of primary and secondary school textbooks. This was followed by an analysis of the conceptions and graphical representations of a group of 78 student teachers in the third year of university teacher training in Zaragoza, Spain. This was done by means of a written questionnaire consisting of nine items relating to aspects of the Sun-Earth-Moon system. Next, a whole class discussion was held on basic ideas in astronomy as presented in the set of school textbooks analysed earlier. Finally, the students were given a problem to solve on the view of the moon as seen by two observers at different locations.

The findings of this research included the identification of school textbooks as a major source of misinformation in this area of astronomy. The artwork in the textbooks was, for various reasons, found to be of poor quality. It was found to be unclear and tended to lead readers to incorrect understandings of the phenomenon of moon phases. The explanatory text and labels accompanying line drawings in the textbooks studied was found to be insufficient to address the shortcomings of the drawings themselves. Learners who were exposed to such learning materials were found to be unable to effectively express themselves by means of diagrams. Out of this research it became apparent that attempting to depict 3-dimensional situations

using oversimplified 2-dimensional line drawings is potentially misleading to learners who view such drawings.

Applying these findings to the decision on whether to adopt the "interview-about-instances" technique in the present study, it was noticed that the line drawings characteristic of this technique are typically of poor quality. Osborne and Gilbert (1980) acknowledge that during the interview-about-instances, before answering questions, respondents may need to ask questions of their own to clarify perceived or actual ambiguities. It was therefore decided that the interview schedule in the present study should incorporate high quality artwork in an effort to generate discussion around model-making in science.

Having said that, the idea behind the technique, namely getting respondent's to talk about a concept based on an illustration, was accepted and implemented in the interview schedule.

A further decision was to use word pictures during the actual interviews in order to sketch relevant scenarios. It turned out that respondents appeared to have little difficulty understanding the word pictures employed. All respondents could relate to the activity of climbing high mountains, and to the phenomenon of wide-bodied passenger jet aircraft taking to flight, when given their verbal description.

4.2.5 Pretesting the interview schedule and questioning on a small sample

A pilot study was done by trialing the interview schedule with the first three respondents. This allowed for the questions, the questioning and the sequencing of questions to be checked. Also, it allowed for any difficulties with the activities and problems set to be identified and rectified. Given the open-ended nature of the investigation, it was difficult to anticipate the outcomes of the interviews.

However, the interview schedule was not found to have any substantive flaws. The schedule had been compiled with care and had been carefully checked by the researcher (who was also the interviewer in this study) and his supervisor, an experienced physicist and science educationist. If any problems did show up during the first three interviews it was with the interviewer talking too much. The pretesting phase alerted the interviewer to the need to talk less when respondents have difficulty answering a particular question. One example of a pitfall into which the interviewer fell was the inadvertent addition of the word "therefore" in the questioning sequence on whether molecules of air have mass and weight. Once it had been

established and agreed upon that they do indeed have both mass and weight, the interviewer on more than one occasion rather gave it away by asking, “Do these molecules **therefore** exert pressure on objects with which they come into contact?” It is a very easy thing to slip up in this way, and this is a source of bias that can creep into the process.

The interviews in the pretesting phase were held during the third teaching block, just before the pre-examination “cramming break”, and the main study shortly thereafter. Each interview lasted no longer than 20 minutes, and was audiotaped and transcribed.

In selecting a sample of first-year physics students, no correlation was sought between conceptions held and the gender, ability, academic, racial or cultural backgrounds of respondents. The pilot study involved three (3) respondents, and the main study seven (7).

4.3 STEPS TO ENSURE RIGOUR

A suitable interview schedule was devised, and considerable attention was devoted to checking the schedule for content validity, a check for correctness related to the content of physics concepts and use of physics terminology. Also, the interview schedule was examined for construct validity. This involved making sure that an affirmative answer could reasonably be given to the following questions:

1. Were the questions asked clear and easily understandable?
2. Were the practical demonstrations and activities carried out easy to perform?
3. Were the instructions to be followed unambiguous?
4. Were the questions asked, the practical demonstrations and activities carried out, and the instructions given suited to the purpose of the investigation?
5. Were the questions asked, the practical demonstrations and activities carried out, and the instructions given appropriate to the level of knowledge and understanding of respondents?

4.4 ETHICAL ISSUES

Strict anonymity of respondents was maintained when reporting interview responses. Respondents were invited to be interviewed on a completely voluntary basis. Further, a completely non-threatening environment was created in which respondents were assured that the interviews being conducted carry no implications whatsoever relative to assessment in the

context of their university studies. Respondents would not be tested on knowledge needed for the successful completion of their studies, and no value judgments would be made, either during or after the interviews, as to the correctness or validity of any views expressed.

4.5 PROCEDURES FOLLOWED

4.5.1 The interview schedule

In this study, the interview schedule for the pilot study made provision for the following:

1. An inquiry into the basic definition for pressure;
2. A demonstration to explore understanding of the terms employed in the definition (referred to in Appendices 1 and 2 simply as DEMO 1 for the sake of convenience). The following picture illustrates the idea. In Figure 1a, the sharp-point pencil is pressed into the soft clay with a certain force. In Figure 1b, the same pencil is pressed with the same force onto a coin placed on the clay. The question directed to each respondent is where the pressure applied would be greater, and why?



Figure 1a: Sharp-pointed pencil pressed down directly into the soft clay

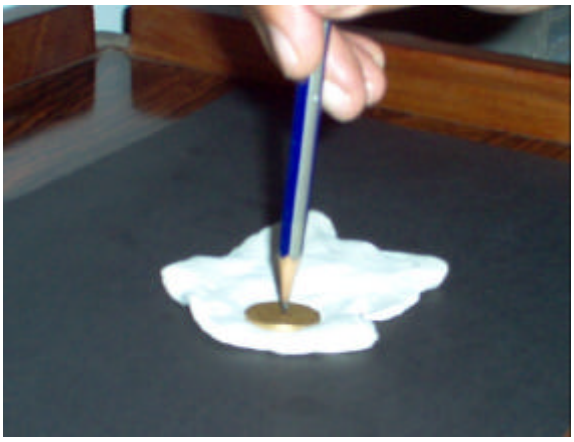
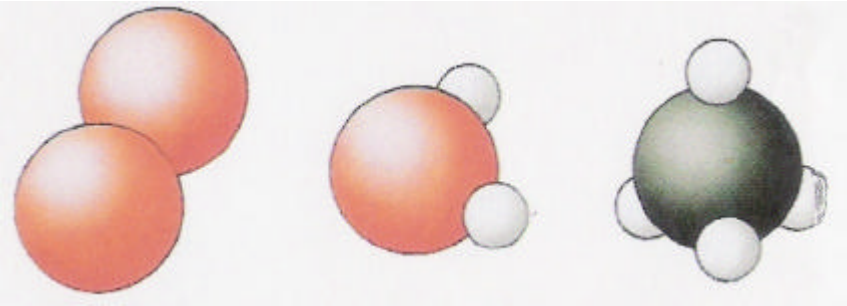


Figure 1b: Sharp-pointed pencil pressed down with same force as in Figure 1a onto a coin on the soft clay

3. A series of questions exploring the respondents' views on what air is, what its components are, and the origin of the pressure exerted by the air on objects with which it comes into contact;

4. A full-colour picture illustrating three-dimensional space-filling models of gas molecules;



Oxygen *Water* *Methane*

Figure 2: Models of molecules

(Reproduced from: The Oxford Children's Encyclopaedia of Science and Technology, p.14)

5. A verbal description or word picture of the activity of climbing high mountains, and of the difficulty that climbers have in breathing at high altitudes, and the question for the respondent is: "Why the difficulty?";

6. A verbal description or word picture of the phenomenon of heavier-than-air flight, and the question for the respondent is: "What makes the flight of large aircraft possible?" That is, why does an aircraft not simply fall to the ground under its weight of thousands of kilonewton?

7. A demonstration of how a open-topped bottle filled with water does not lose its contents when topped with a flat piece of paper and inverted. The respondent is then asked to explain why the water does not simply pour out under its own weight. The following figure illustrates the overturned bottle with a small piece of paper at its mouth. In the interview transcript this demonstration is designated DEMO 2.



Figure 3: Bottle filled with water, a piece of paper slipped over the top and then inverted

4.5.2 The thinking behind the choice of items — a brief review

Item 1 was an apparently straightforward inquiry, based on the simple question "What is the definition of pressure?" On the most superficial level of interpretation, asking such a question may seem a pointless exercise. It would, after all, be completely answered when the respondent recalls that pressure is defined as force per unit area. True, but before commencing each interview, the interviewer explained to the respondents that the aim of the interview was to establish what they themselves knew, and how they understood the concepts under discussion, and not merely what was printed in the textbook. (This study is not concerned with the way aspects of public knowledge are presented in authoritative texts. Its focus is on the extent to which physics learners have constructed portions of such knowledge for themselves.) It was therefore anticipated that the question on the definition of pressure would generate a discussion on the meaning of the terms employed in the definition. Further, it was anticipated that respondents might try to illustrate the definition of pressure by referring to examples. At any rate, the simplicity of the opening question was also intended to help settle the respondents down and ease any anxiety they may have felt about the interview itself.

It is also a good idea to establish common ground between interviewer and respondent by

starting simply and then moving on to more complex issues. This is in line with the advice given by Novak and Gowin (1984), namely to proceed from more to less familiar area of subject matter and from broad to detailed, by Tuckman, (quoted in Cohen & Manion, 1993) to try to make the respondent feel at ease, and to build a comfortable relationship and rapport with the respondent (advice also given by Schumacher & MacMillan, (1993)).

Item 2 was a demonstration to explore respondents' understanding of the terms employed in the definition. The equipment used consisted of:

- a small piece of soft prestik (a sticky claylike material)
- a sharp pencil
- a coin

The piece of prestik was pressed reasonably flat and placed on a table top. The first task was for the respondent to press a hole in the prestik by pushing vertically down with the pencil. (The location of the hole made by the pencil was called point A.) Next, a coin was placed on a different part of the piece of prestik (point B) and the respondent was asked to repeat the procedure by again using the pencil to push down onto the coin. The instruction was to press down as hard (with the same force) as before.

The idea was to see whether the respondent was able to use the definition of pressure to compare the pressures exerted on the prestik at points A and B.

Item 3 consisted of a brief exchange between interviewer and respondent — a series of questions and answers exploring the respondents' views on what air is, what its components are, and whether it is believed that oxygen, nitrogen and carbon dioxide molecules have mass and weight. This is followed up by the question of whether or not these molecules exert pressure on objects with which they come into contact, and why. This line of questioning follows closely the line of reasoning following by Blaise Pascal (1663) in his original paper.

Item 4 presented a full-colour picture in the Oxford Children's Encyclopaedia on Science and Technology illustrating three-dimensional space-filling models of gas molecules. This was intended to generate discussion on respondents' views of model-making in physics. What relationship do learners believe exists between models and the physical entities that they represent? It was hoped that this discussion could shed some light on the ontological views of respondents. Novak and Gowin (1984) recommend that, when conducting clinical interviews,

textbooks, teacher's guides, and reference works can be used as auxiliary materials and as sources for good ideas to generate discussion.

Item 5 presented a description or word picture of the activity of climbing high mountains, and of the difficulty that climbers have in breathing at high altitudes. Genuine understanding of atmospheric pressure should mean that the respondent is able to apply knowledge of this phenomenon to explain natural phenomena. This question relates to the way in which the action of the diaphragm is affected by the atmospheric pressure.

Item 6 pointed the respondent to the reality that jet aircraft with masses measured in thousands of metric tons and carrying hundreds of passengers routinely take off from the local international airport and fly to their destinations. The question "What makes flight possible?" was designed to examine whether the respondent could apply knowledge of atmospheric pressure to explain an important technological application. The idea was to identify and explain the principle that if a difference is created between the pressures above and below the aircraft, such that the pressure above it is less than that below it, the result is an upward force on the aircraft that opposes the downward weight (force of gravity).

Item 7 was a demonstration of how a open-topped bottle filled with water does not lose its contents when topped with a flat piece of paper and inverted. It was preceded by an open-ended question on whether the respondent had any familiarity with the kinetic molecular theory of gases, and if so, whether he or she could apply such knowledge to the problem of explaining this apparently strange demonstration.

This combination of items on the interview schedule was intended to enable respondents to discuss their ideas openly and (hopefully) meaningfully. The aim was to allow respondents to express themselves freely. Since this format had nothing in common with regular assessment techniques at this level, and given the repeated assurances that this interview would have no impact whatsoever on the assessment of students in the first-year physics course, it was understandable that respondents, with one exception, found the conversations completely non-threatening and, for the most part, enjoyable.

The report will next proceed to an analysis of the interviews that were conducted.

CHAPTER 5

ANALYSIS OF RESULTS

5.1 INTRODUCTION

The basis on which the expressions of respondents are analysed is explained in some detail in chapter 3 of this report. However, a succinct overview is appropriate at this point as it will assist the reader to conveniently follow the train of thought.

5.1.1 Research into "children's science"

Gilbert, Osborne and Fensham (1982, pp.625–627) highlight five distinguishing features of "children's science". These are:

6. Young learners tend to offer an account of formal science concepts using everyday language.

7. They often resort to self-centred and human-centred explanations for formal concepts, treating phenomena as personal experiences.

8. To many young learners, "nonobservables" (or that which cannot be seen or directly observed with the senses) do not exist.

9. Objects are assigned characteristics of humans and animals when learners speak of objects as having feelings, exercising their will, or performing purposeful actions. (For example: "Gas molecules try to escape from their pressurised container.")

10. Objects are often endowed with a certain amount of a physical quantity.

In this study there are no *a priori* expectations of the difficulties that respondents' replies are likely to reveal. A careful reading and analysis of the transcript will suffice to reveal whether or not the replies given by respondents have any of the above-mentioned features.

5.1.2 The contrast between "meaningful" and "rote" learning (Novak, 2002)

The analysis will look for evidence of whether any meaningful learning has taken place on the part of respondents in the area of pressure, atmospheric pressure and the kinetic theory. This

is based on the distinction that Novak (2002) makes between rote learning and meaningful learning. For meaningful learning to have occurred would imply that learners have acquired a well-organised, relevant knowledge structure. Also, it would mean that a learner shows a highly developed commitment to connect new ideas with what he or she already knows. The manner in which each respondent speaks about the concepts and phenomena raised during the interviews in this study may (or may not) reveal the degree of conscientious effort put forth to make such connections. An important question is whether the kinetic theory has any explanatory power for respondents. That is, how useful is this theory in explaining the natural phenomena and technological applications under discussion?

5.1.3 The nature of scientific knowledge and the epistemological views that students hold

This aspect of the analysis will concentrate on the ways in which the physics learners in this study view model-making in science. It is based on the work of Désautels and Larochelle (1998) into the epistemological commitments of junior-college students in Canada.

These authors found that students often do not realise that where models are employed in science, such models are tentative in nature and may only facilitate understanding of a small part of some physical entity or phenomenon. This misapprehension often leads learners to either a “specular realist” (in the more extreme case) or an “asymptotic realist” view of the relationship between scientific models and the concepts they attempt to describe.

In the present study, the analysis of the interviews will look for evidence of such realist viewpoints, and an attempt will be made to assess whether respondents have a sense of the tentative nature of scientific knowledge.

5.1.4 The ontological categories identified by Chi, Slotta and DeLeeuw (1994, quoted by She, 2002 and by Lee & Law, 2001)

The categorisation of learners’ ontological viewpoints that has been suggested by Chi *et al.* (1994, quoted by Lee & Law, 2001) will be used, namely:

4. Matter-based conceptualizations;

5. Constraints-based interactions; and

6. Events-based conceptualizations.

Finally, general observations will be made on the ability of respondents to speak lucidly and logically about ideas in physics, and to use such ideas in constructing satisfactory explanations for phenomena and how things work.

5.2 GENERAL OBSERVATIONS

5.2.1 Difficulties in expressing thoughts coherently and logically

A general observation that can be made when considering the set of 10 interviews conducted in this study is that most respondents really struggle to express themselves coherently and logically when talking about concepts in science. If learning science is really, in the words of Clive Sutton (1976, quoted in Scott (1998, p.72)) "learning to talk in new ways", then the group of respondents that was interviewed in this study truly have a long way to go in learning to speak this language of science concepts. Perhaps that is not a realistic prospect. The fact is that all the respondents in this study have had 13 years of formal education, and for all that time and a few years longer had much interaction with peers, parents and other family members, as well as exposure to books, magazines, printed and electronic media. Despite all of this, the inability of respondents to make scientifically acceptable statements, and their failure, at the simplest level, to account for natural phenomena using basic physics concepts such as pressure and atmospheric pressure, does not speak well of the contribution of the education system or of their environment to their science education to date.

5.2.2 A serious lack of confidence and self-esteem

One of the most startling and disappointing features of the interviews came into view before the first question was asked. When invited by the researcher to be interviewed on the subject of a physics concept, and despite reassurances that they would not be adversely assessed during the interviews, several respondents expressed a general lack of confidence. Before the interviews commenced, subjects were invited to settle down, and they were reassured that no judgments would be made of whether their remarks were either "correct" or "incorrect".

Yet, despite the fact that all respondents in this study were willing volunteers, a number did not feel confident about answering the questions in the interview schedule. This may reflect insecurity in their knowledge of physics, or possibly an exaggerated desire to please the

interviewer, to give the answers they may imagine the interviewer may have wanted to hear (which is in itself a possible source of bias). This lack of confidence was expressed in the following ways. Prior to the interview, these words were addressed to the interviewer:

"I'll try to answer your questions, but I must warn you I am not a model student!";

"I'm not good in physics";

"I'm not very intelligent".

The first two remarks were deflected by the simple observation that not being a "model student" was actually an advantage for the purposes of this interview. "Model students" in the South African classroom tend to be those whose rote-learned answers match precisely those expected by their teachers or the memorandum of the question paper in the context of a formal, written examination. The intent of this interview was to cut through all of this and reach down to what individual learners actually knew, how they were able to use that knowledge in constructing explanations, and how coherently and logically they were able to talk about the concepts and phenomena being discussed.

The third comment, *"I'm not very intelligent"*, was far more disturbing. Is that really the effect that 12 years of formal schooling and a full year of exposure to university teaching have had on this otherwise happy, vivacious, confident, gregarious, argumentative and talented young people? (The fact is that many of the interviewees were recruited to be interviewed rather informally, and the interviewer had the opportunity to see these potential respondents in their usual element before the interviews. It is on this basis that these positive adjectives are employed to describe their behaviour outside of the more structured interview setting.)

5.2.3 Clear indications that little meaningful learning has taken place

Another general observation on the course of the interviews conducted in this study is that almost all the respondents could either state the formal definition of pressure, or write that $P = F/A$, or manipulate this formula in some way, or express some recognition of the formula when it was given to them. At the same time, however, almost none of the respondents were able to give a scientifically acceptable explanation for what makes flight possible, why mountaineers report difficulty in breathing at high altitudes, or why the water in the filled inverted bottle did not pour out when a piece of paper was placed on top of it. The

explanations offered by the majority of respondents were unsatisfactory, even to themselves.

In this study, the respondents' general ability to repeat memorisable, rote-learnable definitions, along with their almost total inability to put relevant concepts to work to account for familiar natural phenomena and technological applications, points strongly to a learning mode that has, over the years of their schooling, been predominantly near-rote.

5.3 TALKING ABOUT "PRESSURE" AND "ATMOSPHERIC PRESSURE"

The first question was "What is your definition of pressure?". Only four of the respondents were able to give the straightforwardly rote-learnable reply that "pressure is force per unit area". The rest of the answers given revealed a range of problems related to their knowledge of pressure.

5.3.1 A question of simple ignorance?

Some respondents claimed not to know the definition. This claim was very difficult to understand, because it is a fact that pressure is a concept that is given prominence in both primary school and high school natural science curricula. As it happens, all the interviews in this study were conducted after all first-year physics lectures had been completed, and the concepts of pressure, atmospheric pressure and basic hydrostatics were all included in the syllabus to which each of the respondents were exposed. The question of how it is possible for learners with 13 years of formal education in science, who were neither difficult nor reluctant interviewees (all the respondents in this study were more than willing to discuss their knowledge with the researcher), could claim complete and simple ignorance is an matter that will be briefly addressed later in this research report. Interviewee 10 was asked the question *"What is your understanding of the concept "pressure" in physics?"* and simply answered *"I don't know"*.

Somewhat differently, respondent 2 stated that *"the only thing I know about pressure is that pressure is related to volume"*. The question arising from this reply was whether this was really all the respondent knew, or whether it was simply a case of being unsure of what answer was expected. It turned out that this was a case of ignorance rather than of forgetfulness, because even after the formula $P = F/A$ was drawn to the respondent's attention, in the portion of the interview following the prestik demonstration, it was clear that, for

practical purposes, the meaning of the formula was not clear. In response to the question *"So, over what area did you exert pressure at A?"* the answer offered was *"What do you mean 'what area'?"*

5.3.2 Difficulties in speaking the language

After replying, correctly, that "pressure is the force per unit area" (that is, giving the formal, rote-learnable textbook definition), interviewee 3 attempted a further explanation. This elaboration revealed confusion over the meanings of the terms contained in the definition: *"Pressure is the force per unit area, the force that acts on an object per unit area of that object"*. On the other hand, the respondent who made this mistake was able, in responding to the "prestik" demonstration, to correctly identify the region where the greater and lesser pressure had been applied. This suggests the possibility that the respondent may not have trouble with the concept of pressure, but may simply have difficulty expressing himself in the language of physics.

5.3.3 Symptoms of serious weakness in forming a physics concept

Interviewee 1 tried to explain what pressure was by personalising the matter: *"there is a force on you"*. Similarly, interviewee 6, in response to the question *"What do you understand by the concept of pressure?"* replied: *"When you put a force on something like . . . where air puts a force on the earth. . . "* (emphasis added)

This is a weakness often associated with very early childhood conceptualization. Gilbert *et al*. (1982) refer to this as the expression of a *"self-centred and human-centred viewpoint"* and add that *"[m]any young children have very egocentric views of the world"* (Gilbert *et al*., 1982, p.624). This interpretation would seem to be supported by the respondent's almost total ignorance of the concept of pressure, as revealed during the remainder of the interview.

5.3.4 Resorting to the formula

After claiming ignorance of the definition of pressure, interviewee 10 treated the formula $P = F/A$ in the following way. The interview sequence went like this: *"Q. Can you remember the unit in which pressure is measured?" "A. pascals . . . atmospheres". "Q. OK, and what is a pascal?" "A. . . . pascal . . . I forgot" "OK. If I wrote this (P = F/A), do you think you'd have an idea of what this is?" "A. . . . Ja. It's newtons over metres . . . actually metres squared."*

The respondent is here given the formula $P = F/A$. This seems to jog the memory and he understands F to be force and A area. He knows the units of these quantities, and on the strength of this draws the conclusion that the units of pressure must be *"newtons over metres squared"*.

Something else seems to be happening here. In the absence of an understanding of the definition of pressure, the respondent accepts the formula he is given, and figures out the units from there.

A very interesting use of the formula was seen during the course of interview 9.

Q. *Demonstration with prestik*

A. *[Incorrect.] Isn't it the same, because I applied the same force in both places?*

Q. *So, is the pressure you exerted here greater than that which you exerted here? Are they the same? Are they different?*

A. *It could be greater here because the area is larger.*

The interviewer then allowed the respondent the freedom to do a pencil and paper exercise (at the suggestion of the respondent). The respondent manipulated the formula: $P_1 = F/A_1$ and $P_2 = F/A_2$. The respondent did quite well to substitute possible values into the equations. She found, correctly, that the pressure exerted with a sharp pencil point is large, while that distributed over the area of a coin is smaller.

What emerges from these exchanges is that these learners seemed more comfortable manipulating a formula than talking about concepts and phenomena. In the section on conclusions and recommendations a body of research will be highlighted that points to the adoption of argumentation discourse in science classrooms as a possible way to address this difficulty.

5.3.5 Defining pressure by referring to a single example

Interviewee 4 felt that *"pressure is the amount of gases occupying a fixed volume . . ."*. Undoubtedly this respondent was referring to a gas that is trapped inside a closed container. Of course, the answer is patently incorrect (the question was, in fact, not answered at all), but when the respondent was subsequently pressed for a definition of pressure, simple ignorance

again manifested itself, as can be seen in the following sequence: *"Q. But what about the question of your definition of pressure? If you were to press down on the table, is there a pressure?" "A. Ja" "Q. Is there a definition of pressure?" "A. It's a force . . . sort of like a force . . ."*

A similar attempt to define pressure in terms of a single instance in which the concept is in play, was made by interviewee 2 in the following reply. Again referring to the pressure that an enclosed gas may exert on its container: *" . . . the smaller the volume the greater the pressure, because the less space the molecules have to move, therefore they are closer to each other, interact with each other more, and I think that pressure would be the measurement of the amount of collisions of molecules".*

Interviewee 9 did the same thing when asked to define pressure. *"OK, pressure would be . . . if I've got a compressor . . . if I decrease the volume of the thing, there's going to be more pressure, meaning that there are more collisions"*

5.3.6 Aristotelian ideas

Two Aristotelian notions, namely that "force causes motion" and that the natural direction of the force of gravity is "down", appear to be held by Interviewee 1, who stated that *"[p]ressure is the force that's applied to a certain area . . . it can move anything".* The same respondent added that *"there's the air pressure that's on you . . . it's the air pushing down . . ."*

5.4 RELATIONSHIP OF MODELS WITH THE PHENOMENA THEY SEEK TO EXPLAIN

In this part of the interview, each respondent was shown a high-quality three-dimensional picture of models of an oxygen molecule, a water molecule, and a methane molecule. The question was *"What do these pictures mean to you?"* and when asked for clarification, additional questions asked included *"Do these pictures make sense to you?" "How do you understand these pictures?" "Did anyone ever see such molecules so that they could take a photograph like this in order to publish it in this encyclopaedia?"*

5.4.1 Specular realism

The first observation was that a number of respondents approached the question from a "specular realism" perspective. A few examples will suffice to emphasise the certainty that

rather than the model being like or approximate to a molecule in some respects, to the respondent's mind the picture of the model represented the molecular entity precisely.

In answer to the question "What do these pictures mean to you?", respondent 1 answered that *" . . . these consist of the different atoms, and as you can see here, the hydrogen atom is much smaller than the oxygen atom, because it's got less electrons so that it's so much smaller than the oxygen . . ."* (emphasis added). To this respondent, the model was so close to the molecule itself that even the relative sizes of the atoms in the picture had an exact correspondence with the situation obtaining in the extreme microscopic world of atoms and molecules. In a similar way, interviewee 2 also referred to the relative sizes of the molecules, *"how they are arranged stepwise"*.

Interviewee 4 showed a poor grasp of the most basic definitions, and responded to the picture of models of simple molecules in a very superficial way. For this respondent, the pictures seemed to take on great authority. After all, they're printed in an authoritative textbook. They seemed to be something to cling to in the absence of any constructed knowledge of the subject. This could be seen in the following exchange:

Q. *I want to show you this picture. This is a picture of an oxygen molecule, and this is a picture of a water molecule. I'm sure you've seen many pictures like these. How do you understand pictures like these?*

A. *They show you how, like, gases bond . . . so I understand . . . like, when you've got oxygen gas I know that, normally, . . . two atoms of oxygen are joined.* (emphasis added)

Similarly, respondent 8 stated that *"it's just simple structures of gases that we know"*. This turned out to be merely a view, not a commitment, since it was almost immediately repudiated:

Q. *Is there any connection between pictures like these and the oxygen we actually breathe in?*

A. *No, not really*

The expression made, namely *"of gases that we know"* seems to be a statement of an epistemological viewpoint that is really simplistic. However, this seems, again, to be a viewpoint to which the respondent has no commitment. A complete change of mind was

evidenced when the respondent was challenged as to the authenticity of the pictures showing models of molecules: *". . . it's basically estimates, I guess"* (emphasis added)

Another evidence of a "specular realism" point of view turned up in the notion that, were it possible to take photographs of individual molecules, the pictures would turn out very much like the pictures shown. Consider the following exchange involving respondent 10, in which the idea is expressed that the picture reproduced in a science textbook may be the outcome of microscopic photography:

Q. *Please look at the following pictures. Many science textbooks contain pictures like these. Did anyone ever see an oxygen molecule so that they could photograph it in order to give us a picture like that?*

A. *I don't think they did . . . microscopically probably ja . . . but with the naked eye you cannot (emphasis added)*

5.4.2 Asymptotic realism

Asymptotic realism is the view that a model evolves over time, and with increasing experimental evidence, to the point where it produces a resemblance with the entity it represents. (Désautels and Larochelle, 1998) Respondent 3 seemed to express such a view, emphasising such words as *"try": "trying to connect", "try to make you understand", "trying to explain"* in the following exchange:

Q. *Can you connect these pictures to the actual air that we breathe?*

A. *I have tried to do that before . . . like, trying to connect the molecules . . . I can't get the real connection, like, are these molecules that I'm breathing in exactly like those I see in pictures . . . sometimes they . . . use models to try to make you understand what they are trying to tell you . . . so, for me, I think they are trying to explain to me what molecules air consists of . . .* (emphasis added)

A clear statement that the pictures shown are "just a representation of" whatever they purport to represent was made by respondent 6. On the other hand, respondent 5 concentrated on the explanatory power of models in this way: *". . .so I suppose that when you try to explain something, you have to try to come up with an idea of what it would look like, how you think it's working . . . to explain why it does that . . ."*

There is not a fundamental difference between the viewpoints of specular and asymptotic realism. Both accept that valid models reflect or represent ontological entities, yet the former (specular realism) says that the model exactly represents the entity, and the latter (asymptotic realism) says that the model is very much like (nearly but not quite) the entity.

5.4.3 Science — a world apart from that of everyday experience?

A very interesting sentiment expressed by a number of respondents was that the things learned in science classes have little or nothing in common with what is happening in the world of their everyday experience.

When respondent 1 was shown the picture of molecular models and asked the question: *"Air is invisible. Do you think these pictures have any connection with real air?"*

A. *I think scientifically they do, . . . so if you try to explain to someone if they've never been in a scientific thing, it's going to be difficult to explain . . . but in scientific terms . . . I think . . . we can understand it . . . so I think in the scientific world you talk in different terms.* (emphasis added)

Respondent 2, when asked whether these pictures made sense to him, replied that *"from what I have learned in chemistry I can tell you that these make sense to me".* (emphasis added)

A strong disavowal that the "scientific world" and "real world" have anything in common was also expressed by this respondent. In response to the question *"Do these pictures have any connection to real air?" his answer was "No, not at all. Absolutely none. Because . . . we cannot see molecules of air . . . we can't see air . . . we breathe it in . . . it circulates . . . but no, in terms of looking at air which we obviously cannot see, these (pictures) make absolutely no sense . . . because . . . how many people would actually know about it? I can't see any connection between this and the air I am actually breathing in."* (emphasis added)

Respondent 3 shared respondent 2's concern with the invisibility of air molecules, and in response to the same question stated that *"For molecules which are invisible, . . . like when I look at water, liquid water, the shape is the same as the vapour, and the ice . . . but when I look closer to see whether I could maybe see something of these shapes I can't . . .* (emphasis added)

5.4.4 The tentative nature of scientific knowledge

The notion that scientific knowledge is not absolute, eternal truth is one which the majority of respondents could not express. Interviewee 5, a medical student and a top achiever at school speculated about this matter as follows: *"I've often thought that maybe in the future, we will be taught that this was the theory in the first place, but afterward it has been revised . . . in the future someone might decide that everything we've been taught up to now is actually wrong."*

Such a long-range view was not held by any of the other respondents.

5.4.5 Concern about the truth value of the molecular model

Respondent 6 had a very interesting concern about the truth value of pictures to portray the gas molecules of which air consists: *"no-one actually knows what a molecule looks like . . . you don't know whether what people are drawing in this textbook is the truth . . ."* Here the interviewee tried to relate the picture itself with the manner in which it was arrived at. This view was echoed by respondent 3: *"I don't know whether they use microscopes to see these shapes . . . I don't know how they find that oxygen is this shape, water is this shape . . ."* That this matter of the truth value of a model may well be an important issue to thoughtful learners surfaced during the course of interview 7. An otherwise confident and quite eloquent respondent suddenly resorted to jargon and became very uncertain in the following passage of conversation: *"Q. Has anybody ever taken a picture of a molecule, so that they are able to produce pictures like these? A. No, I don't think it's possible. I think they use . . . spectroscopy or something . . . and they use that to determine it. Q. On the face of it, this looks like two oranges placed together. What do textbook illustrators intend by producing such a picture? This is in full colour. Is oxygen orange? A. I don't think so . . . I don't know . . . you can't tell . . . I get an idea of something that I cannot see with my own eyes . . . I have to basically go on faith".* (emphasis added)

This may very well be an indication of the difficulties that learner may have with the ontology of the scientific concept of molecules. Apart from this last reference to "faith", another perspective came out of the following exchange during interview 5:

A. *I suppose it is a trying to represent what it actually would look like if people had to take a picture of it . . . they would imagine that it would look something like that . . .*

Q. You said "trying to represent" and you used the word "imagine" . . . Are these are works of the imagination?

A. Ja . . . kind of . . . I suppose . . . has anyone actually ever looked at a molecule?

Going on "faith", which in many people's definition is a belief in something for which there is no proof, or a belief that pictures and models are mere works of the imagination, may indeed reflect epistemological difficulties that learners may be experiencing with key concepts in physics.

5.4.6 Awareness that a scientific model may facilitate partial conceptualisation of an entity

An inconsistent epistemological view was revealed during interview 9. Pointing to the picture of molecular models, the interviewer asked: *"Is this the way an oxygen molecule looks?"* To which the respondent answered quite simply *"Yes, because it's diatomic".* (emphasis added) However, when challenged as to the authenticity of the pictures of models of molecules, this view was easily dropped: *"A. Isn't it just a concept to explain . . . to sort of explain what an oxygen molecule would be like . . . it's just a concept to explain to us what's basically happening"*.

At least this respondent acknowledges that the model is able to represent and explain a certain aspect of the phenomenon being examined, namely that it is diatomic.

5.5 THE ONTOLOGICAL CATEGORIES OF CHI *ET AL.* (1994, QUOTED BY LEE & LAW, 2001)

A decision was made to apply the ontological categories of Chi *et al.* (1994, quoted by Lee & Law, 2001) to the question of what makes heavier-than-air flight possible.

In replying *"but I think it's the pressure on the bottom and the top, which kind of pushes the plane up rather than pull it down",* interviewee 1 does not express herself in terms of a constraint-based interaction. This reduces the phenomenon to a **matter** category, some**thing** that either pushes or pulls. This comment also matches one of the features of "children's science" described by Gilbert *et al.* (1982), namely that objects are often assigned characteristics of humans and animals when learners speak of objects as performing purposeful actions. What makes this a particularly disturbing passage of the interview is that

this reply comes from a top achieving medical student who gained admittance to the prestigious medical degree programme on the grounds of top marks in matric in mathematics and physical science.

Interviewee 3 was completely out of the picture, expressing thoughts about spaceships firing up their rockets and travelling to the moon, and not getting anywhere near to the principle behind the flight of a jet plane, even when reminded that the intent of the question was to explain the flight of a plane flying parallel to the ground. In such a case, as in the case of interviewee 4 (*"Uh . . . I wouldn't know, 'cause what I know is . . . it depends also on the speed, and maybe on the shape . . . [laughing] I would be lying . . ."*), no ontological categorisation of the respondent's conceptions is possible, perhaps because there are no conceptions to categorise! The remainder of the respondents were completely in the dark, and it would hardly be worth dwelling for any reason on their mostly fractured expressions and incoherent speech that almost invariably ended in *"I don't know".*

Of all the respondents, number 7 came the closest to a "constraint-based interaction" way of thinking, making a promising start but ultimately petering out in his attempt at constructing an explanation. This may be seen in his statement that *"[a]ir travels a longer distance on top of the wing than it does underneath the wing which causes an upward force . . . as a result of . . . I have no idea . . ."*

5.6 OTHER ISSUES ARISING OUT OF THE INTERVIEWS

5.6.1 The incoherence of the expressions made by respondents

Even a casual reading of the interview transcript will reveal the overall inability of respondents to speak with any coherence about the concepts and physical phenomena related to pressure, atmospheric pressure and the kinetic theory of gases, and the use of such ideas in the construction of explanations of physical phenomena and technological applications.

Duschl and Osborne (2002) maintain that the inability to speak and to reason soundly on science concepts is a result of the way in which science has traditionally been taught and learned. Very few students are ever given an introduction to the epistemic nature of science. A great deal of classroom time is devoted to **what** learners ought to know, and very little time or thought is given to **how** we know that, or **why** we accept the beliefs of science. Learners are

seldom initiated into the manner in which evidence is used in science to construct explanations. Even less consideration is given to the question of what criteria ought to be applied to evaluate the selection of evidence and the construction of explanations.

These authors argue powerfully that language plays an important yet underrated role in learning. They state that a *"prominent, if not central, feature of the language of scientific enquiry is debate and argumentation around competing theories, methodologies and aims"* (p.40). They explain that learners are unable to construct sound explanations because they simply have not succeeded in *"appropriating the syntactic, semantic and pragmatic components"* of the language of science (p.40). These authors further claim that learners will in fact never really succeed if the science classroom continues to be dominated by monologic as opposed to dialogic teaching practices.

5.6.2 The near-total inability of respondents to explain:

a. the difficulty associated with breathing at higher altitudes;

b. the phenomenon of flight of a heavier-than-air aircraft;

c. why the water in the inverted bottle does not spill out onto the ground.

Coming out of the interviews conducted is the observation that respondents experience real difficulties in constructing explanations for natural and artificial phenomena in which atmospheric pressure comes into play. This certainly reflects poorly on the way science is being learned, and this may (but may indeed not) have its origin in the way science has been taught. There appears to be, in the case of the three situations cited above, an absence of application of theory, that is, concepts, definitions, laws and principles of physics, to everyday situations. If we accept the definition of the term "understanding" to include a learner's ability to relate new information acquired to his or her existing knowledge and experience, then certainly the respondents can be said not to understand the physics concept of pressure and the phenomenon of atmospheric pressure.

The third item mentioned above demonstrated a little trick shown in primary school and designed to prove that the air exerts pressure. When asked to account for the fact that the water does not spill out, not a single respondent was able to offer any explanation. That is, not even a partial explanation, and a number of respondents expressed dissatisfaction with their

own efforts at putting together explanations. No respondent in this study was able to construct a sound, scientifically acceptable one. The idea of the demonstration was to explore whether respondents would be able to consider a somewhat unusual phenomenon and account for it using the ideas of pressure, atmospheric pressure and the kinetic theory of gases. The overwhelmingly negative result may indicate that respondents have serious difficulties transferring knowledge gained in one context (the formal setting of the science classroom, that is, the context in which the knowledge was constructed) to another (the light-hearted final demonstration and question of an otherwise insignificant interview). If this is indeed the case, it would mean that their learning has been severely "situated", in the sense used by Lave and Wenger (quoted by Watson, 1988) and Novak (2002).

A further conclusion that may be drawn from the observation that none of the above phenomena were satisfactorily (or even unsatisfactorily!) explained by respondents is that they may simply find the concepts and definitions of physics unusable. The ideas of the kinetic molecular theory of gases in accounting for the pressure exerted by the atmosphere in all directions were lost on them.

5.6.3 The unusability of the ideas of the kinetic molecular theory of gases in accounting for the pressure exerted by the atmosphere

There is clear evidence of a lack of understanding of the kinetic molecular theory of gases, in the sense that respondents are by and large unable to use the assumptions of the theory to explain the phenomenon of atmospheric pressure. Interview 9 provided a good example of this trend.

Q. What do you understand by the concept "pressure" in physics?

A. [Writing] OK, pressure would be . . . if I've got a compressor . . . if I decrease the volume of the thing, there's going to be more pressure, meaning that there are more collisions

The term "collisions" appears to be a reference to the kinetic theory's assumption that molecules are in constant motion and collide elastically with each other and with the walls of the container. What the respondent says here is correct, but not useful to herself. This became clear in following her attempt to account for the inverted water bottle demonstration:

A. I think . . . that the paper is exerting some . . . water doesn't have much pressure . . . isn't it? . . . there's not enough pressure . . . there is . . . I don't know . . . the pressure, right? in the

bottle . . . obviously the molecules are colli . . . coinciding with each other . . . and I don't understand why it's not falling because . . . I don't know . . . uhh . . . the paper somehow . . . with a force . . . it's like Newton 3 isn't it? . . . is it Newton 3? . . . somehow Newton 3 is being applied . . .

The kinetic theory's assumptions that molecules are in random motion without favouring any direction and that they collide elastically with the walls of the container did not prove of any value to any of the respondents in their attempts to explain the upward pressure exerted by the atmosphere on the water in the inverted bottle. Hence the claim that the respondents do not understand the kinetic theory.

5.7 POSTSCRIPT

5.7.1 In the footsteps of Piaget, who interviewed his own children

A decision was made to round off the present study by comparing the results obtained with the outcome of a conversation with a group of school children. Therefore, a group of five school children were taken through the same interview schedule as that used in the main study. This was handled, not as a one-to-one interview, but as a group interview. What resulted was a very lively group interview involving five children of school-going age. The children enjoyed the occasion, and spoke quite freely. All were well-known to the interviewer (two of them were his own children, and the rest were their friends), and it was therefore not at all difficult to establish the necessary rapport with this group. The children are identified only by an initial, as follows:

S: a 17-year-old girl;

P: a 16-year-old boy;

E: a 14-year-old girl;

M: a 12-year-old boy;

A: an 11-year-old girl.

The interviewer is identified by the letter Q.

5.7.2 Analysis

Throughout the entire data-collection exercise, the first mention of an instrument, the barometer, for measuring the pressure exerted by the atmosphere, came in the opening of the

group interview with the children. This point had occurred to none of the older respondents in the main study.

When asked about the definition of pressure, M wanted clarity. He asked *"What kind of pressure are we talking about?"* This was a fair question, given that this 12-year-old knows several different applications for the word "pressure". Since the interview was not conducted in the physics laboratory located within the physics department of a large university, but rather in the home of a friend on a Tuesday evening, the context of the discussion was not necessarily clear. This respondent's gave priority to obtaining clarity on the terms being used, which was most impressive.

The younger children in the group tended to equate pressure with force. When discussing demonstration 1 (pencil, coin and soft clay), M and A differed on where the pressure would be greater. M thought that the pressure is greater where the sharp pencil made a deep hole in the clay, suggesting that *"Well, . . . it's the effect that the pressure had on the clay".* A felt that the pressure would be greater where the pencil pressed down on the coin placed on the clay because the downward force affected a greater part of the clay. Neither M nor A had the tools with which to reason the way S did, namely the formula $P = F/A$, and the greater A the smaller P, but M and A nevertheless explained quite clearly what they thought about the situation.

When discussing the pictures of molecular models, P had never been exposed to any persuasive evidence that oxygen molecules may reasonably be pictured as two spheres linked to each other in some way (the general idea conveyed by the pictures shown).

Q: So what is the meaning of these pictures? Do you believe these pictures?

P: Well it's the only thing we have.

He here indicates that he was being asked to believe something, and this was all he was given as evidence.

E expressed a similar thought in a very interesting way. The pictures represent a form of teaching authority. A scientist perhaps, or a science teacher, has drawn a picture *"to try to help us"* and for the purpose of *"trying to get it across"* to *"us"*. The term "us" in this context would mean novices and non-initiates. According to this view, science appears to be a belief system, operating in a manner not very different from a traditional religious belief system. Scientists and science teachers act in a similar capacity to priests and ministers of religion who make statements *ex cathedra* and call on their followers to believe.

E: I just think they are illustrations that try to help us to picture what we're trying to understand. They're not telling us that the real thing looks like that but they are trying to get it across to us what it is that we are . . . uhm . . . (emphasis added)

An interesting disagreement arose between S and P on the question of why climbers experience difficulty breathing at high altitudes. It was interesting in that it seemed to exemplify the tension that science learners face in deciding between the use of scientific and everyday word meanings.

S: oxygen is heavy . . . because of gravity thicker at high altitudes . . . higher pressure lower down . . . it gets thinner the higher you go

P: isn't there more pressure . . . if they struggle up there, there is probably more pressure up there

S talked about the scientifically accepted picture of atmospheric pressure decreasing with increasing altitude. On the other hand, P seemed to use the everyday meaning of "pressure". After all, in everyday speech, putting pressure on someone means giving that person a hard time! P therefore drew the conclusion that since it is harder to breathe at high altitude the mountaineer is having a hard time up there, and so the pressure must be greater.

In common with the older, more sophisticated university student respondents, the children in the group interview were unable to construct any useful explanation for the difficulty in breathing, for the phenomenon of heavier-than-air flight, or for the inverted bottle that would not spill its contents.

5.8 CONCLUSION

The picture painted in this chapter seems bleak indeed. However, in line with the undertaking made in Chapter 1 of this report, no sweeping claims (either about the educational system or about the respondents themselves) can be made on the strength of such a limited study.

The following chapter will deal with the conclusions reached on the basis of what has transpired in the interviews. It will attempt to deal pertinently with the answers to the research questions posed at the outset of this study.

CHAPTER 6

REFLECTIONS, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

A personal recollection of the way in which teaching and learning took place in school and at university may set the scene appropriately for the conclusions and recommendations to follow. In order to reflect on this in an authentic way, the narrative will change to the first person.

It is hard to forget how my teachers at high school seemed to be under great pressure to get through their lesson plans and stick to their prescribed syllabi. With the additional load of teaching large classes it was not really possible for them to pay personal attention to the interests and needs of any individual learner, and they could not have known whether or not they and their learners were on the same page, so to speak.

The situation was even worse at university. First-year classes were large, the demands of the learning programmes were great, and lectures were impersonal affairs. On the few occasions that I did make personal contact with my lecturers I was faced with the harsh reality that they either could not or were unwilling to engage with me, that is, to spend a reasonable amount of time addressing difficulties I was experiencing. I was on my own.

Lecturers acted as if by giving lectures they were fulfilling an unpleasant chore, and this duty could be discharged as quickly as possible, with the least degree of accountability, by simply walking into the lecture room, rattling off a speech (whether prepared or unprepared) and walking out. This procedure I have now come to see as an exercise in futility. The reason for adopting this view is the point made in Chapter 1 of this report, namely that effective teachers have definite intentions and objectives they pursue. These were summarized as follows:

- To assist learners to learn and appropriate new concepts as these are currently accepted by the scientific community;

- To assist learners to become scientifically literate (that is, to understand the way science is done, that is, the way(s) in which scientists do their work);

- To assist learners to understand and accept the epistemological assumptions implicit in the learning and practice of physics (that is, to gain some insight into the nature of science, a sense of the truth value of the knowledge claims of science, and the way(s) in which science has advanced historically).

A teacher will not achieve any of the above outcomes from a position of remoteness and disengagement from the learners in his or her classes.

The first step in engaging with learners is to establish what they already know. As Scott *et al.* (1994, p.201) argued: ". . . decisions relating to planning and teaching for conceptual development require the teacher to consider first the nature and status of students' existing ideas and understandings . . . " This investigation represented a small case study of the nature and status of its respondents' existing ideas on pressure and the phenomenon of atmospheric pressure. In the following sections, some reflection will be made on what was achieved during the course of the investigation.

6.2 WHAT VIEWS DO LEARNERS HOLD ON PRESSURE AND ATMOSPHERIC PRESSURE?

Most of the respondents were able to state or express familiarity with the definition that pressure is force per unit area. With the demonstration involving the pencil exerting pressure on the soft clay, a majority were able to correctly identify where the pressure applied was greater and where it was less. Most were successfully led along by the Socratic-dialogue type questioning from the idea that molecules of oxygen, nitrogen, water and other gases have mass, to the conclusion that they also have weight, and hence that they exert a pressure on objects with which they come into contact.

The conclusion is that these respondents are familiar with the definition of pressure and they are aware that the atmosphere exerts pressure.

Of course, it must be noted that these are questions that may be answered by simply memorizing a little rote-learnable theory from a physics textbook. The essence of the problem raised in this investigation is not the learning of bits and pieces of public knowledge. Rather, it revolves around the extent to which meaningful learning has taken place in the area of pressure and atmospheric pressure.

6.3 DO LEARNERS UNDERSTAND THE CONCEPT OF PRESSURE AND THE PHENOMENON OF ATMOSPHERIC PRESSURE?

Do they understand these matters well enough to be able to use these in explaining familiar or unfamiliar phenomena and technological applications? In this investigation it became abundantly clear that they do not. By far the majority of the subjects in the study were unable to construct anything resembling a coherent, logical and acceptable scientific explanation of the phenomena and applications discussed.

The most notable revelation that emerged from the interviews was the incoherence of the answers given. The majority of the respondents were, outside of the interview setting, talkative, gregarious, opinionated and outspoken young people. Yet, when confronted with questions related to these physics concepts the answers that were forthcoming reflected an inability to speak about the topics under discussion. Their speech betrayed outright ignorance and an overall lack of any connection between familiar phenomena and the underlying theories.

If, therefore, meaningful learning (the term employed by Novak, 2002) means that "the learner chooses conscientiously to integrate new knowledge with knowledge that the learner already possesses" (p.549) it must be concluded that, in the case of the concept of pressure and the phenomenon of atmospheric pressure, little or no meaningful learning has taken place in the case of the respondents in this study in the area under discussion. Hence, when asked the question of whether these respondents understand these concepts, the answer has to be negative.

In fact, as was pointed out in Chapter 5 of this report, the expressions made and explanations attempted by respondents were by and large unsatisfactory even to the interviewees themselves. Disturbingly, some of the subjects expressed very negative thoughts about the way they see themselves as scholars. Such remarks included: *"I'm not a good student"*, *"I'm not good at physics"* and even *"I'm not very intelligent"*.

6.4 WHAT IS THE NATURE OF THE KNOWLEDGE HELD?

A specific examination of this question was made with reference to the respondents' views on the use of models in physics. An additional aspect of this was the question of how knowledge of atmospheric pressure and the kinetic theory of gases may be used to explain the difficulty that climbers have in breathing at high altitudes and the demonstration involving the filled inverted bottle that would not spill its contents.

6.4.1 On the use of models in science

When shown a high-quality three-dimensional picture of space-filling models of an oxygen molecule, a water molecule, and a methane molecule, respondents answered the question *"What do these pictures mean to you?"* in ways that reflect realist viewpoints. The more extreme form of realism called "specular realism", namely that the picture of the model represented the molecular entity identically, precisely, there being a one-to-one correspondence between the two, was dominant. The more moderate "asymptotic realism", the position that the molecular model was similar to or approximated the real thing, was very much in evidence as well.

Specular realism was reflected in the number of respondents who felt that, were it technically possible to take a photograph of an actual oxygen molecule, the picture would look like that of the space-filling model shown. On the other hand, the asymptotic realists were more cautious in their statements, and settled for the notion that the molecular model shown was an approximation, but not an exact replica, of the molecules they represented. Some respondents felt that the models indicated the relative sizes of the atoms in combination, while others felt that the models had value in showing how individual atoms had bonded to form a molecule, and one reply was that the pictures helped to clarify the basic diatomic structure of the oxygen molecule.

For some respondents the pictures projected an aura of authority that was completely unwarranted. The textbook in which the pictures appeared was the "Children's Encyclopaedia of Science & Technology", published by Oxford, so it had to be authoritative, hence correct.

Overall, respondents were not at all sure of how they were to understand the molecular models. A case in point was the interviewee who vacillated from the idea that these were pictures of the *"structure of gases that we know"* to the diametrically opposed idea that *". . .*

it's basically estimates, I guess" (emphasis added).

However, there was little evidence of an appreciation of the reasons that Davis and Hersh (1988, p.78) enumerate for the use of models in science, namely:

6. To obtain answers about what will happen in the physical world;
7. To influence further experimentation or observation;
8. To foster conceptual progress and understanding;
9. To assist the axiomatisation of the physical situation

One respondent expressed a very mature long-term view of the tentative and changeable nature of scientific knowledge, in the following words: *"I've often thought that maybe in the future, we will be taught that this was the theory in the first place, but afterward it has been revised . . . in the future someone might decide that everything we've been taught up to now is actually wrong."* None of her fellow respondents was able to express such a view.

Finally, the truth value of the molecular models shown was questioned by three respondents in the following words: *"no-one actually knows what a molecule looks like . . . you don't know whether what people are drawing in this textbook is the truth . . ."* and *". . . I don't know how they find that oxygen is this shape, water is this shape . . ."* and quite thoughtfully *"I get an idea of something that I cannot see with my own eyes . . . I have to basically go on faith".*

The term "imagine" was mentioned by a respondent in one of the interviews. Ideas like "imagine" or "go on faith", which in many people's definition is a belief in something for which there is no proof, may indeed reflect epistemological and ontological difficulties that learners may be experiencing with the concept of molecules in physics.

6.4.2 In the matter of heavier-than-air flight: the ontological categories of Chi *et al.* (1994, quoted by Lee & Law, 2001)

A decision was made to apply the ontological categories of Chi *et al*. (1994, quoted by Lee & Law, 2001) to the question of what makes heavier-than-air flight possible. This was by far the most difficult aspect of the analysis of the interviews conducted in this study.

It is totally unrewarding to try to discern what ontological categories learners assign to concepts where concepts hardly exist, or cannot be articulated. Yet this was the nature of the difficulty experienced. The overwhelming majority of respondents were completely in the

dark as to the basic explanation that an aerofoil (the basic shape of a section through the wing of an aircraft) creates two pathways for air flowing past the wing. Air flowing over travels faster and air flowing under travels more slowly, and that translates to a difference in atmospheric pressure above and beneath the wing. By Bernoulli's continuity principle, air flowing faster is at a lower pressure than slower moving air, and this creates a strong upthrust. The nearest that any respondent came to constructing an explanation of this kind was during interview 7: *"[a]ir travels a longer distance on top of the wing than it does underneath the wing which causes an upward force . . . as a result of . . . I have no idea . . ."*

6.5 RECOMMENDATIONS

The picture emerging of the conceptions of first year physics students in the area is not a pretty one. However, in view of the limited scope of this study, any recommendations flowing from the conclusions drawn in the foregoing discussion must necessarily be modest and tentative.

An excellent piece of advice given by Duschl and Osborne (2002) is that, if the goal of instruction is to promote reasoning skills, doing science, or learning about science, then learners have to be given the opportunity to practice the art of reasoned, dialogic argument associated with uncertainty and tentativeness. What these authors suggest is that consideration should be given to plural accounts of phenomena. (The value of such exposure is that learners can be sensitized to the epistemic nature of science, that is, the way in which the scientific community has, over centuries of time, critically explored and coordinated the available evidence in order to derive models, to make predictions and to arrive at explanations for phenomena.) They base this suggestion on the curriculum theories of Joseph Schwab, who proposed as long ago as 1962 that science be taught as an "enquiry into enquiry". It presents a picture of physics as something more than the trivialized examination-passing game of knowing what formula to use in what situations, and then substituting knowns in order to find unknowns, which is the way in which popular television education programmes seem to caricature physical science.

What this means is that curriculum planners and teachers could establish, in the science classroom, a learning environment that is conducive to argumentation (in the best meaning of

the word), that is, open questioning, justification and evaluation by learners of their own and their peers reasoning. This should be done in a manner similar to what is practiced by the scientific community itself. Such a learning environment supports the personal construction of knowledge by learners and learner metacognition. Argumentation is regarded by Duschl and Osborne (2002) as a language genre that can give practice to learners in the skills of constructing explanations, evaluating the way evidence is used in such explanations, reflecting on the criteria for the selection of evidence to be used, and in the revision of scientific arguments.

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APPENDIX 1: COMPLETE TRANSCRIPTION OF INTERVIEWS

Interview 1

Q. What is the definition of the term "pressure"?

A. Pressure is the force that's applied to a certain area . . . it can move anything . . . there's the air pressure that's on you . . . it's the air pushing down . . . [there's] also hydrostatic pressure . . .

DEMO 1

Q. Over here you pressed with a certain force. What is the area over which you pressed? (At point A.)

A. The area's just the tip of the pencil there . . . that's a very small area that I pressed down on.

Q. And the area over here? (At point B)

A. The coin, its the whole area of the coin. That's why when you push the same force down, the pressure . . . ja . . . let me think . . . the equation is . . . F, what? . . . p = f over a . . . so if you've got a small area, the pressure will be greater . . . same force but different pressure . . . same forces different pressures.

[Interviewer shows pictures of models of molecules]

Q. What does air consist of?

A. Mainly nitrogen, then oxygen, some water, some carbon dioxide

Q. These pictures often appear in science textbooks. Would you be happy to call these things the "building blocks" of air?

A. Generally, yes.

Q. What do these pictures mean to you?

A. Well, these consist of the different atoms, and as you can see here, the hydrogen atom is much smaller than the oxygen atom, because its got less electrons so that it's so much smaller than the oxygen . . .

Q. Very often we see pictures of things, but are those pictures a good way of seeing reality? Air is invisible. Do you think these pictures have any connection with real air?

A. I think scientifically they do, but if you showed a layman something like that . . . like a kid or that . . . they kind of visualise . . . like, or even that size. . . but you can't exactly explain to them how small the particle is . . . so if you try to explain to someone if they've never been in a scientific thing, it's going to be difficult to explain that this is what air is made of, but in scientific terms . . . I think . . . we can understand it.

Q. Your statement "in scientific terms" . . . is interesting. Do you think that "scientific world" and the "real world" are two different things?

A. It took me a while. . . I can think in 3-D and all the rest . . . but if I had to show someone, like a little cousin . . . they won't be able to understand how small it is and all the rest . . . so I think in the scientific world you talk in different terms.

Q. Do these molecules that air consists of have mass?

A. [Quickly and confidently.] Yes.

Q. And do they have weight, in your opinion?

A. [A little more slowly, thoughtfully] I think they do. But, they are so small . . . their mass is so tiny . . . they are

being pulled down . . . to the earth . . . they do have weight, ja.

Q. So, therefore, would you say that they exert pressure on objects?

A. Yes.

Q. Can you relate that back to the definition that you gave me on pressure?

A. Well, they've got a very small surface area, but in large chunks of them . . . and they are pulled down . . . a force on an area . . . and they do exert pressure on it.

Q. People who climb high mountains, such as Mount Everest, report that they have difficulty breathing at high altitudes. Can you explain this?

A. We are often told in class . . . they relate to . . . like at the coast . . . Joburg is at such a different height above sea level . . . I mean I come from PE . . . at the coast when you are on sea level you have so much more . . . a kilometre or two of pressure on you than you do in Joburg . . . and Mount Everest is so much higher than Joburg . . . there's less pressure pushing down on you . . . and there's less molecules there so that you battle to breathe.

Q. What makes flight possible?

A. [A little laugh.] A lot of technology . . . aerodynamics . . . I think [it's] related to the pressure on the bottom of the plane to the pressure on the top, and with the wings as well which go through the air . . . I'm not **quite** sure how it works . . . exactly how they get it up — but I think it's the pressure on the bottom and the top, which kind of pushes the plane up rather than pull it down.

Q. Did you come across the kinetic molecular theory of gases in your studies?

A. Yes, I think I did . . . every particle has a specific kinetic energy that makes it move . . . no particle is stationary, they're always moving from one place to another . . . and the average amount of the moving gives you the temperature . . .

Q. Do you have an idea of how fast they might be moving?

A. I have no idea.

Q. There actually are calculations in which that is worked out, but do you think that it is realistic to try to calculate such a speed?

A. Yes, I think it is possible, with all the leaps and bounds that they're taking with technology at the moment, I think it's possible to figure it out.

Q. Of course, the kinetic molecular theory of gases was worked out halfway through the nineteenth century . . . long before the present advances in technology . . . Do you think it is realistic to believe that people could make such a calculation?

A. Yes, I think it is realistic.

DEMO 2

Q. How would you account for this?

A. [Laughter] . . . that's a difficult one! . . . uhmm . . . isn't it the surface tension of the water against the . . . no . . .

Q. Do you think our present conversation about atmospheric pressure is relevant to this?

A. Isn't it also the amount of pressure that the water is exerting on the paper to the amount of pressure that the air is

exerting . . . so the paper will only move when there is a change in pressure or something.

Q. Alright. But you mentioned earlier that the air molecules were being pulled downwards . . . now, which way was the air pressing? (Remember that I turned the bottle over.) Which way was the air pushing the water to keep it from falling?

A. It had to be the air, because you realise that there are lots of molecules in the air . . . and they're all pushing down, but there are so many of them that they're stacked up quite a bit.

Q. OK. Interesting, hey!

A. You know you've stumped me . . . you've stumped me . . . I'm trying to figure it out!

Interview 2

Q. What do you understand by the term "atmospheric pressure"?

A. To me?

Q. To you.

A. Well, personally, I think atmospheric pressure is the external pressure exerted on everything . . . on anything that's in the earth's atmosphere . . . this is what I know about it.

DEMO 1.

Q. Do you know or remember a definition for pressure?

A. The only thing I know about pressure is that pressure is related to volume . . . the smaller the volume the greater the pressure, because the less space the molecules have to move, therefore they are closer to each other, interact with each other more, and I think that pressure would be the measurement of the amount of collisions of molecules

Q. [intervenes by recalling the respondent's reference to "volume" in the above passage] . . . Could I suggest the following: (writes down that P = F/A)

A. . . . force over area . . . uhm . . . (repeating himself as if for reassurance) pressure is force over area . . . (Q. Are you familiar with this?) . . . what are the units of pressure again?

Q. . . . (not sure how to deal with such a lapse) . . . uhm . . . we have the pascal

A. (suddenly remembering something) . . . ja I see, that's actually perfect, ja that's fine . . . square metres . . .

Q. So are you happy with area rather than volume?

A. Ja, I wouldn't mind area either because . . . ja

Q. So, over what area did you exert pressure at point A?

A. What do you mean "what area"?

Q. You exerted a pressure here (pointing to point A) and you exerted a pressure there (pointing to point B).

A. Pressure is a force exerted on a particular space . . . obviously here I exerted a force over a greater area . . . so using the same force, according to the formula the pressure here would be . . . uhm . . . the larger the area the smaller the pressure.

Q. What does air consist of?

A. Gases . . . around 80% nitrogen . . . 16% or 17% oxygen, I think . . . some CO_2 . . . I should imagine

Q. Please look at the following pictures. [Interviewer shows pictures of models of molecules] In many books you get pictures like these . . . this is supposed to be a molecule of O_2. Do you agree with these pictures?

A. What do you mean?

Q. Do they make sense to you?

A. Yes. In terms of the size of the molecules . . . how they are arranged stepwise . . . from what I have learned in chemistry I can tell you that these make sense to me.

Q. Do these pictures have any connection to real air?

A. No, not at all. Absolutely none. Because . . . we cannot see molecules of air . . . we can't see air . . . we breathe it in . . . it circulates . . . but no, in terms of looking at air which we obviously cannot see, these (pictures) make absolutely no sense.

Q. So here is a picture in a science textbook. Do you think there is any connection between the scientific world and the real world?

A. Yes, there is. But you cannot talk in the real world in terms of atoms and molecules, because . . . how many people would actually know about it? In the real world out there, if I were to ask the man in the street what air is made up of, the chances are that he is probably not going to know . . . if I were to show him this and tell him that this is an O_2 molecule he is probably not going to know what you're talking about.

Q. Now quite apart from what the man in the street might have to say about this, what about you? If you are working with pictures like these, and you work with a theory in chemistry, and you work with equations to solve problems, and so on, what has that to do with real air? Is there any connection between these things and the air you actually breathe?

A. No, absolutely not! I can't see any connection between this and the air I am actually breathing in.

Q. Would you be OK with the idea that these molecules are the building blocks of air?

A. Yes, I can accept that.

Q. Do they have mass?

A. Yes, even if it is negligible.

Q. Do they have weight?

A. I suppose they must have. If something has mass it must have weight, even if it is very small . . . because of the formula ($w = mg$)

Q. Do they exert pressure on objects with which they come into contact?

A. Yes, even if it is not a very big pressure, but negligible like . . . because of this formula . . . yes

Q. Can you explain why people who climb high mountains report problems with breathing?

A. There obviously is a formula, but I can't think about it now, but . . . looking at the millimetres of mercury . . . as you get higher so the pressure increases . . . something along those lines . . . the pressure is not constant on the earth's surface . . . so, the higher you go the greater the pressure exerted on your body, also the lower you go, like when you go down into the sea, again people do battle more . . . you can feel a stronger force on your body the lower you go . . . (Q. You mean when you're diving?) . . . the pressure is greater the lower you go . . . on your body . . . and

when you're higher as well . . . on your body, your lungs . . . I think

Q. What makes flight possible?

A. I suppose . . . I really don't know . . .

Q. Have you encountered the kinetic molecular theory of gases in your studies?

A. Possibly, but I have no idea what it is.

Q. Do have any idea how fast the molecules in a gas are moving?

A. Haven't got a clue.

DEMO 2

Q. [no question asked, just a look up at the respondent was sufficient]

A. Why does it happen? I have no idea . . .

Q. What would you expect to happen?

A. Naturally I would expect the water to fall out straight away. The paper is light. The water is, relative to the paper, very heavy.

Q. In the context of our discussion, where we're talking about air pressure, do you think that may have something to do with it?

A. Ja, it's got something to do with pressure. But quite honestly I cannot explain it, I have no idea. I'd like you to explain it.

Interview 3:

Q. What is the definition of pressure?

A. Pressure is the force per unit area, the force that acts on an object per unit area of that object

DEMO 1

A. [Correct.]

[Interviewer shows pictures of models of molecules]

Q. What does the air consist of?

A. Nitrogen, oxygen and carbon

Q. Would you agree with me that molecules of nitrogen, oxygen, carbon dioxide and water are the building blocks of air?

A. Yes.

Q. Now, textbooks contain pictures such as these. The question is: Can you connect these pictures to the actual air that we breathe?

A. I have tried to do that before . . . like, trying to connect the molecules . . . I cant get the real connection, like, are these molecules that I'm breathing in exactly like those I see in pictures . . . sometimes they . . . use models to try to make you understand what they are trying to tell you . . . so, for me, I think they are trying to explain to me what molecules air consists of . . .

Q. It's very interesting . . . that word that you used: "models". Scientists use models to try to explain something. So you have the "scientific world" on the one hand and the "real world" on the other. Do you find it easy to connect the two?

A. For molecules which are invisible, I can't quite connect it. . . I understand when they explain it . . . but when I try to connect it, like when I look at water, liquid water, the shape is the same as the vapour, and the ice . . . but when I look closer to see whether I could maybe see something of these shapes I can't . . . I don't know whether they use microscopes to see these shapes . . . I don't know how they find that oxygen is this shape, water is this shape . . .

Q. Do molecules of air have mass?

A. Yes

Q. Do they have weight?

A. I don't know . . . let me think . . . if it has mass, then it must also have weight, because weight is dependent on mass.

Q. Do these molecules exert pressure on objects with which they come into contact?

A. Ja, I think so.

Q. Do you want to explain that to me.

A. Because it has weight, and weight is equivalent to the force, and force is proportional to the pressure, so I think because the molecules have weight, they must have pressure, because their weight is equivalent to force.

Q. Can you explain why people who climb high mountains report problems with breathing at high altitudes?

A. According to what I have read . . . when you go high, the amount of oxygen decreases as you go up . . . at high altitudes there is less oxygen . . . and you need a certain amount of oxygen . . . so if you are at high altitude there is not enough oxygen, you will have difficulty and you need to [respondent demonstrates taking a deep breath] to get the oxygen you need.

Q. What makes flight possible? Think of a jet plane. What principle is at work that enables the plane to fly?

A. I also have that question, but I've seen on TV a spaceship that goes to the moon . . . when they go up . . . a rocket . . . when it's starts, the fire is a force and it pushes down, and the force pushes it up . . . but I'm not sure whether it is the same with planes because I've never seen a rocket . . .

Q. The plane flies parallel to the ground . . . and something must be keeping it there . . .

A. Ah, that's my question . . . I don't have the answer . . .

Q. Are you familiar with the kinetic molecular theory of gases?

A. Ja, the kinetic theory . . . the molecules . . . the collisions . . . there are elastic collisions, there are no forces between the molecules . . .

Q. These are some of the assumptions of the theory . . . Do you have any idea how fast the molecules in a gas are moving?

A. I know it's fast, but don't remember the calculations.

DEMO 2

A. [A very long silence . . . and after extensive prodding: "What do you think? . . . Is this unexpected? (A. Ja, it is

unexpected . . .) Could you offer an explanation? The obvious and logical question is: 'Why does the water not simply run out?' In particular, this topic we are discussing — atmospheric pressure — do you think it can help you to explain what you have just seen?" A complete blank! I can believe it . . . I don't know . . .

Q. No problem. Thanks for your time!

Interview 4

Q. What is your definition of pressure?

A. I think pressure is the amount of gases occupying a fixed volume . .

Q. OK. So, in any kind of container, if the container is empty, it is not really empty is it?

A. Ja.

Q. So what would be the pressure of the gas in that container?

A. It depends . . . on the number of moles of the gas in the container . . . the more moles of gas the greater the pressure

Q. But what about the question of your definition of pressure? If you were to press down on the table, is there a pressure?

A. Ja.

Q. Is there a definition of pressure?

A. It's a force . . . sort of like a force . . .

Q. What does the air consist of?

A. Gases

Q. Can you name them?

A. Oxygen, carbon dioxide and a little bit of nitrogen . . . uhh . . . that's what I can think of . . .

Q. I want to show you this picture. [Interviewer shows pictures of models of molecules] This is a picture of an oxygen molecule, and this is a picture of a water molecule. I'm sure you've seen many pictures like these. How do you understand pictures like these?

A. They show you how, like, gases bond . . . so I understand . . . like, when you've got oxygen gas I know that, normally, . . . two atoms of oxygen are joined.

Q. How does this relate to the air we actually breathe?

A. I guess that when we breathe, we actually breathe in many molecules of oxygen . . . not just . . . where there's only one thing . . . but these things that are combined.

Q. Do these molecules have mass?

A. Ja.

Q. [Rather giving it away!] Will it therefore have weight?

A. Uhmm . . . I think . . . ja, if it has mass, then it must have weight . . . [laughing] but I don't know if gravity acts on it, because . . . its density is very low

Q. OK, but then the question is: Does it exert a pressure on objects with which it comes into contact?

A. Ja. It might. Ja.

Q. Now, people who climb high mountains report having difficulty breathing. Can you think of why that might be?

A. I think it may have something to do with the altitude . . . because, I think that when you go up to very high altitudes, there is a lot of air there . . . and then you have difficulty breathing . . . because there is high pressure up there

Q. OK. Now flight, perhaps a paper plane flying across this room, or a jumbo jet flying overhead — what makes flight possible?

A. Uh . . . I wouldn't know, 'cause what I know is . . . it depends also on the speed, and maybe on the shape . . . [laughing] I would be lying . . .

Q. That's OK. There are no right or wrong answers in this [conversation], I'm just happy that you are expressing your opinions on some of these questions! Have you come across the kinetic molecular theory of gases in your work this year?

A. Ja. Though I forgot which chapter it was . . . but I do remember coming across it . . . gases move in different directions . . .

Q. Do you remember approximately how fast the molecules in a gas are moving at normal temperature and pressure?

A. No.

DEMO 2

A. I would want to say that the atmospheric pressure is higher than the pressure in there, but I don't know quite what I want to say!

Q. Think about it.

A. The pressure of the gas inside [!] is . . . must be . . . smaller than the pressure outside . . . so the pressure outside will exert a force on the [beaker] . . .

Q. Which way would you expect the water to fall?

A. Down.

Q. Sure, but the fact is that it was in equilibrium. So, what is pushing it upwards?

A. It's not atmospheric pressure . . . you know, the gas might be flowing upwards, and so it might be pushing it upwards.

Q. Quite amazing, hey! (A. Ja, sure!) Thanks for your time.

Interview 5

Q. What is the definition of pressure?

A. Force per unit area. You apply a pressure if you exert a specific force over a certain amount of area. Atmospheric pressure? That's . . .

Q. Pressure itself is sufficient for now, we'll talk about that later. DEMO 1. How does the pressure differ from this situation to that situation.

A. [Correctly identified] I would say that your pressure is less, because your area is greater.

Q. What does air consist of?

A. Gases. A mixture of gases. Nitrogen, carbon dioxide, oxygen, and some other stuff.

Q. I'd like to show you some pictures. [Interviewer shows pictures of models of molecules] Science textbooks contain lots of pictures like these. What do those pictures mean to you?

A. They just look like gas molecules . . . or molecules of these substances.

Q. [pointing] So this is a molecule of water, right? (A. Right.) But that's not really a molecule of water, is it?

A. [laughing] I don't know! I think . . . when you think about these concepts, that's just how you imagine them to be . . . one little oxygen atom here and there are two little hydrogen atoms.

Q. But, that is not a photograph. No-one has actually taken a picture of an oxygen molecule. So what do you think that really is?

A. I suppose it is a trying to represent what it actually would look like if people had to take a picture of it . . . they would imagine that it would look something like that . . .

Q. You said "trying to represent" and you used the word "imagine" . . . Are these are works of the imagination?

A. Ja . . . kind of . . . I suppose . . . has anyone actually ever looked at a molecule?

Q. That's the question, you see. How valid are these pictures, in your opinion? When you take a breath of air, are you really breathing in something that looks like that?

A. I don't know. I suppose if you don't do science, you don't really think about it . . . you just imagine you are breathing in a whole lot of gas . . . but, I've often thought that maybe in the future, we will be taught that this was the theory in the first place, but afterward it has been revised . . . in the future someone might decide that everything we've been taught up to now is actually wrong. So I suppose that when you try to explain something, you have to try to come up with an idea of what it would look like, how you think it's working . . . to explain why it does that . . .

Q. But for now, are you happy to accept that molecules that may look something like that are the building blocks of air?

A. Ja.

Q. Do those molecules have mass?

A. uhmm . . . ja!

Q. Do they have weight?

A. I suppose if they have mass, then they must have a weight . . . gravity must be exerting some kind of force on a mass, so they should have a weight.

Q. Do they exert pressure on objects with which they come into contact?

A. Ja, they do. If you think about a container of gas molecules, they exert a pressure against the sides . . . so they must exert a pressure.

Q. Climbers who climb high mountains report having difficulty breathing at high altitudes. Do you know why?

A. The higher you go, the atmospheric pressure gets less . . . and it's all to do with what we learned in biology . . . how you breathe in has to with a pressure gradient between outside and inside your body . . . so if the pressure's less it's

going to be closer to the pressure in your body, so not as much air is actually going to be forced into your body.

Q. What makes flight possible?

A. I don't know, but I'm sure it must have something to do with pressure . . . the pressure inside a plane and the pressure outside the plane . . . because it's very dangerous if there is a hole in the plane and the plane goes down . . . I don't know the answer!

Q. Does the kinetic molecular theory of gases ring a bell for you?

A. Uhmm . . . the more energy they have, the faster they can move, and the more pressure they can exert on a container . . .

Q. Do you have any idea, within the context of the kinetic molecular theory of gases, how fast gas molecules may be moving?

A. No.

DEMO 2

A. [In utter surprise] Oh, gosh! . . . [laughter] . . . I've never seen that . . . Oh, my word! . . . And it's not going to fall down, ever? . . [Q. Hold it yourself.] . . Oh, my! . . .

Q. Would you like to explain what happened?

A. Well, . . . is there an upward pressure from the bottom? . . . I'm trying to think now . . . uhmm . . . I would assume that if it doesn't fall, that there must be an equal force from the top and from the bottom . . . but I don't know where the force comes from . . . it must the atmospheric pressure exerting a force from the bottom, and then the pressure from the water . . . but, I don't know why it (eventually) falls down . . .

Q. The water is expected to fall out downwards. (A. Right.) What would be the balancing upward force?

A. It must be the pressure from the atmosphere.

Q. Does atmospheric pressure act downwards?

A. That's a good question . . . I don't know . . . it's supposed to act downwards, isn't it? . . . no, it can act upwards

Q. So, in which direction does atmospheric pressure act, and why?

A. I think it acts in all directions.

Interview 6

Q. What do you understand by the concept of pressure?

A. When you put a force on something like . . . where air puts a force on the earth

Q. Do you know the definition of pressure?

A. No.

DEMO 1.

A. [Incorrect, and persistently incorrect.]

Q. What does air consist of?

A. Nitrogen, oxygen, and . . . I think that's all.

Q. [Interviewer shows pictures of models of molecules] Now, science books are full of pictures like these. What's that?

A. These are the molecules in the air of oxygen . . . that's when hydrogen binds to the oxygen . . . that's water . . .

Q. But now, nobody ever took a photograph of a molecule, so what's that?

A. It's just a representation of . . .

Q. Why do people produce pictures like these?

A. So that you can understand better . . . what the air is made up of and . . . no-one actually knows what a molecule looks like . . . this is just to give people a better understanding of it.

Q. [Referring to the picture] Does an oxygen molecule look like two oranges placed together?

A. I know oxygen has two . . . but I have no idea!

Q. What is the difference between these pictures and real air?

A. There is a big difference, because you can't actually see air . . . you don't know whether what people are drawing in this textbook is the truth . . .

Q. Do the molecules that the air consists of, do they have mass?

A. Yes.

Q. Do they have weight?

A. No.

Q. What is the connection between mass and weight?

A. The mass is the actual thing that they weigh, isn't it? Right? . . . and the weight is the effect of . . . no, weight is the mass times the g, so it has something to do with the earth . . . so they do have weight, because the molecules are moving in earth . . . ja

Q. Do they exert pressure on objects with which they come into contact?

A. They do.

Q. How does that work?

A. [Long silence . . . several attempts at starting a sentence . . .] . . . I don't know.

Q. People who climb high mountains report having difficulty breathing at high altitudes. Can you perhaps explain why?

A. If you go higher . . . isn't it the air? . . . the oxygen levels decrease . . . isn't it? . . . what, er . . . or the carbon dioxide level increases . . . no, the other way . . . (Q. You tell me.) . . . as you go higher the pressure increases . . . so uhm . . . no, as altitude decreases pressure decreases . . . oh, I'm so nervous . . . (Q. Please relax, don't let it worry you.) . . . it's something because of, uh . . . the air level decreases, so they don't have that much air to take in, and . . . it also has to do with the pressure . . . something to do with the pressure . . .

Q. What makes flight possible? What principle explains why a heavy passenger jet plane is able to fly through the air?

A. It's also to do with pressure . . . because . . . uhm . . . as you're going higher . . . OK . . . I have no idea . . .

Q. Can you tell me anything about the kinetic molecular theory of gases?

A. No.

Q. Do you have any idea of how fast gas molecules move around at normal temperature and pressure?

A. No.

DEMO 2.

A. When you push the paper onto the bottle, the pressure is . . . and when you turn it over the suction causes the paper to stick to the bottle

Q. Would you like to tell me what you mean by suction?

A. . . . How do you explain . . . it's like . . . I have no idea . . . you see what I'm saying by suction . . .

Q. I'd like to know what you mean by suction.

A. It's the pressure in the paper and the pressure in the water

Q. So what is pressing against what?

A. The water is pressing . . . [at this point the water in the inverted bottle pours out, and the conversation comes to an end] . . . the pressure in the water is exerting the paper, which causes the paper to stick to the water . . .

Q. Thanks very much.

Interview 7

Q. What is your definition of pressure?

A. Force per unit area, basically, from the formula.

DEMO 1.

A. [Correct, and well-expressed.]

Q. I am interested to know your opinion of these pictures. Firstly, could you remind yourself of what air consists of?

A. It consists of atoms and molecules of gas . . . and water vapour . . .all that stuff

Q. And what about these pictures? [Interviewer shows pictures of models of molecules]

A. It shows you the shapes of molecules and how you can compare them

Q. Has anybody ever taken a picture of a molecule, so that they are able to produce pictures like these?

A. No, I don't think it's possible. I think they use . . . spectroscopy or something . . . and they use that to determine it

Q. On the face of it, this looks like two oranges placed together. What do textbook illustrators intend by producing such a picture? This is in full colour. Is oxygen orange?

A. I don't think so . . . I don't know . . . you can't tell . . .

Q. Is there any connection between these pictures and the air we actually breathe?

A. I don't know . . . because we don't actually care about the microscopic thing when we're breathing and such . . .

Q. Would you agree with me when I state that the purpose of physics is to study the natural phenomena in the world around us, and we do it because we are naturally curious about our world? We naturally want to understand things. (A. Ja.) Now I would like to understand the air that I breathe. Do these pictures help me?

A. . . . ja, I suppose it does . . . I get an idea of something that I cannot see with my own eyes . . . I have to basically go on faith, because I haven't done the experiments myself

Q. That's a very interesting idea . . . to go on "faith". Let's move on. These molecules (that make up the air we breathe), do they have mass?

A. Yes, very, very little mass . . . all matter has mass.

Q. Do they have weight?

A. Yes, they do. Very little as well, because of the small mass . . . and gravity . . . especially the air that tends to be higher up will experience less gravitational (force)

Q. Do they exert pressure on objects with which they come into contact?

A. Yes, they do. Because they experience a very minute force . . . and even if though its a small area because it is a very small molecule, it's a very minute pressure

Q. Now, people who climb high mountains report that they have difficulty breathing at high altitudes. Can you perhaps explain why?

A. I think . . . it's the result of lower air pressure higher up . . . and then the difference between the pressure in the body . . . in the blood . . . and the air . . . there would be a smaller difference so its harder for the air . . . the oxygen in the lungs . . . to go into the blood vessels . . . and the pressure gradient is much smaller . . .

Q. What makes flight possible?

A. Air travels a longer distance on top of the wing than it does underneath the wing which causes an upward force . . . as a result of . . . I have no idea . . .

Q. Do you remember anything about the kinetic molecular theory of gases?

A. Yes, in chemistry. Gases consist of molecules that are in constant collision and moving, the collisions are elastic.

Q. Do you have any idea of how fast the molecules in a gas are moving?

A. I don't really . . . I think they're moving quickly . . . but relatively they're not moving far because they keep crashing into one another . . .

Q. But in that space between collisions, how fast are they moving?

A. I have no idea.

DEMO 2.

A. I would think that the forces on the paper are balanced . . . I think the force exerted down on the paper is equal to the force exerted up by the air . . . underneath the paper.

Q. Now, we talked about the molecules of air, we established that they had mass, and weight, and that they exert a pressure on objects with which they come into contact (A. Ja.) But the weight is downwards, is it not? (A. Ja, weight is down.) So doesn't air pressure then act downwards?

A. I think it is in all directions.

Q. Ah . . .

A. Because the particles are all . . . I think of it as lying on the ground . . . and they're all lying on top of each other . . . so that there's an upward pressure as well

Interview 8

Q. How would you define pressure?

A. Force per unit area . . .

DEMO 1.

A. [Correct.]

Q. What does air consist of?

A. Air is just gas, to me

Q. Anything more specific?

A. Oxygen, nitrogen . . . other than that, dust and stuff

Q. [Interviewer shows pictures of models of molecules.] What do these pictures mean to you?

A. Just molecules of the stuff we breathe in in everyday life, I guess . . . it's just simple structures of gases that we know

Q. Has anyone ever seen these things, so that they can actually take a photograph and give it to us like this?

A. No.

Q. So what are these things then?

A. It's basically estimates, I guess

Q. Is there any connection between pictures like these and the oxygen we actually breathe in?

A. No, not really

Q. On the other hand, what's the point of physics? Is it not a science in which we strive to understand the natural phenomena around us?

A. I'm not really sure what to say . . .

Q. These molecules that we looked at now, could we think of them as the building blocks of air?

A. Could do, yes.

Q. Do they have mass?

A. I guess everything has mass, yeah . . . that's what we've been taught, that everything has mass . . .

Q. Does it have weight?

A. Must do . . . according to Newton, it should have weight, ja . . .

Q. Does it exert pressure on objects with which it comes into contact?

A. Ideal gas or real gas?

Q. Air

A. Just air? . . . everything must exert a pressure . . . 'cause it's my understanding that everything should . . .

Q. Go back to your definition of pressure for a moment

A. Force per unit area

Q. Let's review our conversation briefly. Do molecules of air have mass? We said, yes. Do they have weight? We said, yes. Pressure is force over area. Does the air then exert pressure?

A. I'm not sure, actually.

Q. OK. People who climb high mountains report having difficulty in breathing at high altitudes. Can you explain why?

A. According to my biology textbook, it's because the pressure, the air pressure, is thinner, or less, at high altitudes than at low altitudes, so we have to struggle to get air into our lungs . . . up there, than at lower altitudes . . . uh . . . that still doesn't explain the force over area thing

Q. What makes flight possible?

A. I guess the force exerted up from the engines to keep it . . . I'm not sure

Q. "The force exerted from the engines" — would you like to speak to that?

A. The force is more than that of gravity trying to pull the plane down . . . so we can keep the plane in the air I guess.

Q. Do you remember something called the kinetic molecular theory of gases?

A. [Long silence] . . . I'm just trying to remember what it was . . . if a molecule had more speed and it had more energy . . . something to that effect . . . I can't really remember what it was . . .

Q. Imagine a sample of gas trapped in a container. Do you have any memory of how fast those gas molecules might be moving?

A. No.

DEMO 2.

A. There must have been some kind of attractive force to be able to keep the paper in place, keeping the water above the level.

Q. What do you expect to happen?

A. We expect the water to just pour out . . . due to gravity . . .

Q. But it doesn't. So what might be keeping the water from gushing out?

A. The attractive forces of the paper keeping . . .

Q. There has to be a force that's big enough to counteract the weight of the water. (A. Ja.) So what force do you think that might be?

A. I'm not sure actually . . .

Interview 9

Q. What do you understand by the concept "pressure" in physics?

A. [Writing] OK, pressure would be . . . if I've got a compressor . . . if I decrease the volume of the thing, there's going to be more pressure, meaning that there are more collisions

Q. Do you have a definition for pressure

A. When you exert pressure . . . [very nervous and incoherent] . . . I don't know what to say

Q. If I gave you the following formula: p= f/a . . . does it look familiar to you?

A. Pressure would be [called] by area, isn't it? . . . ja . . . oh, OK.

DEMO 1.

A. [Incorrect.] Isn't it the same, because I applied the same force in both places?

Q. So, is the pressure you exerted here greater than that which you exerted here? Are they the same? Are they different?

A. It could be greater here because the area is larger.

[Q. and A. then engaged in an exercise where A. manipulated the formula: $P_1 = F/A_1$ and $P_2 = F/A_2$. A. did quite well to substitute possible values into the equations. She found, correctly, that the pressure exerted with a sharp pencil point is large, while that distributed over the area of a coin is small.]

Q. I'd like to show you some pictures of atoms and molecules. [Interviewer shows pictures of models of molecules]

What does air consist of?

A. Molecules

Q. The air we breathe

A. Molecules of oxygen, nitrogen and a lot of . . .

Q. [Pointing to the picture] Is this the way an oxygen molecule looks?

A. Yes, because it's diatomic

Q. It looks like two oranges next to each other . . . is that true? . . . has anyone taken a photograph of an oxygen molecule so that they can give us this picture and tell us that this is what it looks like?

A. No . . .

Q. So where do these pictures fit in?

A. Isn't it just a concept to explain . . . to sort of explain what an oxygen molecule would be like . . . it's just a concept to explain to us what's basically happening

Q. Do you agree that these pictures are not photographs of the real thing?

A. Yes, I agree.

Q. The oxygen molecule, do you think it has mass?

A. Yes.

Q. Do you think it has weight?

A. Something that has mass must have weight, isn't it?

Q. Why? What is the connection between mass and weight?

A. Uhmm . . . I don't know.

Q. Do they exert pressure on objects with which they come into contact?

A. Well, yes . . .

Q. Why do you think so?

A. I don't really understand these physics concepts . . . you know when things collide with each other, they sort of give pressure through to the other side . . . I think

Q. OK. People who climb high mountains report having difficulty in breathing. Can you explain why?

A. I think 'cause there's less air or something . . . I don't know . . . pressure in the atmosphere . . . high up there than here . . . that's what I heard

Q. What makes flight possible?

A. If there's more pressure here . . . can it be less pressure there . . . I don't know

Q. Have you come across something called the kinetic molecular theory of gases?

A. Yes.

Q. Can you tell me something about it?

A. . . . kinetic molecular theory of gases . . . I have . . . I know I have . . . like, gases compress readily, isn't it? . . . and, they are more compressible than, uh . . . and they occupy volume, I think . . .

Q. So, do you have a picture in your mind of molecules moving and colliding with each other and colliding with the walls of the container?

A. OK, if the gas is in a container, they just move randomly, you know . . .and they collide with each other and with the wall, you know . . . something like that

Q. Do you have an idea of how fast they may be moving?

A. I think they're very fast.

Q. Do you have any idea of how fast, more or less?

A. Not really, but I think they're very fast.

Q. OK, that's fine. We're nearly finished.

DEMO 2.

A. I think . . . that the paper is exerting some . . . water doesn't have much pressure . . . isn't it? . . . there's not enough pressure . . . there is . . . I don't know . . . the pressure, right? in the bottle . . . obviously the molecules are colli . . . coinciding with each other . . . and I don't understand why it's not falling because . . . I don't know . . . uhh . . . the paper somehow . . . with a force . . . it's like Newton 3 isn't it? . . . is it Newton 3? . . . somehow Newton 3 is being applied . . .

Q. Thanks very much for your time.

Interview 10

Q. What is your understanding of the concept "pressure" in physics?

A. I don't know . . .

Q. Can you remember the unit in which pressure is measured?

A. pascals . . . atmospheres

Q. OK, and what is a pascal?

A. pascal . . . I forgot

Q. OK. If I wrote this ($P = F/A$), do you think you'd have an idea of what this is?

A. Ja. It's newtons over metres . . . actually metres squared.

DEMO 1.

A. (When asked to press down at point B with the same force as he pressed down at point A) The force has to be greater . . I know that . . . (Q. The force is the same, because I want you to press as hard.) . . . the force is the same, but then the effect is not the same, the pressure is not the same . . . it depends on the area . . . it is proportional to the area . . . the bigger the area the lower the pressure . . .

Q. So which pressure is greater?

A. It has to be this one (pointing to the coin) . . . the bigger the area the bigger the pressure . . . this one . . . smaller area, bigger pressure . . .

Q. So if you were to compare the pressure you exerted here (point A) to the pressure you exerted her (point B), which one is greater?

A. [Incorrect.]

Q. What does air consist of?

A. Molecules.

Q. Do you want to be more specific?

A. Like air . . . oxygen, nitrogen . . . all those things

Q. Please look at the following pictures. [Interviewer shows pictures of models of molecules]

Many science textbooks contain pictures like these. Did anyone ever see an oxygen molecule so that they could photograph it in order to give us a picture like that?

A. I don't think they did . . . microscopically probably ja . . . but with the naked eye you cannot

Q. Molecules of oxygen are invisible. But in this picture they are coloured orange. Is this realistic?

A. It's just an image . . . two oranges put together . . . look like two oxygens put together

Q. Do these molecules have mass?

A. They should . . . according to physics they should

Q. And according to you?

A. According to me it's just air . . . (if the wind blows) you can feel there's a force

Q. Do you accept that air molecules have a mass, even if it is a very small mass?

A. Yes, I accept that

Q. Do they have weight?

A. weight and mass . . . mg . . . ja, they should

Q. Do they exert pressure?

A. Yes, they do.

Q. People who climb high mountains report that they have difficulty breathing. Can you explain why?

A. I don't know . . . there's too much concentration of air . . . the pressure there . . . the higher you go the more pressure you experience from the air . . . probably

Q. And that will have an effect?

A. On your breathing . . . on your lungs . . . I don't know . . . it probably does, but the concentration of molecules the higher you go up, I don't know honestly . . .

Q. What principle of physics do you think makes flight possible? Think of a passenger jet plane flying through the air.

A. Probably the reason why it's above the air . . . it's flying there . . . they've made it in such a way that . . . the pressure of it is less than the pressure of the air below it . . . probably then it can stay up there . . . I don't know how . . . I think that's it . . .

Q. OK. The kinetic molecular theory of gases, does that mean anything to you?

A. It does mean something, but I don't remember . . . I've met up with it somewhere, but I don't know . . .

Q. Can you tell me anything about it?

A. The molecules are more further apart . . . is that what you want to know?

Q. That's OK. Do you have any idea with what speed molecules in a gas are moving?

A. No . . . only of light . . .

DEMO 2.

A. There's no air in there . . . the air pressure

Q. What do you expect to happen?

A. I should think that when you turned it around just now, the piece of paper probably jumped up.

Q. But we know that things don't simply jump up out of their own initiative. Can you talk to me about forces? Can you talk to me about pressure, maybe?

A. I don't know . . .

APPENDIX 2: TRANSCRIPT OF GROUP INTERVIEW WITH FIVE SCHOOL CHILDREN

This is not a comprehensive transcript. For the sake of brevity, only the salient parts of the conversation are transcribed below.

Q: What do you understand by the term “pressure”?

S: The force that is exerted on the earth, that I could measure with a barometer . . . force pushing down on something.

Q: If you were to try to explain what pressure is to someone, what would you say?

M: What kind of pressure are we talking about?

A: It’s like . . . force.

E: I’d say it’s just basically a force exerted on something.

DEMO 1. (M was asked to use the pencil.)

Q: Did M exert pressure on the clay?

P: yes

Q: Why?

A: He used force.

Q: Is force the very same thing as pressure?

[General murmur of disapproval] : No.

S: When you apply a force over a particular area, and here the area was quite small, and the force was quite big.

Q: So what is the relationship between pressure, force and area?

S: Pressure is equal to force divided by area.

Q: Have the rest of you ever heard of what S has just said? [No.]

Q. Is the pressure here the same as the pressure there?

Two respondents: Yes

M: I would say no.

Q: Why not?

M: Well, . . . it’s the effect that the pressure had on the clay.

Q: Here you made a deep hole in the clay, and here you hardly dented the clay, look, not a very deep hole! Where would the pressure be greater?

M: [correct]

Q: Who agrees with M? [nobody else] Who disagrees with M?

A: I think the pressure here will be greater, because the area is wider . . . when you push down it will affect more of the clay.

P: I agree with A.

S: I agree with M . . . $P = F/A$, and F is the same in both places, but where A is greater, P will be less.

[This means that the opinion of the group was divided: two correct versus three incorrect.]

Q: What do you think the atmosphere consists of?

S: oxygen . . . A: nitrogen . . . E: hydrogen . . . P: all those funny little gases make up 1% . . .

Q: [Interviewer shows pictures of models of molecules] What do these pictures mean to you?

M. Life

Q: Could you please explain . . .

M: [silent]

Q: These are simple building blocks . . . atoms.

S: of the atmosphere . . . matter, ja . . .

Q: Has anybody ever seen an oxygen molecule, so that they can take a photograph and publish pictures like these in these textbooks?

E: No.

Q: So how do they know? Does this not look like two oranges next to each other? Is oxygen orange?

P: No.

Q: So what is the meaning of these pictures? Do you believe these pictures?

P: Well it's the only thing we have.

Q: Surely when we read something we ask ourselves whether we believe this or not, is this the way it is or not?

S: . . . a simplified diagram of how different types of elements combine in order to make things that are very common to us, like oxygen and water.

E: I just think they are illustrations that try to help us to picture what we're trying to understand. They're not telling us that the real thing looks like that but they are trying to get it across to us what it is that we are . . . uhm . . .

Q: Air. We said it consists of oxygen. . . atoms . . . molecules. . . do they have mass?

[General agreement] Yes

Q: Do they have weight?

S: It depends whether they are near a force field of gravity?

Q: We're talking about the air.

S: Ja, no they do.

Q: OK, do they exert pressure on things that they come into contact with?

S and P: Yes.

Q: Mountaineers complain that they have difficulty breathing at high altitudes. Can you explain this?

S: oxygen is heavy . . . because of gravity thicker at high altitudes . . . higher pressure lower down . . . it gets thinner the higher you go

P: isn't there more pressure . . . if they struggle up there, there is probably more pressure up there

Q: What makes flight possible?

S: . . . the thrust exerted from the engine of the plane . . . out the back . . . is so strong that it overcomes the force that would naturally keep something . . . pull something as heavy as a passenger plane down to earth . . . doesn't that have something to do with it?

Q: But if the engine exerts a force to the back, that could propel the plane forward, but it doesn't explain why the plane lifts . . . the car does the same, engine drives the car forward but the car doesn't fly . . .

P: aerodynamics . . . air flow

DEMO 2

[Everyone in the group agrees that the result is unexpected, in that the water should be falling out.]

S: Isn't it that air pressure is in all directions.

Q: Has anyone heard about the particle nature of air? How does that work?

Silence.